Hafsteinn Einar Håkonarson

The Development of a Shuttlecock Sorter

Master's thesis in Mechanical Engineering
Supervisor: Dr. Amund Skavhaug, MTP
June 2022

Master's thesis

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I Summary

Badminton is a popular racket sport that utilizes shuttlecocks instead of balls. Shuttlecocks are complex objects with unique aerodynamic properties and individual traits. Shuttlecocks are sorted into different speed classes, and it is important to select the correct speed class for the environment that you will be playing in. Testing of shuttlecocks is done in large tournaments, but in local tournaments testing might be skipped. It is important to test shuttlecocks so that the correct shuttlecock speed is selected. The pre-work for this thesis concluded that a device should be developed to sort shuttlecocks in a unbiased way.

This thesis aimed to design and develop a device which could analyse shuttles and their environment and sort the shuttles depending on if they were fit to be used. Aspects of the shuttle and the environment were discussed, and the device was divided into separate components. Different designs and concepts for each component was presented and discussed, and prototypes for each component were developed. In the end a final prototype was developed and used as the result for this thesis.

The final prototype was able to perform certain functions which the final device was supposed to be able to perform, such as dispensing single shuttles and analysing the shuttles. The final prototype was unable to analyse its current environment due to the lack of environmental sensors implemented. Due to the lack of environmental sensors the device was unable to properly sort the shuttlecocks.

Implementation of environmental sensors, as well as further testing of the prototype are recommended for further work. Improvements and optimizations of the prototype are also recommended before it is ready to be used in tournaments.

II Sammendrag

Badminton er en populær idrett som bruker fjærballer i stedet for baller. Badmintonballer er komplekse objekter med unike aerodynamiske og individuelle egenskaper. Badmintonballer er sortert i ulike fartsklasser, og det er viktig å velge riktig fartsklasse for det miljøet de skal brukes i. Testing av badmintonballer gjøres i store turneringer, men i lokale turneringer kan testing hoppes over. Det er viktig å teste fjærballer slik at riktig fartsklasse er valgt. Forarbeidet til denne oppgaven konkluderte med at en maskin burde utvikles for å sortere badmintonballer på en objektiv måte.

Målet med oppgaven var å designe og utvikle en maskin som kunne analysere badmintonballene og deres miljø, og sortere dem avhengig av om de var egnet til bruk. Aspekter av badmintonballene og miljøet ble diskutert, og maskinen ble delt inn i forskjellige komponenter. Ulike design og konsepter for hver komponent ble presentert og diskutert, og prototyper for hver komponent ble utviklet. Til slutt ble en endelig prototype utviklet og brukt som resultat for denne oppgaven.

Den endelige prototypen var i stand til å utføre visse funksjoner som maskinen skulle kunne utføre, for eksempel å slippe ut badmintonballer og å analysere dem. Den endelige prototypen var ikke utstyrt med miljøsensorer og kunn derfor ikke sortere badmintonballer utifra miljødata.

Implementering av miljøsensorer, samt videre testing av prototypen anbefales for videre arbeid. Forbedringer og optimaliseringer av prototypen anbefales også før den er klar til bruk i turneringer.

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1 Introduction

This thesis is the conclusion of a masters project for the Department of Mechanical and Industrial Engineering at NTNU in Trondheim, Norway. It is a continuation of the semester thesis *A Study on Shuttlecock Testing in Badminton*[2], which concluded that the method that shuttlecocks are currently, as of this thesis, tested is flawed, and that the process should be automated. This masters project aimed to develop a solution to decrease the inaccuracies in shuttlecock testing. It was decided that the solution would be a device which could test shuttlecocks, based on aspects of the shuttlecocks and the testing environment. The device was split into different components. Different concepts for each component were proposed, and different prototypes for each components were developed. Finally a final prototype was developed, which included each of the different components.

1.1 Background

This background chapter is based on the background chapter from the semester project *"A Study on Shuttlecock Testing in Badminton"*[2] which this thesis is based on, and written by the same author.

Badminton is a racquet sport played either by two opposing players (in singles) or by two pairs of opposing players (in doubles). The game is played on a court with the dimensions 13.41 meters by 5.18 meters (length by width), and is divided by a 1.55 meter tall net which is placed in the middle of the length of the court and spans the width of the court. For doubles games the width of the court is extended from 5.18 meters to 6.1 meters (image shown below). Where other racquet sports (such as tennis and squash) hit balls with their racquets, badminton instead uses shuttlecocks. Each side may only strike the shuttlecock once before it passes over the net, and a point is scored by striking the shuttlecock over the net and landing it within the opponents side of the court. A point is scored once the shuttlecock impacts the ground or a player commits a fault. A game ends when a player has reached 21 points or more with a two point lead or the first that scores the 30th point. A match is determined by the best of three games.

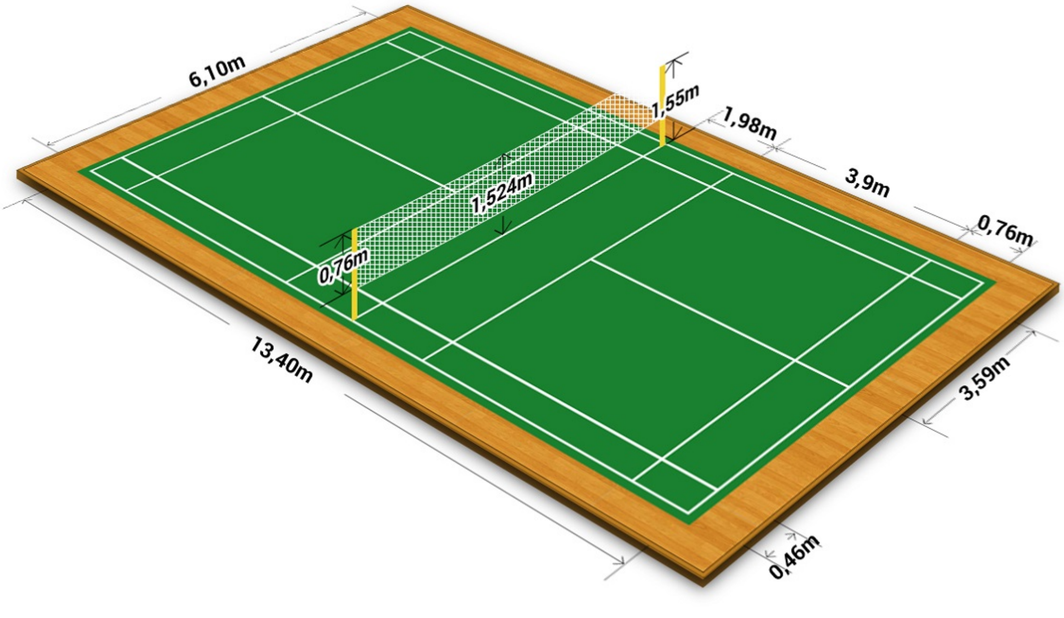


Figure 1: Illustration of a Badminton Court

1.2 Problem Description

Shuttlecocks need to be tested before use to see if they are valid as described in *The Laws of Badminton*[1]. The process of testing shuttlecocks before tournament is flawed as was concluded in the project thesis *"A Study on Shuttlecock Testing in Badminton"*. These flaws can result in a wrong shuttlecocks speed being used, causing the shuttles to fly a longer or shorter distance than what players might intend.

A proposed solution was the development of a device that was able to analyse shuttlecocks and the environment that the device is placed in, and using the data gathered to sort the shuttlecocks depending on if they were fit to be used in the devices current environment.

The purpose of the device was broken into separate functions. The functions of the device should include:

- **Shuttle Storage**: The final device should be able to store multiple shuttles. It should not be required to be hand fed a few shuttles at a time for analysis.
- **Dispense Shuttles**: The final device should be able to dispense shuttles one at a time. Only a singe shuttle should be analysed at a time.
- **Analyse shuttles**: The final device should be able to analyse each shuttle, measuring any number of different aspects of the shuttle which could be used to see if it should be used or not.
- **Analyse Environment**: The final device should be able to analyse the current environment, measuring any number of different environmental factors to determine what shuttles could be used.
- **Compare Data**: The final device should be able to compare the data gathered from the shuttles and the environmental measurements to determine which shuttles are fit to be used in the devices current environment.
- **Sort Shuttles**: The final device should be able to sort shuttles according to whether they were fit to be used in their current environment or not, physically separating the ones that are fit and the ones that are not.

The aim of this thesis was to design and develop the device that can perform each of these functions.

1.3 Thesis Structure

The thesis was structured in this manner:

Theory: This chapter discusses theory around the testing of shuttlecocks, aspects of the shuttlecock that can be measured and used, factors of the environment that may effect the performance of the shuttlecock which can be measured and used, as well as previous studies on topics related to the thesis. This chapter ends with the method of how the device was designed and developed.

Brainstorming: This chapter presents factors of how the prototype should be built and divides the prototype into separate components. Different concepts and designs for each component of the prototype are presented and discussed.

Prototyping: This chapter details the steps and stages of development process of the device. This chapter is divided into different sub-chapters, with each sub-chapter focusing on the prototyping stages of the separate components of the device.

Results: This chapter presents the final prototype, the results of testing the final prototype, and which functions and factors it fulfilled. A simple user guide on how to operate the final prototype will conclude this chapter.

Discussion: This chapter contains a discussion on the final prototype, its functions and possible improvements.

Conclusion: This chapter presents the conclusion of the thesis and recommendations for further work.

Appendix: Collection of materials such as code and technical drawings.

2 Theory

This chapter will discuss previous studies that can be connected to the topic of this thesis, as well as factors that can be used to attempt to analyse how the tested shuttles perform in different environment. It concludes with theory regarding the methods used to design and develop the device.

2.1 Previous studies

This masters thesis is the continuation of the semester thesis *A Study on Shuttlecock Testing in Badminton*[2], which looked at how shuttlecocks were being tested for tournament us. It featured an experiment held in the Norwegian Under 23 Badminton Championship at Sit Dragvoll Fitness over the weekend of the 23rd and 24th of October 2021. The thesis concluded that most players who tested the shuttlecocks were not consistent, and the results between players varied significantly. Its results suggest that automating the testing procedure of shuttlecocks might result in a fairer game. The semester thesis it can be found in its entirety in **Appendix C**.

This thesis aims to begin the design and development of the suggested device, and therefor there are no relevant previous studies on the device. There have however been several studies done on different aspects of the shuttlecock, such as its trajectory, speed, and aerodynamics. There are also some studies on conditions affecting the performance of the shuttlecocks. Studies will be brought up, mentioned and discussed in the next chapters where they are most relevant.

2.2 Factors

The objective of the device is to analyse shuttles, as well as the local environment, and use the data gathered to determine whether the shuttle is fit to be used in the devices current environment. In order to analyse both the shuttle and the environment the device needs to be able to measure certain aspects of the shuttle and the environment. To do this the device needs to be equipped with the correct measurement tools to measure each factor. It is therefor important to find and choose which factors, regarding either the shuttle or the local environment, is the most effective to be able to correctly analyse and sort the shuttle. There can possibly be multiple factors effecting the results, however the device should preferably not be very big or bulky, and therefor important to know which factors should be prioritized, and which factors can be ignored.

2.2.1 Shuttle Factors

There are multiple factors that can be looked at and analysed when it comes to shuttles. It is therefor important to hone in on what the device is trying to accomplish and focus on the shuttlecock factors that might be directly influential to the devices purpose. As the main purpose of the device is to decide whether a shuttle can be used in its current environment it is difficult to decide which factors are to be used.

Examples of different factors regarding the shuttles that can possibly be used include: trajectory, speed, weight and condition.

There have been multiple studies conducted on the trajectory of shuttles. The trajectory of the shuttle would be influenced by the player striking it, however it would also be determined by the state of the shuttle. When it comes to the players influence on the shuttles trajectory it will vary from player to player as discussed in *A Study on Shuttlecock Testing in Badminton*[2], and the usage of a machine to test shuttlecocks has the potential to be more effective and not subjective.

The trajectory of the shuttle is effected by how it is launched. Is it launched from a shuttlecock launcher, or is there a player launching it? If it is a player launching it what kind of stroke is the player performing? When discussing the trajectory of the shuttle it might also be related to discuss the shuttle in air. Is the shuttle rotating properly? Does the shuttle follow its intended trajectory?

Shuttlecocks are notorious for being the fastest moving objects in sports (excluding gun sports). According to an article written for engineering.com[3] the fastest shuttle recorded was measured at 493 km/h when testing racket technology, or 426 km/h during an official tournament. The shuttles do however not hold that speed for long, as they are designed as high-drag projectiles, meaning they decelerate quickly.

They weight of a feather shuttle should be between 4.74 and 5.5 grams as specified by the World Badminton Federation in *Laws of Badminton*[1]. In a video made by RSL International [4], they explain that the weight of shuttles within a speed class may vary, but that is due to three factors effecting the speed of the shuttle: weight, circumference of the shuttle, and the angle of the feathers. Thereby the geometry and form of the shuttles can effect their performance, and can be used as factors to evaluate if they should be used.

Usually it is easy to evaluate the condition of the shuttle. Inspection of broken or damaged feathers is not needed when a new tub is opened, as they are protected while inside the tube, and assumed to have come right from the producer. If the shuttles are however to be sorted if they can be used for practices or warm ups, the condition of the shuttle should also be looked at. The condition of the shuttle can also refer to if the feathers of the shuttle are dry. It is often recommended to humidify shuttles before use to increase their durability.

2.2.2 Environmental Factors

There are several environmental factors that can alter the qualities of a shuttle, both flight and trajectory. These factors include temperature, humidity, and geographical altitude of the environment. All of these factors manifest themselves as change in air density, which affects the air resistance and therefor the flight of a shuttle. Higher air density causes more air resistance for shuttles, slowing them down. For conditions with higher air density shuttles with a faster speed class are required.

The research paper *'Effect of Local Conditions on the Flight Trajectory of an Indoor Badminton Shuttlecock'* by Raghavan Subramaniyan [5], conducts an experiment viewing how different badminton strokes are effected when these factors (temperature, humidity, and altitude) are changed. This was done by performing the different strokes (long serve, overhand clear, underhand clear, and short serve) in two different locations: an air-conditioned badminton court at sea level, and a non-air-conditioned court in Bangalore at an altitude of 3000 feet (approximately 915 meters). The air density was calculated from the three factors. The research paper concluded that the conditions effected the shuttles, having over 10% variation in distance traveled by the shuttles. He also concluded after varying each of the environmental factors, that the environmental factor that had the most pronounced effect on the air density was altitude, while temperature and humidity had a smaller effect.

2.3 Method

As mentioned in **1.2 Problem Description** the aim for this thesis is to design and develop a device that can analyse shuttlecocks to see if they are fit to be used in their current environment.

The basic structure of the device has been decided beforehand. There are multiple different structures that could have been used, however this structure was chosen to keep the product cheap and simple. The structure consists of three essential parts: a top part which stores and dispenses one shuttle at a time, a middle part which analysis the environment and the shuttle, and a bottom part which using the data from the middle part will sort the shuttles into an approved or not approved group. The shuttle factor chosen to focus on was the speed of the shuttle, the reasoning for this is discussed in **6.1 Shuttle Factors**.

The method of designing and developing the device will be split into to different methods, those being idea brainstorming and prototyping.

2.3.1 Idea Brainstorming

The first part to designing and developing the device is idea brainstorming. The idea brainstorming chapter will split up each essential part of the device (the top, middle and bottom parts) into separate sub-chapters, discuss the purpose of each part, and then present and discuss different designs or concepts for each part. The chapter will also present some factors that are important to the final product, such as cost and efficiency. It will also present pros and cons for each design. The effect of some features are more easily identifiable than others, however there are always some subtle differences that may not look major until further development stages. Due to this the initial designs choices presented at the end of the idea brainstorming chapter may not be the same designs as the ones used in the final prototype.

2.3.2 Prototyping

The second part to designing and developing the device is prototyping. The two main components used in this thesis for prototyping are 3D printing to construct the larger constructions or custom parts, as well as for mechanical assemblies, and the Arduino Uno as the microcontroller to run all electrical components.

3D Printing

3D printing is a great tool for prototyping. In this thesis there was a lot of 3D printing used when it came to prototyping and developing the device. It is fast, cheap and easy to use, making it an attractive method to develop quick prototypes, as well as smaller complex structures.

There are multiple different types of 3D printing, with the two most popular being FDM(fused deposition modeling, sometimes also referred to as fused filament fabrication, or FFF) and SLA (stereolithography).

FDM 3D printing works by extruding thermoplastic filaments through a heated nozzle, melting the plastic and applying it in layers, one layer laid at a time, to construct the desired object. SLA 3D printing uses a laser to cure liquid resin into hardened plastic. SLA 3D printing will usually produce prints with finer details and a smoother texture than FDM prints, however SLA prints have to be rinsed in isopropyl alcohol(IPA) to remove uncured resin, and sometimes need to be cured (with light, heat or both) to reach their highest possible strength. FDM prints can be used right after printing. Due to accessibility and simplicity the FDM printing was used to develop prototypes.

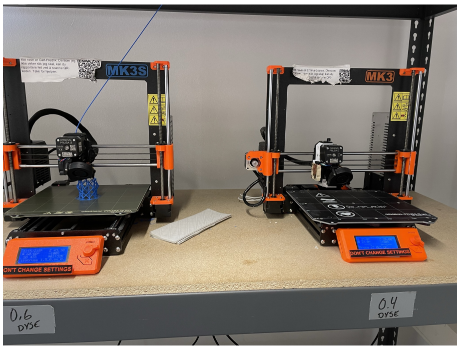


Figure 2: Prusa i3 MK3 and MK3S Printers at NTNU's 3D Printer Lab

Prusa Research was founded by the Czech hobbyist, maker and inventor Josef Prusa in 2012. Originally starting as modifications to the open-source RepRap project, a project to develop a low-cost 3D printer that could print most of its own components, getting as close as possible to self replicating 3D printer, it spiraled into its own product, becoming one of the most popular 3D printers on the market.

The filament used in these printers for this thesis was PLA. PLA plastic, also known as polyactic acid or polyactide, is a vegetable-based material. It is marked as biodegradable, however it is a plastic material and requires a long list of conditions to effectively break down. PLA is a popular 3D printing filament due to its biodegradability, low cost and good shelf life, it can however deform because of heat and is less sturdy than ABS (Acrylonitrile Buradiene Styrene, another popular 3D printing filament, notably the same plastic as used in Lego bricks).

The process of using the 3D printers is simple. The process is described below with the example printed being a 10 millimeter cube with a 8 millimeter hole through its center. For simplicity the example printed will be referred to as the cube.

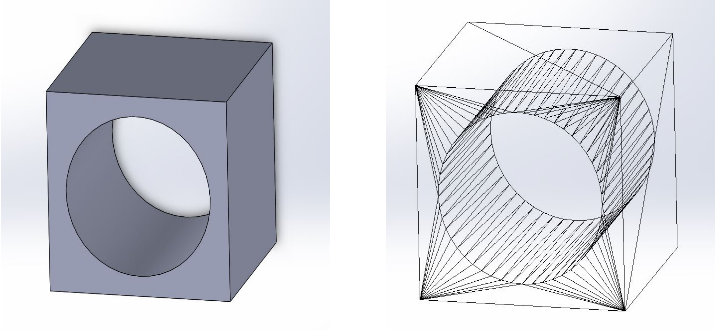


Figure 3: The Cube in: (1) SolidWorks(CAD), and (2) STL file.

The cube is first constructed in CAD (computer-aided design) software (SolidWorks was used for this thesis).

Next the CAD cube is converted into an STL file. STL stands for stereolithography, and an STL file describes the surface geometry of a three dimensional object, containing data based on triangulations of the surface of the CAD models. The STL file does not include other details of the object, such as color, texture or other common CAD model attributes. The STL file can then be uploaded to a slicing software (Prusaslicer was used in this thesis, as it is the standard when using Pruse printers).

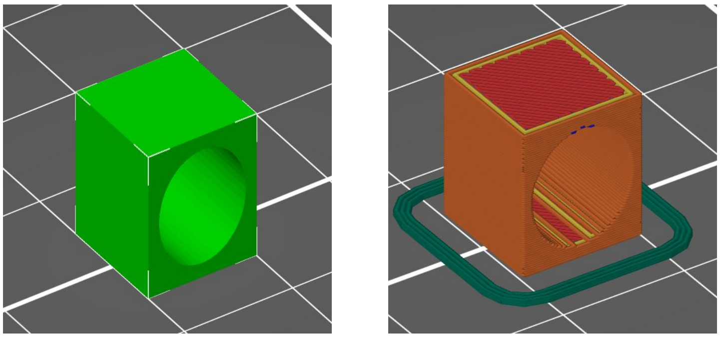


Figure 4: The Cube in Slicer: (1) Before Being Sliced, and (2) Sliced.

Slicer software is a computer software which converts STL format files to printer commands in g-code format. It does this by dividing or slicing the object into a stack of flat layers, then describes each layer as linear movement for the 3D printers extruder to follow. The g-code is composed of these movement commands, printer specifications, extruder and bed temperatures and more. Slicing software often has multiple other settings which can be tweaked to change how the object is printed. Some setting examples include the infill, supports and layer height.

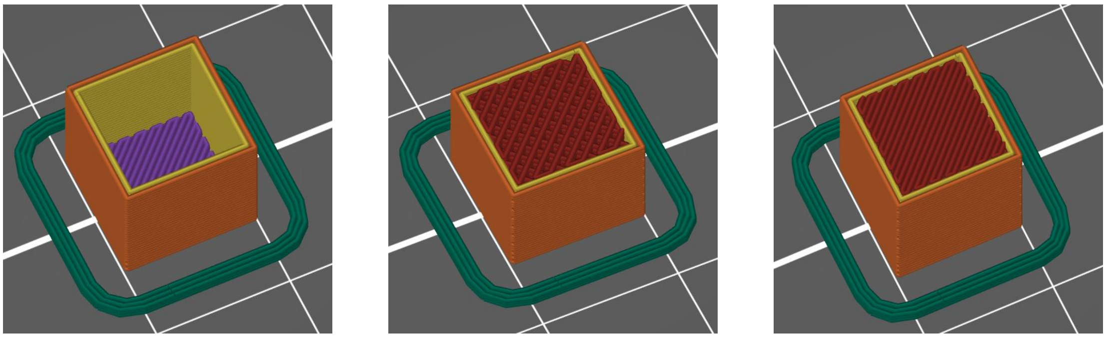


Figure 5: The Cube with: (1) 0% Infill, (2) 50% Infill, and (3)100% Infill.

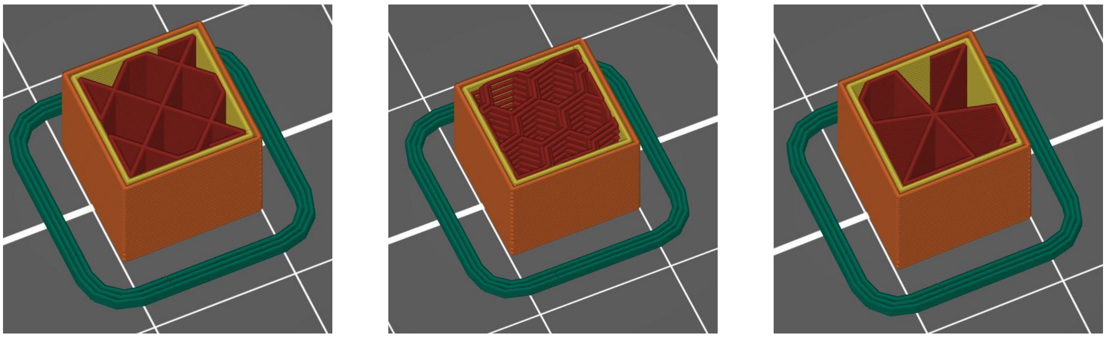


Figure 6: The Cube with Different Infill Patterns: (1) Grid Pattern, (2) Honeycomb Pattern, and (3) Triangle Pattern.

The infill settings usually include how much infill is desired (where 0% infill prints a hollow shell, and 100% infill prints a solid object) and the infill pattern (grid, honeycomb, triangles, etc). For most parts printed in this thesis a 5% infill was sufficient, however for thinner pieces that would have to carry load 10% infill was used.

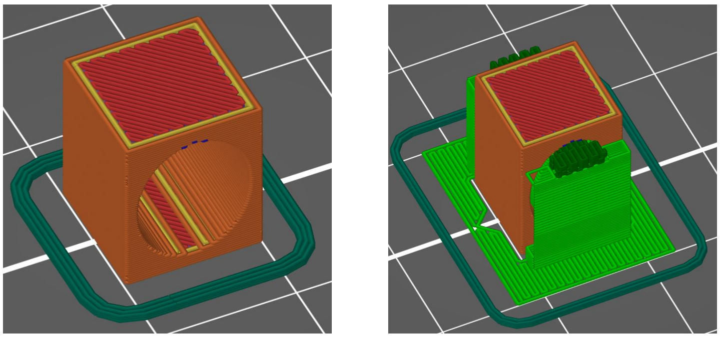


Figure 7: The Cube with: (1) No Supports, and (2) Supports Everywhere

Sometimes it is required to add supports onto the 3D models so that the 3D printer can properly print them without ruining the object. Supports structures are printed in simple patterns to avoid fails in prints due to the objects geometry and are simple to remove. Often if the 3D object has an overhang of less than 45 degrees it does not require additional supports, however this depends the condition of the printer and which printer is used. The slicing software usually allows you to choose specifically where to add supports, or to add supports everywhere.

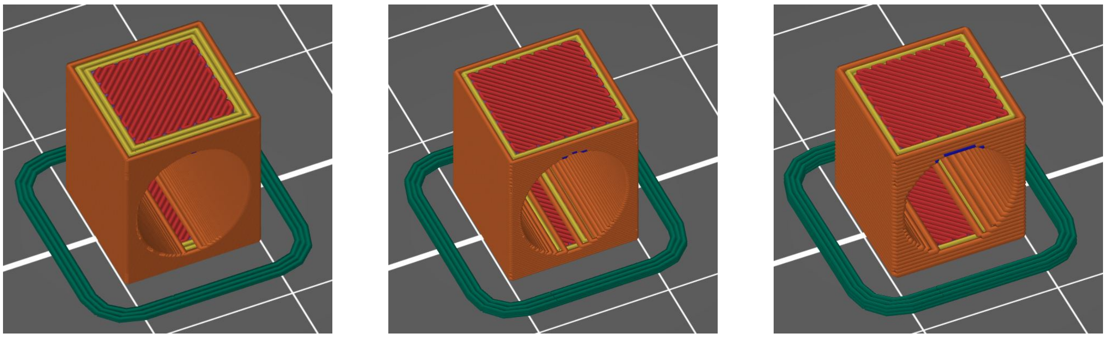


Figure 8: The Cube with Different Layer Heights: (1) 0.05mm, (2) 0.15mm, and (3) 0.3mm

Changing the layer height of the print can change the quality and speed of the print. A smaller layer height can print more details but will take longer to print, while a larger layer height will give less details but print much faster. As an example the time to print the cube varied from 5 minutes using 0.30mm layer height, to 31 minutes using 0.05mm layer height.

The g-code is uploaded to the printer(in this case transferred via SD-card). The printer has a knob which can be turned and pressed to select which file or object is to be printed, and to initiate the print. The nozzle and bed are heated up to correct temperatures. For the Prusa printers using PLA filament the nozzle is heated to 215 degrees Celsius and the bed is heated to 60 degrees Celsius, however the temperature can differ when using different materials. After the nozzle and bed are heated the printer will calibrate, then initiate the print, following the instructions given to it in the g-code.

Arduino

The prototypes constructed and tested used a few different electronic components, such as motors and sensors. The electrical components will be disclosed in **5.1.1 Electronics and Connections**. Prototypes constructed in this thesis are controlled by Arduino Uno micro-controller boards. The Arduino Uno was chosen due to its familiarity, as it was used in the course TPK4125 - Mechatronics, its simple programming language, and due to its cheap cost.

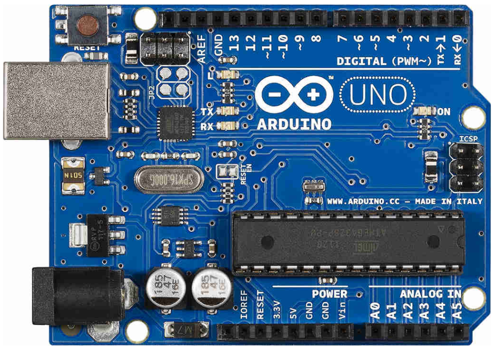


Figure 9: Arduino Uno

The Arduino Uno has 14 digital input/output pins where 6 of them can be used as PWM (pulse width modulation) outputs, 6 analog inputs and a ATmega328P microcontroller as its brain. It is easily programmable by connecting it to a computer via a USB cable. It can be powered the same way, connecting it to a computer via USB, or by other external power sources such as batteries. The main features used by the Arduino Uno in this thesis are its digital input/output pins to receive data from sensors, as well as its I2C (Inter-Integrated Circuit) function which communicates to an external motor controller, which allows the Arduino Uno to control multiple servo motors.

Motor Controller

Some parts of the prototype are controlled by servo motors. When using multiple servo motors with an Arduino it is best to use a motor controller module. The Arduino Uno can use its I2C function to communicate to an external motor controller, and control the servo motors through it.

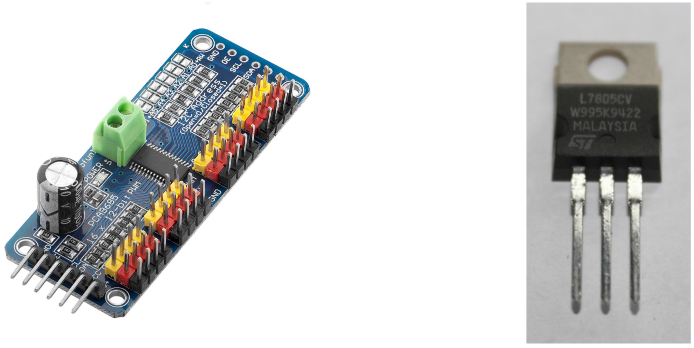


Figure 10: (1) PCA9685 Motor Controller, and (2) L7805CV Linear Fixed Voltage Regulator

The motor controller used through this thesis is the PCA9685. The PCA9685 is an I2C controlled PWM driver with a built-in clock, that can control 16 PWM outputs, but is also designed to be able to be directly connected to another PCA9685 up to 62 additional times, making it able to control up to 992 PWM outputs. The PCA9685 is connected to an Arduino Uno by I2C communication, as well as to the Arduinos ground and 5 volt, however it requires an additional external 5-6 volt power supply to generate the PWM signals. For this thesis this is done by connecting it to a 9 volt battery through a L7805CV linear fixed voltage regulator. The L7805CV required a heat sink to function.

3 Brainstorming

Brainstorming a new concept is an important step when designing a new system.

It was assumed that a shuttlecock can be sorted by its speed during free fall, that its velocity and falling acceleration can be used to determine whether the shuttlecock can be used in its current environment.

Factors that were considered in the design of the device were:

- **Sensors:** The device needs sensors, both to calculate the speed of the shuttles free fall, but also to assess the conditions of the environment the shuttle is to be used in.
- **Mobile:** The device should neither be very heavy nor very large. The size of the device can be discussed more later, however a person should be able to move the device to and from storage preferably without the assistance of an external lifting device. The height of the device should also preferably not exceed the height of a badminton net (1.55 meters).
- **Cheap:** The device should not be expensive to develop, and if the prototype is successful the final product that might be produced should have a relatively low cost, either for cheaper production or to make it more attractive as open source for badminton clubs.
- **Speed:** The device should preferably not take longer to sort the shuttles than it takes a player to test and collect shuttles.

When it comes to the device itself, it was be split into three different parts: A shuttle release mechanism, a free falling measurement tube, and a sorting mechanism.

- **Shuttle Release Mechanism:** The top part of the device was the shuttle release mechanism. This part was divided into two separate components. The first component was a feeding system which could store multiple shuttles and feed them into the release mechanism. The function of the release mechanism was to dispense one shuttle at a time to be analysed and sorted. The speed of the release mechanism was as mentioned before preferred to be faster than a player. It was however not to be faster than the sorting device could sort the shuttles to avoid failures.
- **Free Falling Measurement Tube:** The middle part of the device was the free falling measurement tube. Its function was to use sensors to measure the velocity of the shuttles as they fell through it.
- **Sorting Mechanism:** The bottom part of the device was the sorting mechanism. Its function was to receive the velocity of the shuttle tested from the middle part of the device, as well as the current environmental conditions from external sensors, and sort whether the shuttle could be used within its current environment. After receiving the data the sorting mechanism would then sort the shuttle into whether it could or could not be used in its current environment.

The different parts of the device will be discussed and brainstormed further in the next sub-chapters. At the end of each sub-chapter there will be a table with the overview of each concept for the different parts of the device.

3.1 Release Mechanism

The top part of the device was the shuttle release mechanism. The purpose of the release mechanism was to release or dispense one shuttle at a time, with the length of time between shuttles dispensed to be determined by how fast the device could analyse and sort the shuttles.

The shuttle release mechanism consisted of two parts: The releasing mechanism which dropped one shuttle at a time, and a feeding system which stored multiple shuttles, and fed them into the release mechanism, making the device able to work over longer periods of time without the need to place shuttles one at a time into the device.

3.1.1 Release Mechanism

The Release mechanism is an important part of the device. Its main purpose is to release one shuttle at a time. Different from dropping one shuttle at a time by hand is that the release mechanism will drop the shuttles from the same distance, where as the distance dropped by hand will always have some discrepancies, and the release mechanism will drop the shuttle from rest, while dropping from hand might often introduce an initial velocity either upward or downward depending on how the shuttle is released. In other words, the release mechanism is used to make the device more automated, and to keep the dispensing of shuttles consistent, which is important when shuttles are being compared to each other.

When it comes to developing the shuttle release mechanism of the device inspiration can be found in the current badminton serving machines. These machines are used so that players can practice certain strokes without the aid of another player, however most if not all of them have a shuttle release mechanism to be able to serve a single shuttle at a time.

There were three different release mechanisms considered for the device, most of which are already in use by different badminton serving machines.

First Release Mechanism: Gripper Mechanism

The first concept for the release mechanism was a gripper mechanism, which was one of the more popular mechanisms for larger badminton serving machines. Shuttlecock serving machines such as the Siboasi and the Baddy both use a mechanism similar to the gripper mechanism, the shuttles are fed through a tube, gripped and dragged out of the tube by a gripper mechanism, released and fall along tracks into the launching mechanism.

Figure 11: Demonstration of the Gripper Mechanism Concept

(Images in figure 1 from: https://www.youtube.com/watch?v=Gwg-Ge4gu9g&ab_channel=Jeroen1278, accessed 05.03.22).

As mentioned, the general concept of this mechanism was a gripper which could open, close and move up and down in a vertical movement. The mechanism required that the end of the feeding system had an opening slightly smaller than the largest diameter of the shuttle, so that the shuttles peek out of the feeding system but would not fall out without assistance. The gripper would move upward towards the feeding system and grab onto the bottom shuttle. It would drag the bottom shuttle out, the feathers of the shuttle flexing inward to let it be released from the tighter end of the feeding system, moved downward toward the free falling measurement tube and open up, dropping the shuttle into the tube. When the bottom shuttle was removed from the feeding system the next shuttle would fall down and be stopped by the smaller opening, sitting in the same position as the bottom shuttle was in previously. The gripper would then move back upward towards the next shuttle and the pattern would repeat.

The gripper mechanism, or its variants, were, as mentioned, popular when it came to badminton serving machines. Due to the tighter end of the feeding system the mechanism could easily and safely dispense a single shuttle at a time, with little risk of failing. The mechanism also only used one opening and closing mechanism, which could mean that total number of parts required for the mechanism were minimal. The mechanism did however require that the gripper would be able to move along a linear axis. This both required a unique design for the vertical movement, as well as possibly being vertically larger than other designs, making the total height of the device longer than possible wanted. The design also required the feeding system to have a tighter end, which might not be a big issue, but it did mean that the design was dependent on the design of other parts of the system. Using a single gripper could also mean that the shuttle might not be dropped straight down each time, which could cause issues in analysing the shuttles, as if the shuttle would hit the wall of the free falling measurement tube it would likely fall slower than it would if it fell straight down.

Second Release Mechanism: Diaphragm Mechanism

Another mechanism, similar to the gripper mechanism used in most shuttle serving machines, was a mechanism using diaphragms or iris mechanisms. Working similarly to the gripper mechanism, this mechanism used two diaphragms controlled by motors to grab and release the shuttles. Acting like two gates, the top diaphragm, which would initially hold the shuttle, releases the shuttle, letting it fall to the bottom diaphragm, which would be closed. Next the top diaphragm would close again, grabbing the second shuttle, holding it in place, and pulling it slightly upward due to the conical shape of the shuttle. Finally the bottom diaphragm would open, letting the first shuttle fall, then closes to be ready for the next shuttle, and repeating the pattern.

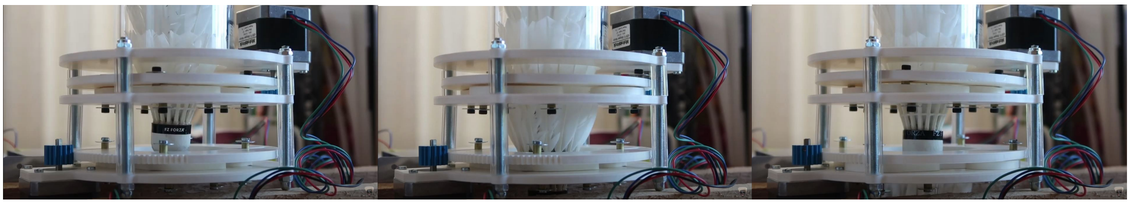


Figure 12: Demonstration of the Diaphragm Mechanism Concept

(Images in figure 2 from: https://www.youtube.com/watch?v=iClGBVuTGQo&ab_channel=RiediProjects, accessed 05.03.2022).

This mechanism avoided the issue of vertical movement, and the possibility of grabbing the shuttle off-center that the gripper mechanism introduced. It would also possibly take less space, making the device itself smaller, and possibly more mobile. The diaphragm mechanism would still require two motors, one for each diaphragm, which may have possibly meant that the weight difference between the diaphragm and the gripper mechanisms would have been negligible. The total height however would have been smaller when using the diaphragm mechanism. The diaphragm mechanism would also not depend on the design of the feeding system, as the top diaphragm worked in a similar way as the tighter end of the feeding system worked for the gripper mechanism. The diaphragm design was however much more complicated when it came to designing. The movement of each tooth of the diaphragm was complicated, and could take longer to design. The diaphragm was also composed of many more smaller parts than the gripper mechanism, meaning that the construction would take longer, and that there was a larger chance for a mechanical failure, compared to the gripper mechanism which only consisted of the gripper and the vertical movement.

Third Release Mechanism: Double Gripper Mechanism

The third concept was a combination of the previous two concept mechanisms (diaphragm and gripper). The concept is called the double gripper mechanism.

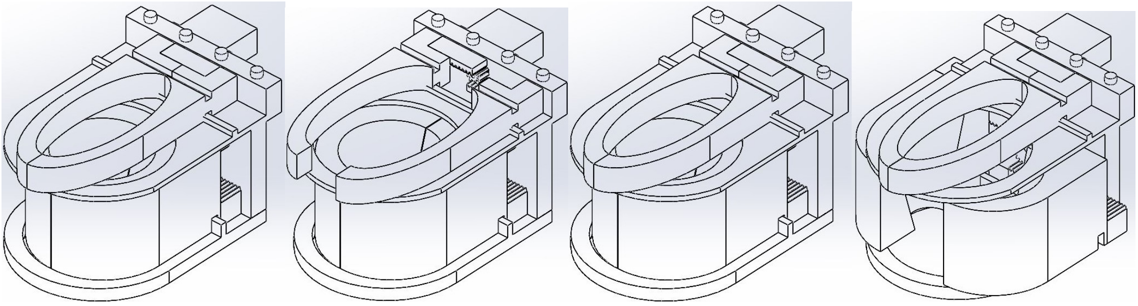


Figure 13: Demonstration of the Double Gripper Mechanism concept

The double gripper mechanism worked similarly to the diaphragm mechanism, where a top gripper would grab and hold the shuttles in place, then release them down to the bottom gripper. The top gripper would then grab the second shuttle again, holding it and all shuttles above in place, while the bottom gripper released the bottom shuttle to fall down. The bottom gripper would close again and the pattern would be repeated.

This mechanism avoided the vertical movement and the dragging of the gripper mechanism, and was much simpler to design than the diaphragm mechanism. The double gripper mechanism consisted of more parts than the gripper mechanism, but fewer than the diaphragm mechanism, meaning that there was a lower chance for the double gripper to fail than the diaphragm mechanism. The parts were however larger than those of the diaphragm parts, so the initial construction of the mechanism would take the same time as the diaphragm mechanism, and if parts would fail, it would take longer to replace them. Due to the design of the double gripper mechanism it was much easier and faster to redesign it compared to the diaphragm mechanism if issues would arise due to its form or dimensions. This mechanism was also larger and potentially heavier than the diaphragm mechanism.

Overview of Release Mechanisms

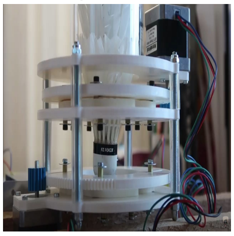
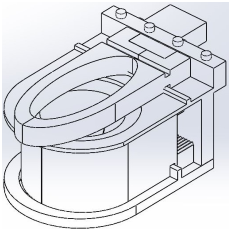
Concept Nr.	1	2	3
Concept Name Concept Image	Gripper 	Diaphragm 	Double Gripper 
Concept Pros.	• Fewer Parts. • Popular Design in Badminton.	• Small and Compact. • No Vertical Movement. • Independent of Feeding System Design.	• No vertical Movement. • Independent of Feeding System Design • Simple Design.
Concept Cons.	• Dependent of Feeding System Design • Features Vertical Movement of Motor. • Tall Design.	• Multiple Parts. • Complex design.	• Moderate Amount of Components. • Larger design than Diaphragm.

Table 1: Overview of Release Mechanism Concepts

3.1.2 Feeding system

Most of the release mechanisms used in badminton use tubes with a slightly constrained ends, so that the shuttles slide to the bottom of the tube but stop with their base sticking out, however the method of how the release mechanism of the device would be fed was discussed. The two different feeding systems were: a funnel system, and a tube.

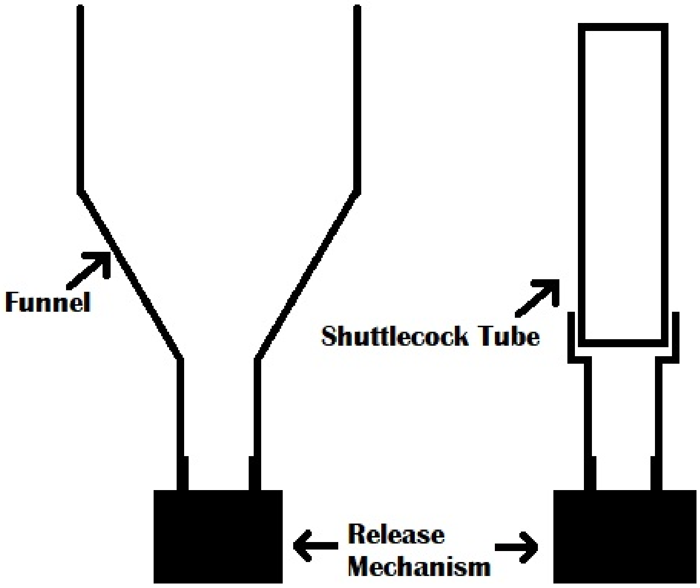


Figure 14: Funnel and Tube Concept Illustration

The release mechanisms discussed all used tubes, however the feeding system itself did not necessarily need to be a tube. Pros and cons could be set up for both the funnel and the tube feeding systems. The funnel had the potential of having more shuttles loaded at a time, possibly making it easier for the person feeding the machine, as the person could offload a lot of shuttles at once, then have the machine sort them all. The cons of the funnel system were that it might take more space than connecting a tube to the device, making the device larger when transporting and storing the device. Throwing shuttles into the funnel and having them funnel into the release mechanism could also possibly damage the shuttles.

It is important to mention that the tube concept did not refer to the storage tubes shuttlecocks come in when bought. The shuttles are held tightly in the tube, and to release the shuttlecocks from the tube they either have to be pressed out or the tube shaken, neither of which seem efficient methods to be used in the release mechanism. Instead a separate tube system was made, in which the shuttles slid down more easily, and were held in place by a tighter opening.

Both concepts for the feeding system, the funnel and the tube concepts, were both simple and could easily be implemented for most designs. Due to this one could have been chosen after the final prototype is constructed, to see which worked better in the end.

3.2 Free Falling Measurement Tube

The middle part of the device was the free falling measurement tube. Its function was to measure the velocity and acceleration of the shuttles as they fell. It measured the time between each sensor being triggered. Using the time between the triggers and the known distance between each sensor, the device was able to calculate the velocity and acceleration of the shuttle as it fell down through the tube. The idea for the method is illustrated below.

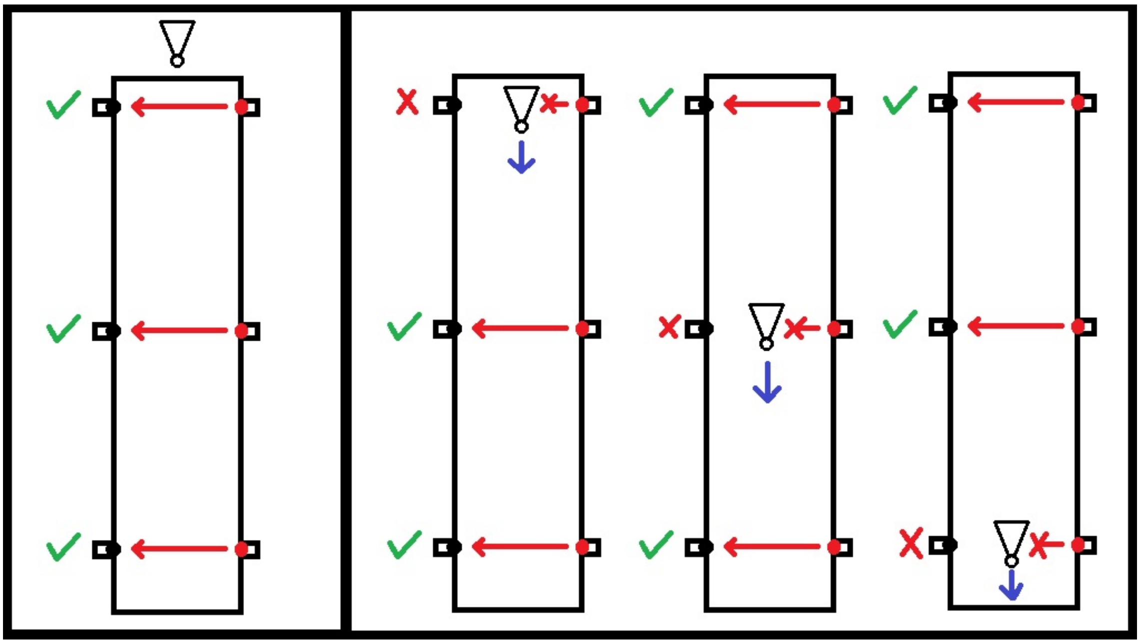


Figure 15: Free Falling Measurement Tube General Concept Illustration

The concept illustrated above uses infrared sensors and LEDs. The infrared sensors(black on illustration above) detect light from an LED (red on illustration above) and when a shuttle passes the sensor it blocks the light from the LED. The output voltage of the sensor reflects how much light it senses, and therefor an output voltage boundary can be established, activating a trigger whenever the shuttle passes the sensor.

The designing and developing of the free falling measurement tube was separated into two components. The first was the sensors used, and the second was the design of the tube itself.

3.2.1 Sensors

The purpose of the sensors used in the free falling measurement tube was to measure the speed and acceleration of the falling shuttles. The sensors were used as triggers, when the shuttle passed the sensors they sent signals to the microcontroller and the time between each trigger was recorded. As the distance between each sensor was known the velocity and acceleration could be calculated. A few sensors were considered to be used, due to their availability, their size, and their simplicity.

First Sensors: Infrared-LED and Infrared-Photodiode Combination

The first sensors that were considered were a combination of an infrared-LED and an infrared-photodiode. The infrared-LEDs shined directly at the infrared-photodiodes, which continuously sent signals with a value to the microcontroller. When the line of sight between the infrared-LED and the infrared-photodiode was broken, the value received by the microcontroller from the sensors became noticeably smaller. The microcontroller would be programmed so that when the change in value received dropped below a predetermined tolerance the microcontroller would register it as a trigger and start the timer.

Figure 16: First Sensors: Infrared-LED and Infrared-Photodiode Combination

This sensor combination was first considered due to the simplicity of the sensors and their cheap cost. Both the infrared-LED and the infrared-photodiode were small (size of normal LEDs) so they could easily be fitted to the tubes. There were some potential problems however. Depending on the design of the free falling measurement tube the sensors could be exposed to external light sources, which might cause the change in sent value when the shuttle passed to be unnoticeable. This might have also been an issue when using the device in different environments, as the amount of light could differ significantly, which meant that it was necessary for the sensors to be re-calibrated before use each time, to assure that the sensors would be working correctly. The cost of the sensors was low, however each of the sensors requires resistors to be connected to each of the parts of the sensors, and in the end the cost of this sensor combination would be similar to other sensors.

Second Sensors: Infrared Distance Interrupter

The second sensors considered were the infrared distance interrupter v1.2 by Grove. The infrared distance interrupter was a module consisting of an infrared-LED and a phototransistor. The infrared-LED emitted light which would get reflected by an object (in this case the passing shuttle) and this reflection would be detected by the phototransistor.

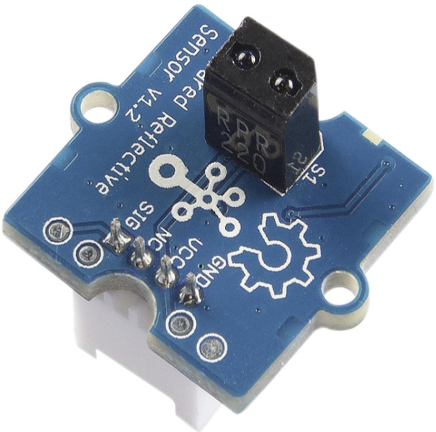


Figure 17: Second Sensors: Infrared Distance Interrupter

The infrared distance interrupter returned either a digital HIGH or a digital LOW depending on if it detected the reflection, which worked well for the device as it used the sensors as triggers. The detectable range of the sensor was 7.5 - 40 centimeters, and the sensitivity could be adjusted by adjusting the gain of the amplifier via a potentiometer on the module. This module was based on the same concept as the previous sensors, however as it was a module everything that was usually necessary such as resistors or potentially transistors were already included. This meant that the sensor could simply be attached to the free falling measurement tube, connected to the microcontroller and they would be ready to be used. Due to the inner diameter of the tube being 100 millimeters the gain on the amplifier could be set to its strongest setting and it would detect the shuttle without reflecting on the walls of the tube. This meant that the sensors potentially did not require any calibration between uses. The shape of the modules were however awkward, as they were rectangular with fastening holes on each side of the rectangle. This made it difficult to fasten the module to a round surface, like the side of a tube. It was also more expensive than the previous sensors, even when considering additional components such as resistors.

Third Sensors: Infrared Obstacle Avoidance Sensor

The third sensors considered was the infrared obstacle avoidance sensor module. The module had an inbuilt infrared transmitter and infrared receiver. It worked the same way as the infrared distance interrupter, with the transmitter sending out infrared light, and the receiver detecting if the infrared light was reflected.

Figure 18: Third Sensors: Infrared Obstacle Avoidance Sensor

The module was also fitted with a potentiometer to adjust its detection range, similar to the previous sensor. In many ways it was very similar to the infrared distance interrupter, however where it differed was with its shape and cost. The infrared obstacle avoidance sensor had a longer rectangular shape, compared with the square shape of the infrared distance interrupter. The module also had a single three millimeter hole it the middle of it, making it easy for it to be attached to the tube. It was also much cheaper than the previous sensor, to a point where if additional components are counted, the module was even cheaper than the first sensor combination. The biggest flaw with the infrared obstacle avoidance sensor was that its infrared transmitter and infrared receiver were exposed, and sometimes somewhat loose. External light sources did not seem to effect the modules output, however sometimes the transmitter and receiver could be angled in a way that they reflected off of each other, outputting a non-stop trigger.

Overview of Considered Sensors

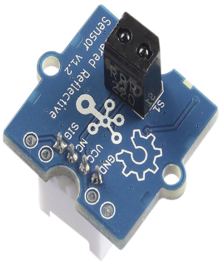
Sensor Nr.	1	2	3
Sensors Name Sensor Image	Infrared-LED and Photodiode 	Infrared Distance Interrupter 	Infrared Obstacle Avoidance Sensor 
Sensors Pros.	• Cheap. • Small and easy to fasten to most tube designs	• Module: Does not require additional components. • Not effected by external light sources. • Does not require re-calibration.	• Module: Does not require additional components. • Cheap. • Does not require re-calibration • Easy to fasten to tube designs.
Design Cons.	• Effected by external light sources. • Re-Calibration required between tests. • Require additional components.	• Awkward shape, can be difficult to attach to tube. • More expensive than other sensors.	• Unreliable designs sometimes. • Diodes can be loose, sending unending triggers.

Table 2: Overview of Considered Sensors

3.2.2 Tube Design

When it came to the design of the tube it was pretty general. It was a tube. The main function of the tube design was that the shuttles would fall down through it, and that sensor were to be attached to it. With that in mind there were two similar but somewhat distinct tube designs that were considered.

First Tube Design

The first tube design was the simplest design. It was simply a PVC pipe with holes drilled into it and the sensors fastened into the holes.

Figure 19: First Tube Design: PVC Tube

Depending on what sensors would be used they might have to be bolted into the tube, or simple glued into the holes. The solution was simple, cheap, and easily adjusted, as new holes could always be drilled and the sensors moved to the new holes. A potential flaw with this design might have been finding a way for it to be attached to a base. The sorting mechanism was fitted to the lower end of the tube, which means that an additional part would need to be designed to be fitted to the tube and the base, while bypassing the sorting mechanism. Another potential problem would be fitting the sensors to the tube, depending on if a larger sensor would be used.

A solution was drafted to solve the last potential problem (fitting sensors onto the tube). The design was similar to the first design, using a PVC tube, but cutting it in half lengthwise, and fastening it together with 3D printed clamps.

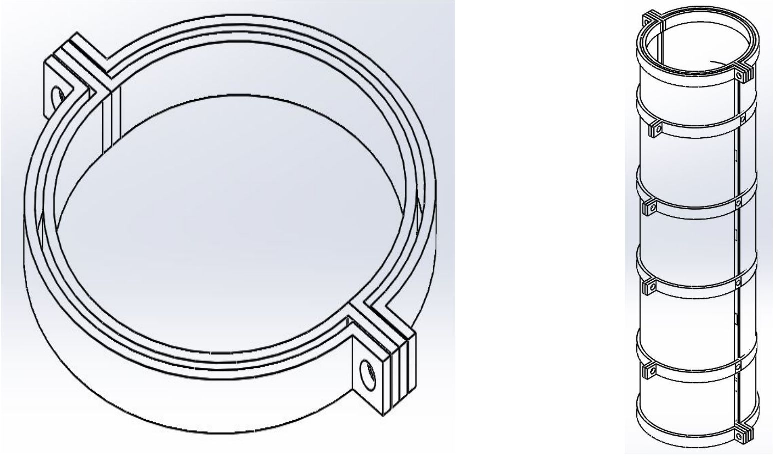


Figure 20: Tube Design 1.5: (1) Clamps, and (2) Design.

The clamps would hold the two halves of the PVC tube together, as well as being designed to have the sensors used embedded into them. The sensors embedded in the clamps would be located in the gap that would be made between the two halves of the PVC tube, rendering it unnecessary to drill holes every time the sensors would have to be moved. The clamps could also be designed to be able to have a solution for a base mount which would bypass the sorting mechanism. This design would be slightly more expensive than the previous design due to the 3D printed parts, however due to the open 3D printer lab at NTNU the cost in this case is negligible. A potential problem with this design depended on what sensors would be used, as the design exposed the inside of the tube to more external light, and depending on the sensors used, they might have to be re-calibrated before each use. Another problem with this design was the difficulty of cutting the PVC tube in half lengthwise. The tool available for that task during the thesis was a straight-toothed handsaw, and the likely-hood of a clean cut along the entire length of the tube was low to none.

Second Tube Design

The second tube design was slightly more complicated. The design would not use a PVC tube, but instead have 3D printed plates attached to threaded rods and held in place with nuts. The 3D printed plates would be designed depending on which sensors would be used, so that the sensor could easily be attached to the plate.

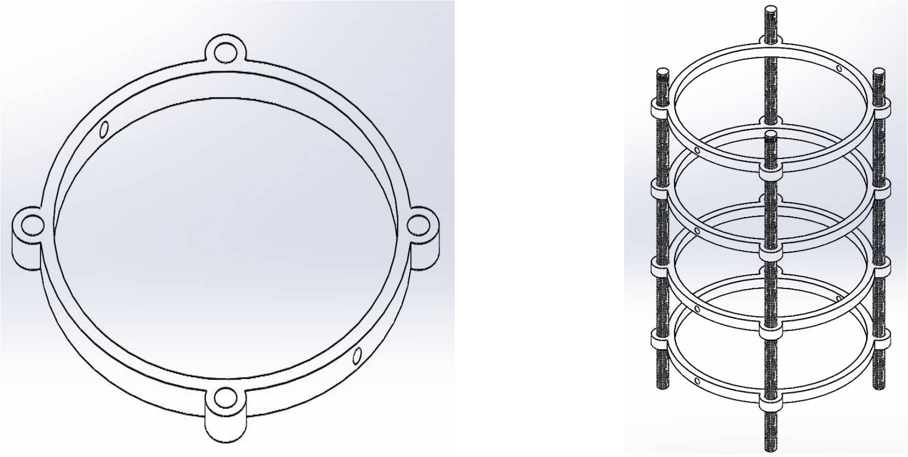


Figure 21: Second Tube Design: (1) 3D Printed Plate, and (2) Design.

The placement of the sensors could easily be changed, as the plates would slide along the threaded rods, and the nuts could be threaded upwards or downwards depending on the change of the plates location. Due to the design not using a PVC tube the shuttle can be seen when falling down. The design had the potential to be slightly heavier and expensive than the previous designs due to the threaded metal rods and the nuts. This design also shared a potential problem with the previous design, in that the sensors were exposed to external light sources, and depending on which sensors were used the sensors would have to be re-calibrated each time they were to be used. Using threaded rods and nuts also meant that the design would take longer to assemble, as the nuts had to be threaded one at a time. Another possible problem which was introduced with this design was that the shuttles were exposed to the environment when they were tested, such as wind which could cause the shuttles to be improperly tested.

Overview of Tube Designs

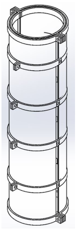
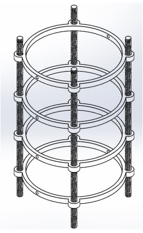
Design Nr.	1	1.5	2
Design Name	PVC Tube	Split Tube	Threaded Rods
Design Image			
Design Description	Sensors embedded into walls of PVC tube	PVC tube split lengthwise, attached together with 3D printed clamps that hold sensors	3D printed plates with embedded sensors attached to threaded rods
Design Pros.	• Simple and Cheap. • Sensor positions easily changeable (drill a new hole). • Sensors exposed to minimal external light sources.	• Cheap. • Avoids drilling holes into the PVC tube. • Can be designed to attach to a base. • Design can be adapted for different sensors.	• Avoids cutting or drilling PVC tube (as the design does not include a PVC tube). • Plate design can be adapted for different sensors. • Easily attaches to a base. • Shuttle seen in flight.
Design Cons.	• Potential problems with sensor embedding depending on sensors used. • Potential problems attaching to base.	• Potential problem with sensors being exposed to external light sources. • Potential difficulties cutting PVC tube lengthwise.	• More expensive, and potentially heavier. • Takes longer to assemble. • Sensors exposed to external light sources. • Shuttles Exposed to environment.

Table 3: Overview of Tube Designs

3.3 Sorting Mechanism

The bottom part of the device was the sorting mechanism. This mechanism would receive a signal from the microcontroller, which analysed the data gathered in the free falling measurement tube, and had to sort the shuttles after they fell. Theoretically this sorting mechanism could possibly be used to sort the shuttles after their speed class, or if the shuttles were damaged or not. For this thesis however, the device would only sort the shuttlecocks on whether they could or could not be used in their current environment. By that logic the sorting mechanism only needed to sort the shuttle into one of the two cases.

Pneumatic Concept

One of the early sorting mechanism concepts was a pneumatic solution. The simple concept was that the shuttle would keep falling after the free falling measurement tube, and if the data gathered showed that the shuttle was not fit to be used in its current environment, then compressed air would shoot into the side of the shuttle, moving it to a tube running parallel to the main tube. This parallel tube would then lead the shuttle to go with the rest of the unused shuttles.

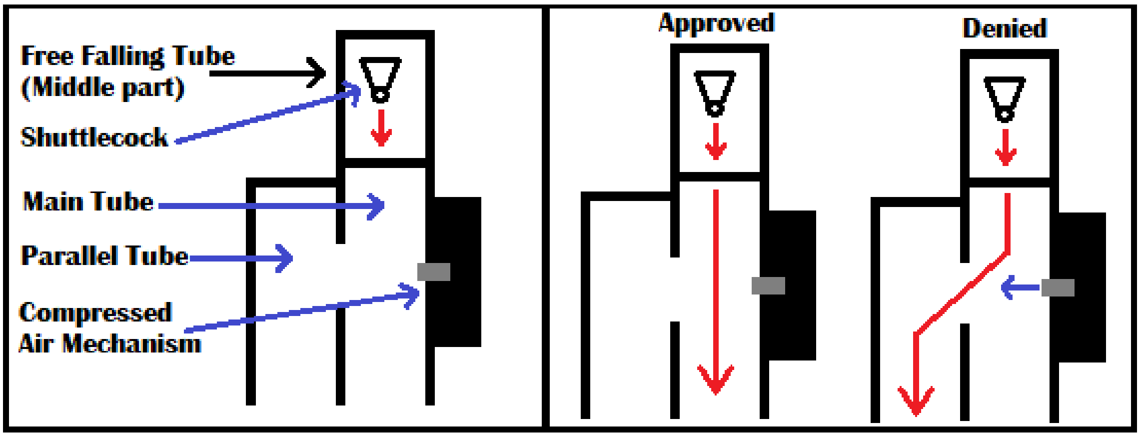


Figure 22: Pneumatic Mechanism Concept Illustration

Using compressed air to sort objects is a somewhat common solution, often used in the food industry to remove items that are not considered up to par. Often used with the assistance of cameras, they can recognize deformities and jet them off of the conveyor belts. Example of one of these machines is GP Graders AirJet which is used to sort cherries into multiple different grades. Taking into account internal and external damages to the cherry, size, and color. Often when using compressed air technology, tanks of compressed air are required, or an air compressor. Having to replace tanks of compressed air was not optimal for the device, as air compressors are large, expensive and heavy, not filling most of the factors stated in the beginning of the chapter **3 Brainstorming**.

Wall Plate Mechanism

Another sorting mechanism concept was called the wall plate mechanism. This concept had a second tube fasted to the side of the main tube, and an opening in the side of both tubes connecting them together. A motor was connected to a plate attached to the inside of the main tube wall, and when the shuttle was not to be used the motor would drive the plate out, blocking the shuttle from continue falling down the main tube. The wall would then lead the shuttle to fall down the parallel tube instead.

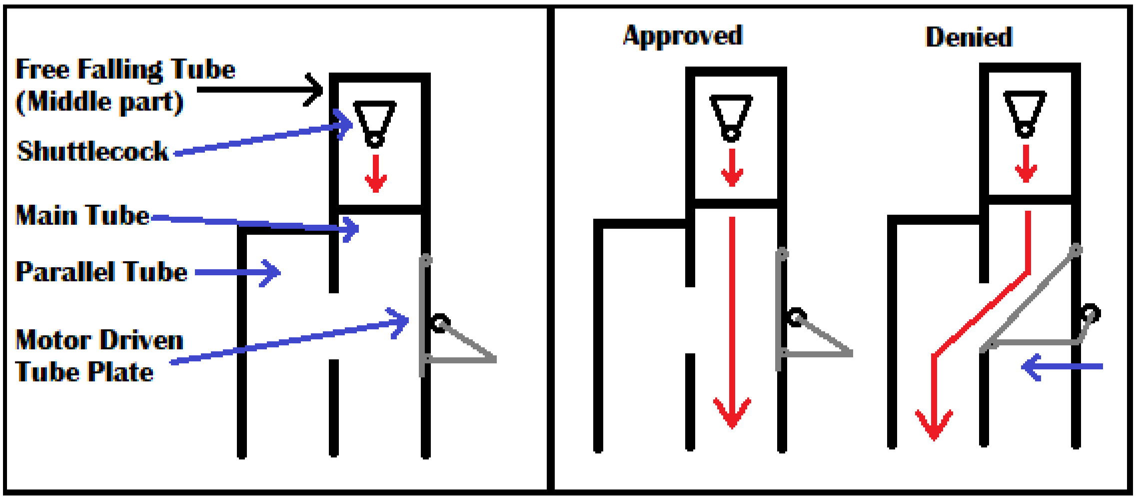


Figure 23: Wall Plate Mechanism Concept Illustration

The illustration above shows the basic concept, however there were many smaller variations on this concept. The illustration uses a piston rod like mechanism to drive the plate, however the motor can drive the plate a number of different other ways, such as different gear orientations or possibly just using the motor to hold up the plate.

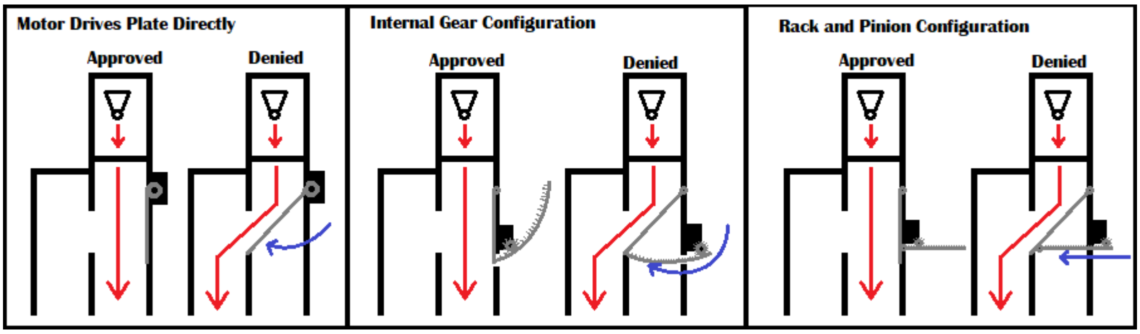


Figure 24: Wall Plate Mechanism Concept Variations Illustrated

It would have also been possible to drop the motor and instead use hydraulic or pneumatic pistons to drive the plate. Those would however have required additional equipment to be driven, and that equipment would have been heavy. As one of the preferences of the device was to be mobile, hydraulic or pneumatic pistons were not considered.

Rotating Bottom Mechanism

Another concept for the sorting mechanism was called the rotating bottom mechanism. This concept was using a single angled tube at the end which would be rotated by an external motor. The angled tube would be rotated, so that shuttles that would be approved would fall onto one side of the device, and shuttles not approved would fall down to the other side of the device.

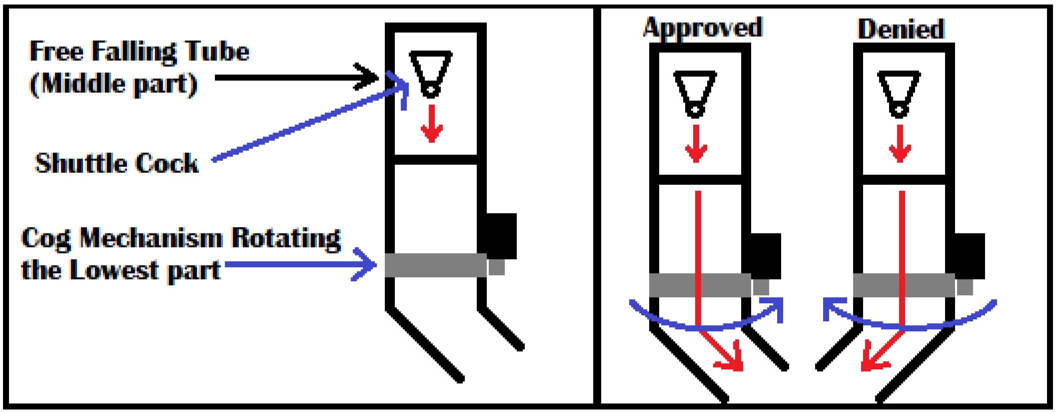


Figure 25: Rotating Bottom Mechanism Concept Illustration

This mechanism was more mobile than the previous two concepts as it was composed of only one tube, and therefor would avoid the additional bulkiness of the other designs. The tube would also not have to be altered like the previous designs, nor would there have to be parts placed into the tube. This concept was very simple in theory, however it was suspected that it could be slow to rotate the full 180 degrees needed when sorting the shuttles. If the motor would have a gear connected to it and an external gear would be around the tube, then the motor would have to be able to rotate multiple times in one direction just to be able to rotate the angled tube into correct position. To avoid this there could be additional gear attached so that the motor would not have to rotate as much, however this would add bulkiness to the concept which was not wanted. The rotation of the tube can also cause the device to move out of balance, or require a larger base.

Wedge Mechanism

The final sorting mechanism concept was called the wedge mechanism. This concept had either two smaller tubes or a Y-shaped three way fork at the end of the device, and a motor which would turn the wedge. After receiving a signal from the microcontroller the motor will turn the wedge, blocking one tube exit and leading the shuttle into the other.

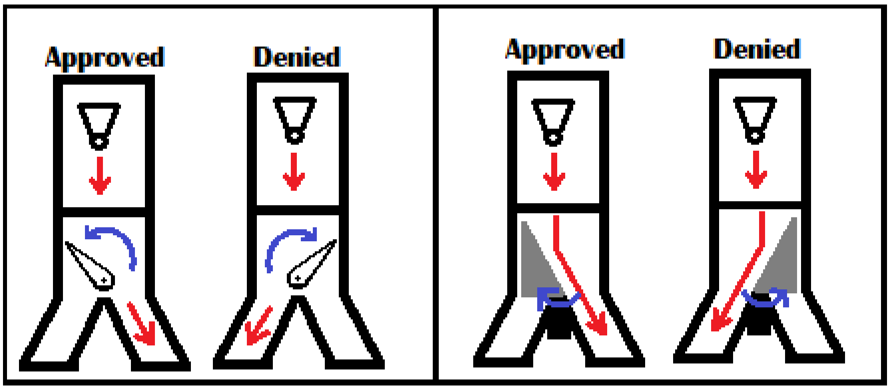


Figure 26: Two Tube Variations of the Wedge Mechanism Illustration

This was possibly one of the simpler mechanisms for sorting the shuttles. It was lighter and more compact than the previous designs. The wedge could be fastened directly to the motor with no additional gearing needed, as the motor would only need to turn at maximum 180 degrees. A problem could arise if the motor could not react fast enough from the signal, and therefor the shuttle might be sorted incorrectly. It would also be difficult to create this design from PVC tubes, and 3D printing the components could be time demanding.

Overview of Sorting Mechanism Concepts

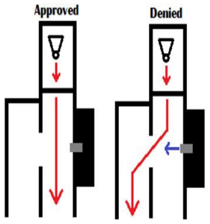
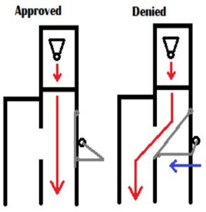
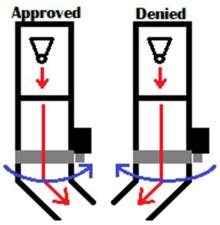
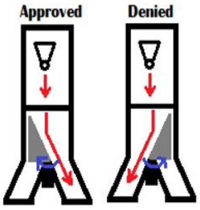
Concept Nr.	1	2	3	4
Concept Name	Pneumatic	Wall Plate	Rotating Bottom	Wedge
Concept Image				
Design Pros.	• Common solution in many industries.	• Lighter than previous concept. • Does not need additional equipment, such as compressed air tanks. • Can be driven in many different ways.	• Only uses a single tube. • Simpler design than previous concepts. • Does not require tube to be altered, or components to be inserted into the tube. • Small and compact.	• Only uses a single tube. • No additional gearing required to drive efficiently. • Small and compact. • The tube itself does not rotate.
Design Cons.	• Heavy. • Addition equipment required, heavy and bulky. • Uses an additional tube. • Compressed air tanks need to be replaced, or a generator to compress air.	• Uses an additional tube. • Requires the tube to be modified. • Component needs to be placed on inside of the tube.	• Possibly slow. • Can require gearing, making it bulky. • Rotation of tube can cause device to tip over.	• Can be difficult to construct. • Can take long time to produce. • Can cause shuttle to be sorted incorrectly or get stuck in design.

Table 4: Overview of Tube Designs

4 Prototyping

After brainstorming different concepts for each part of the device, an initial concept was picked and prototyping was initiated for each part of the device. A prototype of each part discussed earlier was developed separately before finally being all put together for the final prototype.

In the next sub-chapters each part of the device, the top, middle and bottom parts, are presented, with the initial chosen concept, and their prototyping process to the final functioning prototype. Most steps of the prototyping process were documented, however only large changes were discussed in details, while minor changes such as changes in dimensions of certain parts of the prototype might only be briefly mentioned. The reasoning for larger changes in the prototype were also presented.

The shuttle release mechanism went through the most drastic changes in the prototyping phase, while the free falling measurement tube and the sorting mechanism went through fewer and smaller changes.

4.1 Release Mechanism

The initial concept for the shuttle release mechanism was the diaphragm mechanism **(see 3.1.1 Release Mechanism)**. This concept was initially chosen due to it being the smallest and most compact design, as well as it being independent from whatever feeding system would be chosen. Choosing to use the diaphragm mechanism also avoided the vertical movement that the gripper mechanism required. The diaphragm design was simpler in the sense that it only uses motors to rotate the opening mechanism, however it was more complicated to design, and there were more parts that needed to be constructed due to its more complex design. The increase in parts also resulted in it taking longer to produce and test.

The release mechanism consisted of two diaphragm or iris mechanisms that were distanced from each other in such fashion that a single shuttlecock can be deployed at a time. Therefor when starting to prototype the release mechanism only one of the diaphragm mechanisms would be tested until a design that worked sufficiently was developed. Thereafter the distance needed to deploy a single shuttle at a time was found and an additional diaphragm mechanism was created to finish the design.

The release mechanism went through different changes over time, the most significant changes were documented into different prototype versions documented and discussed below. The prototypes were altered multiple times, however the descriptions below only mention the larger changes, and some of the subtler changes can be seen as well.

First Prototype

The first prototype was, as mentioned, based on a diaphragm mechanism design. Initially only one of the diaphragms would be designed, and then two identical ones would be produced and assembled so that there would be enough space between them to properly work, as described in the chapter **3.1.1 Release Mechanism**. The prototype consisted of a top plate, 12 teeth, and a base.

The top plate was circularly shaped, with a circular hole in its center. It had cog teeth around its perimeter, and curved holes on the inside. The teeth had a peg extruded on one of their faces, and a line extruded on their opposite side. The base was circularly shaped, with a circular hole in its center and straight grooves cut into it.

The base would sit in place and the teeth would be attached by connecting the extruded lines of the teeth to the cut grooves of the base. The top plate would lie on top of the teeth, with the pegs of the teeth going through the curved holes in the top plate.

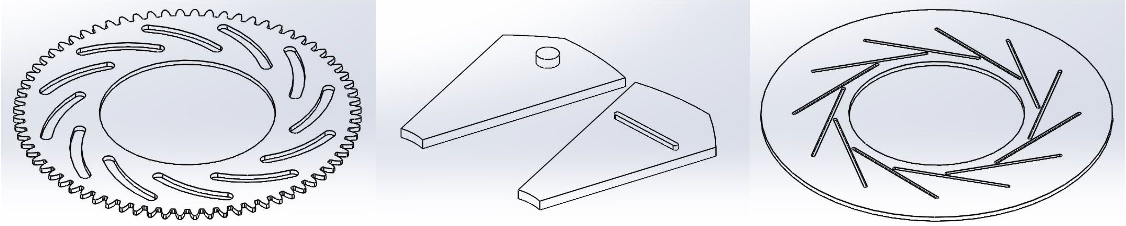


Figure 27: Prototype 1 parts in SolidWorks: (1) Top plate, (2) Tooth (right - front, left - back), and (3) Bottom plate

A gear would be attached to a motor, and the motor would then rotate the top plate, by connecting the motors gear to the gear teeth on the top plates outer perimeter. As the top plate would rotate the pegs would move along the curved hole in the top plate, and slide with their extruded lines along the cut grooves of the base. This would cause the teeth to move toward or away from the center of the diaphragm mechanism in an almost linear fashion.

Figure 28: Prototype 1: (1) In SolidWorks, and (2) Printed Prototype.

A problem found in the first prototype was that the teeth and the top plate were somewhat loose. This resulted in the whole mechanism falling apart when it was driven by the motor. To try to resolve this issue a new component was developed for the prototype. The new component was a cage which would hold the base, the teeth and the top plate together so they would not fall apart as easily as they had before. The cage was designed so that a motor could be fastened to it, having the motor sit in one place so it would be easier to drive the mechanism. The design also feature arms on the outer perimeter of the design, which could be fastened to threaded rods. The arms were designed so that two diaphragms could be placed on top of each other, and distanced from each other so that the mechanism could work as intended.

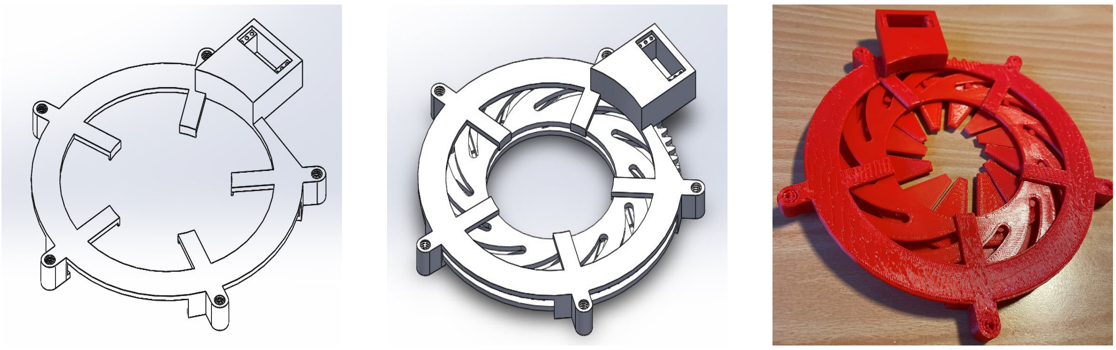


Figure 29: Prototype 1 Cage: (1) Part in SolidWorks, (2) Assembly in SolidWorks, and (3) Printed Prototype

The cage went through a few different iterations, where the changes mostly consisted of changing dimensions and tolerances. This was due to the base, teeth and top plate being held either too tightly, resulting in the diaphragm not rotating properly, or being too loose, which resulted in the diaphragm falling apart as before. After a few iterations it was decided move onto a slightly different design.

Second Prototype

The second prototype was somewhat similar to the first prototype, and it was still based on the diaphragm mechanism. The second prototype, like the first prototype, consisted of a top plate, 12 teeth, and a bottom plate.

The top plate from the first prototype was kept for the second prototype. The teeth had a similar design to the first prototype, however they had extruded pegs on both sides of them, replacing the extruded line that was on the first prototype. The biggest change from the first prototype was the base. The base of the second prototype had a circular design, with a circular hole in its center and curved holes similar to the ones on the top plate. The base also had a small motor mount, as well as arms similar to the ones on the cage of the first prototype.

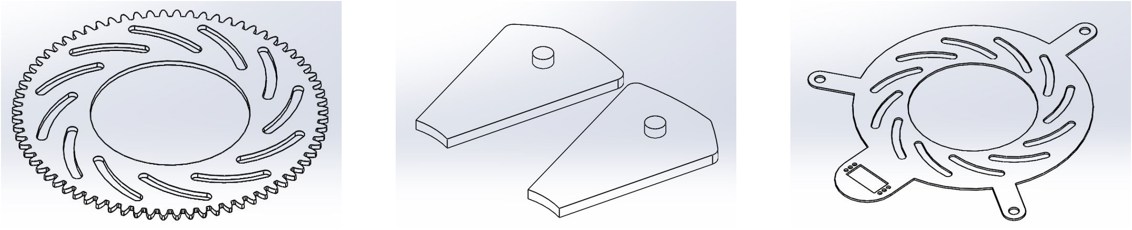


Figure 30: Prototype 2 in SolidWorks: (1) Top plate, (2) Teeth, and (3) Base

The second prototype was assembled in a similar manner to the first prototype. The teeth were placed on top of the base, with the pegs on one side of the teeth would be inserted into the curved holes of the base. The top plate would be placed on top of the teeth with the teeth on the other side of the teeth being inserted into the curved holes of the base. The top plate would be rotated by a gear attached to a motor fastened to the base. An important detail was that the curved holes on the base and the top plate would have to be oriented in separate directions. This caused the teeth to move toward or away from the center of the diaphragm when the top plate rotated.

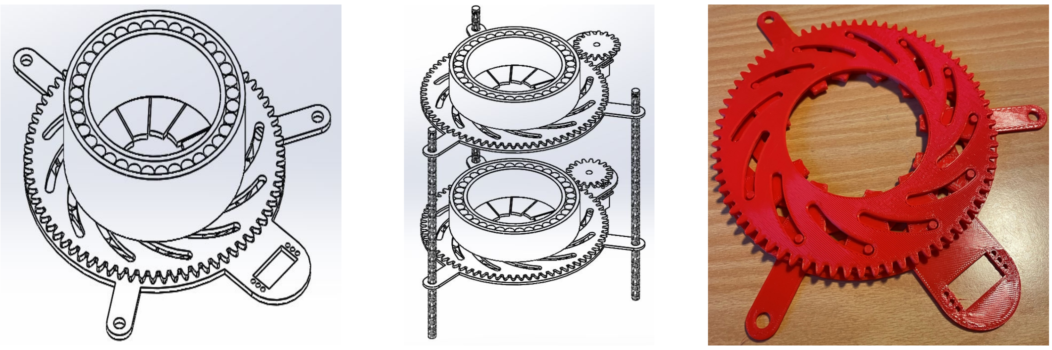


Figure 31: Prototype 2: (1) Assembly in SolidWorks, (2) Diaphragm Assembly in SolidWorks, and (3) Printed Prototype

The second prototype would be held up by fastening the arms of the base to threaded rods with nuts, to an appropriate height, so that the diaphragm could function properly. The prototype went through a few slight iterations, with the largest one adding a bearing to keep it in place while allowing it to rotate properly, however, likely due to its similar design to the first prototype, similar problems to the ones the first prototype arose, such as the top plate not rotating properly and the whole design falling apart when driven by a motor. The teeth would also not always move as intended. After a few iterations, and many problems, it was decided to make more drastic changes to the prototype.

Third Prototype

The third prototype was based on a similar concept as the diaphragm mechanism. This design instead used more cog mechanisms and the movement of the teeth of the diaphragm mechanism was changed. The teeth now moved linearly toward or away from the the opening instead of rotating like in the previous prototypes. The third prototype consisted of a top plate, six teeth and a base.

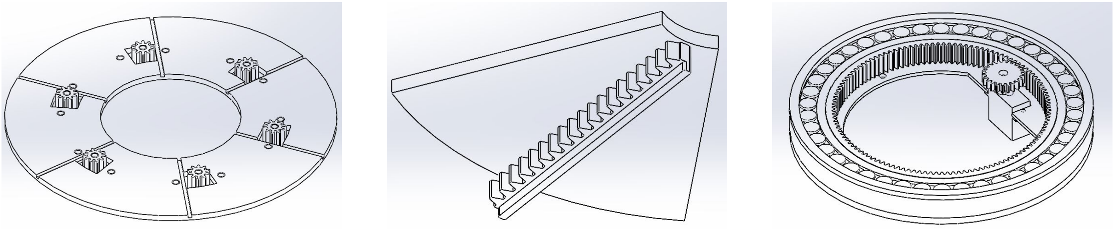


Figure 32: Prototype 3 in SolidWorks: (1) Top Plate, (2) Tooth, and (3) Base.

The teeth of the third prototype were larger than the previous prototypes. Instead of extruded pegs the teeth had a rack on their underside. The top plate of the third prototype was very different to the ones of the previous prototypes. It had grooves on its top face for the racks of the teeth to slide along. The top plate also had long pegs where gears would be placed. The base of the third prototype was a large bearing, with an internal gear along its inner diameter. The bottom of the base had a motor mount.

This prototype used a single servo motor connected to a spur gear, which drove an internal spur gear connection, and the internal spur gear drove six individual gears that were connected to a gear rack which the teeth were attached to.

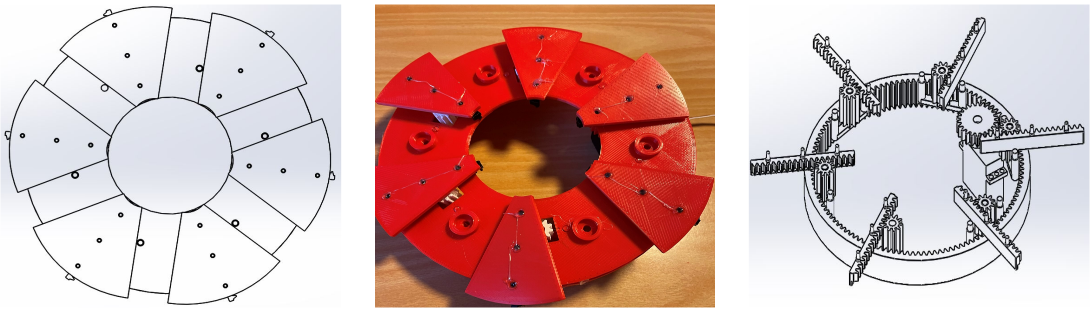


Figure 33: Prototype 3: (1) Assembly in SolidWorks, (2) Printed Prototype, and (3) Gear Mechanism in SolidWorks.

The racks under the teeth were driven by spur gears and slid along the grooves on the top plate. The spur gears sat on rods attached to the top plate, and were driven by the internal gear on the inside of the base. The internal gear was rotated by a spur gear controlled by the motor. The bottom of the base is fastened to the outer wall of the base, while the internal gear is attached to the inner wall of the base. The base is a bearing, which allows its inner wall to rotate freely while the outer wall is static. The top plate is also attached to the outer wall, as it is not to be rotated.

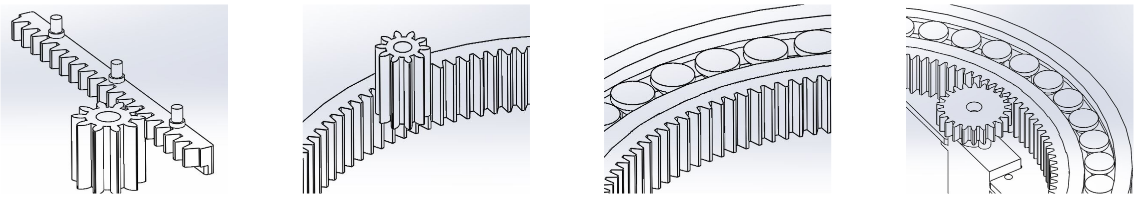


Figure 34: Prototype 3 Connections: (1) Gear Rack to Spur Gear, (2) Spur Gear to Internal Gear, (3) Internal Gear to Bearing, and (4) Internal Gear to Servo

A few iterations of this prototype were made, with the largest changes being making the teeth smaller, adding slots for rods, which would separate two copies of the prototype, as it would work similarly as the diaphragm mechanism (using two copies to release single shuttles). A problem arose with the teeth falling out of the grooves when driven. To try to fix the problem the grooves for the rack gears were changed.

The third prototype worked much better than the previous prototypes, as it did work for the most part, however the grooves where the rack gears slid were never good enough, making the movement of the rack gears wobbly when driven at slow speeds, and the rack gears falling out of the grooves when the speed of the motor was increased. The prototype consisted of multiple parts, meaning that more assembly was required, and more parts had to be made with each iteration. At a point the release mechanism had become large and bulky, and it was decided to change to a different design.

Fourth Prototype

The fourth prototype changed from a diaphragm mechanism to a double gripper mechanism. The third prototype had become larger and bulkier, and therefor the choice was made to change to the double gripper mechanism. As mentioned in the chapter **3.1.1 Release Mechanism**, one of the larger strengths for using a diaphragm mechanism instead of the double gripper mechanism was that the diaphragm was smaller, however at this stage the size difference between the double gripper and the diaphragm had become so small that it could be considered negligible.

The fourth prototype primarily consisted of the upper gripper, the lower gripper and the hub. The upper grippers were designed to be smaller and longer, as they would grab onto the feathers of the second lowest shuttle. The lower grippers were designed to be able to hold a shuttle comfortably, with the head of the shuttle sticking out under the lower grippers when closed. Both grippers had racks on one of their ends as they were driven with a rack and pinion connection. Both grippers were also designed to have grooves cut into them both on their top and bottom faces, so that they would slide along the base without being displaced while driven. The base was designed to hold both grippers firmly while allowing them to move freely along a determined axis while being driven. The base also had two motor mounts, one close to the upper gripper and one close to the lower gripper.

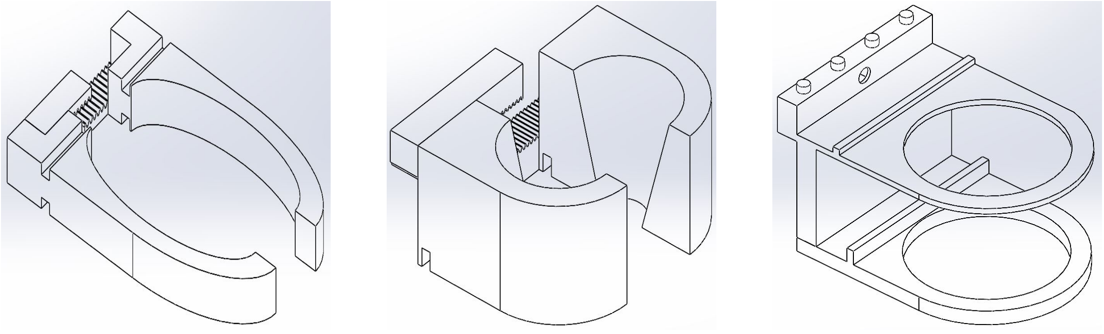


Figure 35: Prototype 4 in SolidWorks: (1) Upper Gripper, (2) Lower Gripper, and (3) Hub

The grippers would be slid into place on the base, with extruded helping bars on the base fitting into the grooves of the grippers. A spur gear would be placed between the racks of the grippers and attached to a motor mounted on the other side of the base. The motors drove the rack and pinion connection of the gears, allowing the rotational movement of the motor to be translated to a linear motion of the grippers.

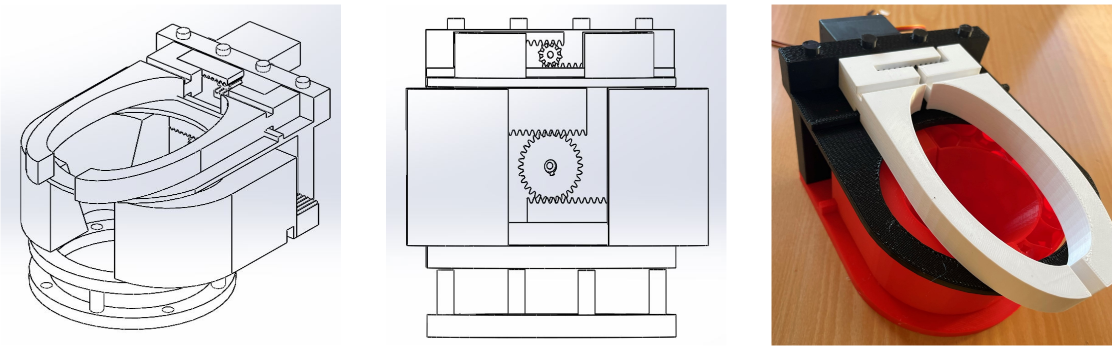


Figure 36: Prototype 4: (1) Assembly in SolidWorks, (2) Front View in SolidWorks, and (3) Printed Prototype.

The bottom gripper held the shuttle which is to be released. The upper gripper closed and grabbed onto the next shuttle and held it by the feathers. The bottom gripper opened and released the first shuttle to fall down the measurement tube, then closed again. The upper gripper released the shuttles into the bottom gripper and closed again to grab the next shuttle. These actions repeated as programmed to automatically dispense the shuttles.

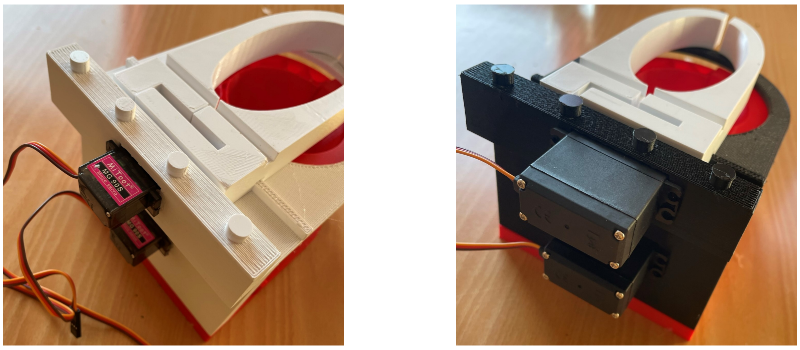


Figure 37: Release Mechanism Prototype 4: (1) With MiTooT MG90S, and (2) With Towerpro MG996R

The prototype was initially tested with **MiToot MG90S micro servo**, as it had worked when used with the third prototype, however the friction of the grippers to the plates seemed to be too great for the motors to be able to move the grippers. The motors were replaced with **Towerpro MG996R servo motors** which had more torque. The motors were able to move the grippers, however due to the shape and length of the upper grippers they would not move properly, instead the motor would move the part of the gripper closest to to the motor and pivot farthest from the motor. This along with the design being somewhat heavy on one side, lead to the prototype being reworked again.

Fifth Prototype

The fifth prototype continued using the double gripper mechanism, similar to the fourth prototype. The fifth prototype consisted primarily of an upper gripper, a bottom gripper and a base, similarly to the fourth prototype.

The top grippers were changed significantly, as the design was changed to a straight cylinder design, with small plates on each of their ends. The plates had racks fixed to them which would fit to the rack and pinion connections. The plates were also introduced to hold the gripper in place, not allowing it to slide in certain directions, and as the plates were taller then the diameter of the cylindrical parts of the upper gripper, which raised it up, reducing the friction of the upper gripper by reducing its contact area with the surfaces of the base.

The lower gripper kept some design details of the fourth prototype, such as the inside of the lower gripper being designed to hold a shuttle comfortably with the shuttles cork head sticking out under the closed gripper. The design changed however in other ways, having the profile of the lower gripper changed to a rectangular design instead of a circular similar to the fourth prototype, as well as adding an additional rack on the other side of the lower gripper. The same design was also made of elevating the gripper from the surfaces of the base at the rack connections, to reduce the friction of the gripper while it was being driven.

The base if the fifth design was also changed significantly. To hasten the construction of the base, it was split into multiple similar parts which could be fastened together with peg and hole connections (similar to Lego). The base consisted of three identical plates, two lower walls and two upper walls. The plates had a circular hole at their center where the shuttles would be dispensed through, extruded helping bars similar to those of the fourth design, and holes on their bottom face and pegs on their top face to be put together. The only difference between the upper and lower walls were their height, as the lower grippers were taller than the upper grippers, and the walls would have to reflect that.

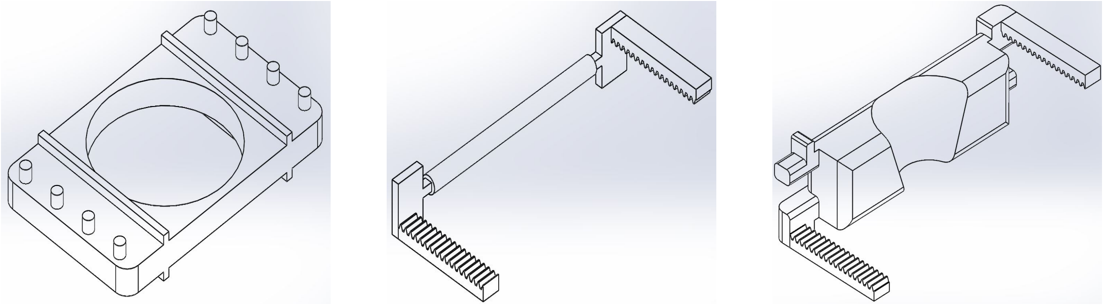


Figure 38: Prototype 5: (1) Base Plate, (2) Upper Gripper, and (3) Lower Gripper

To avoid the problem that the fourth prototype had with friction and in one end of the gripper pivoting, another rack and pinion connection was placed on the side opposed to the motor. This connection was not motor controlled, instead allowing the connection to be moved freely. This helped the grippers move in a parallel fashion in the direction that the motors was moving them in. This design was also more symmetric, avoiding the asymmetrical design of the fourth prototype

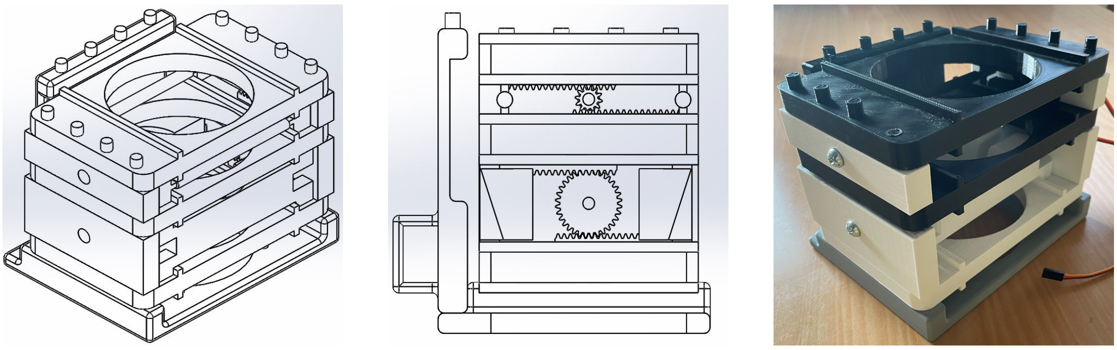


Figure 39: Prototype 5: (1) Assembly in SolidWorks, (2) Sectioned View in SolidWorks, and (3) Printed Prototype.

For the fifth prototype additional components were also designed and constructed, those components being a tube mount which would connect the prototype to the free falling measurement tube, and a controller mount, where all electronics would be fitted.

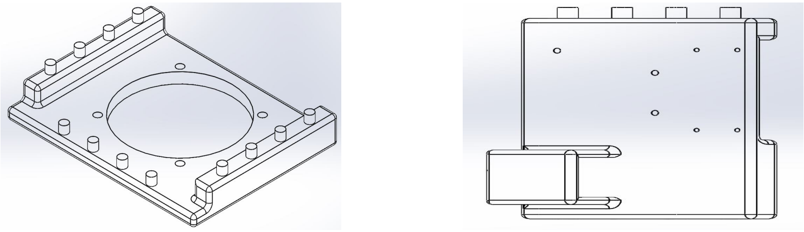


Figure 40: Prototype 5: (1) Tube Mount, and (2) Controller Mount.

The tube mount was fastened to the bottom of the prototype. The mount had elevated pegs to fasten to the bottom plate, as well as pegs to fasten the controller mount which was on the side of the prototype. There were holes around the center hole. These holes would fit the threaded rods which were used in the free falling measurement tube prototype, and was how they connect to each other.

The prototype was driven by two **Towerpro MG996R servo motors**(same ones used in the fourth prototype), a Arduino Uno, a PCA9685 motor-controller, a L7805CV linear fixed voltage regulator, and an external 9 volt battery. All of these components were fastened to the prototype. The motors were fastened to walls of the base, as they drive the rack and pinion connections controlling the movement of the grippers directly, while all the other components were fastened to a controller mount. The controller mount was fastened with pegs to the tube mount and had pegs on top of it to be later fastened to a top plate of the prototype. The thickness of the mount varied, the thickness was thinner where the Arduino and motor-controller were fastened as they were fastened with small bolts (M3 for the Arduino and the motor-controller). The mount also had a compartment fixed to it where a 9 volt battery would sit, which was connected to the voltage regulator and powered the motor-controller.

4.2 Free Falling Measurement Tube

The initial concept for the free falling measurement tube was the threaded rods concept **(see 3.2.2 Tube Design)**. This design was initially chosen to avoid modifying the PVC pipe, as well as the more customizablity of the design, and to be able to easily fix it to a base. The initial sensors used were the infrared-LED and infrared-photodiode **(see 3.2.1 Sensors)**, due to them being the smallest sensors, as well as being the cheapest ones.

The free falling measurement tube consisted of multiple 3D printed plates fastened onto threaded rods with nuts. The infrared-LED were embedded on one side of the plate, and the infrared-photodiode were placed on the opposing side of the plate. The infrared-LEDs and the infrared-photodiodes were tested to see what values they would output to the microcontroller, and tested to see how the value changed when a shuttle passed them. The microcontroller was then be calibrated to be able to start a timer, and save time values for when each sensor was triggered, thereby being able to calculate the velocity and acceleration of the shuttles passing.

The free falling measurement tube went through few changes, most of them minor, with one more significant change. These changes are documented below.

First Prototype

The first prototype was, as mentioned, based on the threaded rod design concept, and used the infrared-LED and the infrared-photodiode as the sensors.

The prototype consisted of four M6 threaded rods (each 1 meter long), a base, five 3D printed plates, five sets of the sensors, and a mount for the microcontroller. The threaded rods and nuts were bought, and the threaded rods were only available to be purchased in 1 meter lengths, so it was chosen to have five sets of sensors, with a distance of 20 centimeters between each sensor.

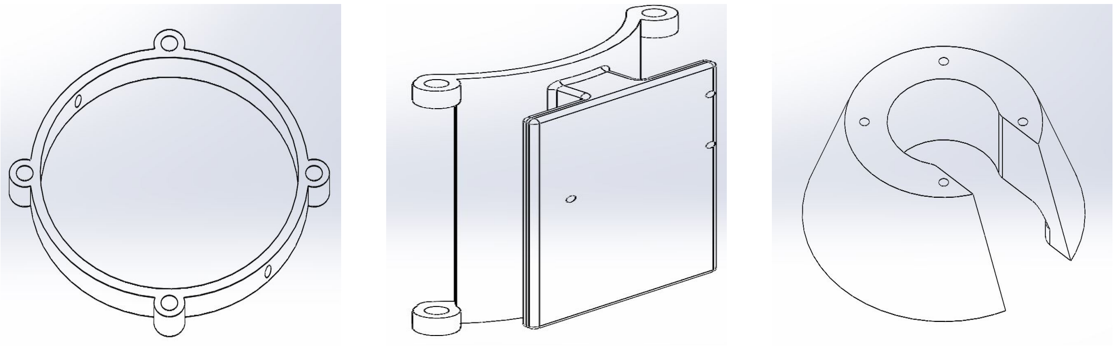


Figure 41: Prototype 1 in SolidWorks: (1) Plate, (2) Microcontroller Mount, and (3) Base

The 3D printed plates had a circular tube design, with an inner diameter of 100 millimeters, a wall thickness of 4 millimeters, and a height of 8 millimeters. Along the outer perimeter of the tube like design were four smaller tube like designs, where the threaded rods would be slid through, and the diameter of those holes were slightly larger than the diameter of the threaded rods, so that the rods could slide more easily through the plates. There were also two 5.5 millimeter holes cut through the walls of the plates. Those were where the infrared-LED and the infrared-photodiodes would be placed.

The microcontroller mount 14 centimeters tall and curved with the same diameter as the 3D printed plates. A plate to mount the microcontroller was place with some distance away from the curved part which would fit to the prototype, so that the microcontroller could be fastened with screws, and that the nuts could be placed more easily to fasten them. The mounting plate had holes where the microcontroller had mounting holes, so that the screws could be more easily be slid through them and fastened with nuts on the other side of the mounting plate. The mounting plate also had additional empty space underneath where the microcontroller would be fastened. This empty space was where a breadboard would be placed, so that all connections could be made there instead of directly to the microcontroller.

The Base of the prototype was cylindrical in form, with a larger diameter at the bottom. The base had four holes, slightly larger than the diameter of the threaded rods where the rods would slide through, and a cut opening between two of those holes. This opening was made so that when shuttles were tested before the sorting mechanism was made, they could more easily be removed from the bottom of the prototype. The underside of the base also had a hollow, so that nuts could more easily be threaded to the rod on the underside of the base.

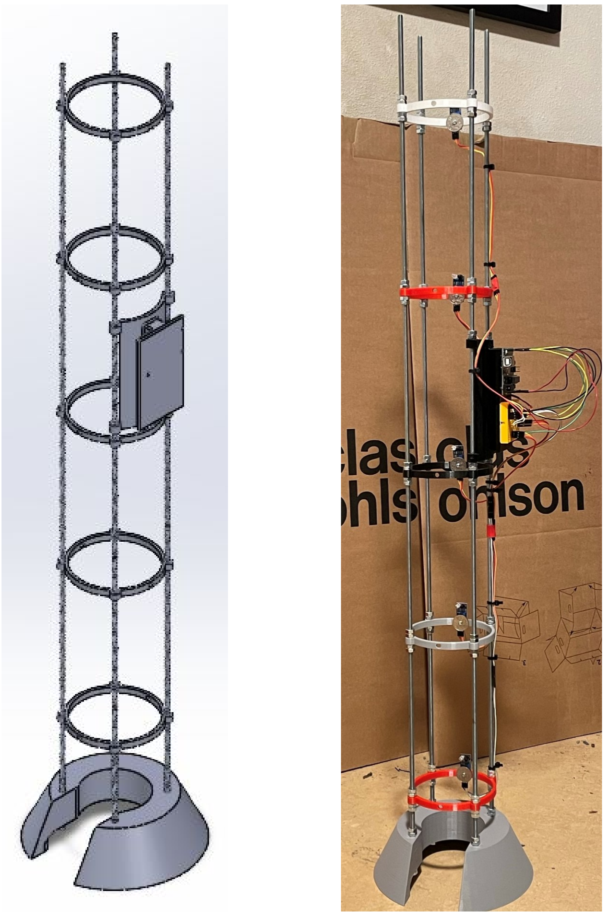


Figure 42: Prototype 1: (1) In SolidWorks, and (2) Finished Prototype

As previously mentioned the initial sensors used were the infrared-LED and infrared-photodiode pair, however after failing to get them to work properly, as well as realising that due to the prototypes exposure to external light sources meant that the sensors would need to be re-calibrated before each use they were replaced with the infrared obstacle avoidance module. The module was simple to use and cheap, so it was seen as an easy replacement to try to start testing the concept of the device.

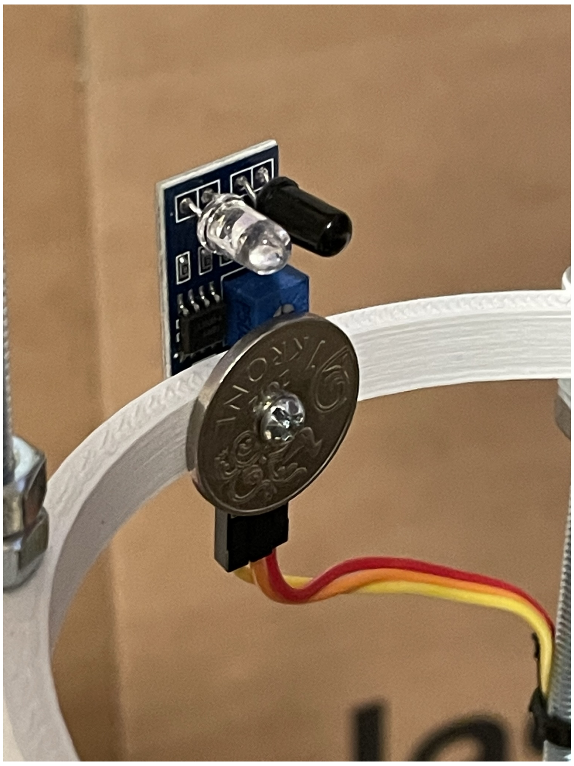


Figure 43: Infrared Obstacle Avoidance Module Fitted to the Plates

The 3D printed plates fastened to the prototype were designed to hold the infrared-LED and infrared-photodiode, which posed a new problem in attaching the new sensors to the plates. The infrared obstacle avoidance module had a hole in the middle of it for mounting, which a M3 bolt could be fitted through. The mounting holes on the 3D printed plates had a larger diameter than the head of the M3 bolts, so the M3 bolts slid right through them. It would have been possible to redesign the models of the plates to have smaller holes, re-print the plates, and replace the plates attached to the prototype, however that would have been very time consuming. Instead this problem was fixed when it was discovered that the diameter of a Norwegian kroner is perfect for a M3 bolt. This lead to Norwegian kroner being used as washers for the M3 bolts so that the infrared obstacle avoidance module could be properly fitted to the 3D printed plates.

As mentioned in the chapter **3.2.1 Sensors** the infrared obstacle avoidance module outputs either a HIGH or LOW signal depending on whether something is blocking it. All the sensors were connected to an Arduino Uno and a code was written so that when all the sensors had been triggered the Arduino would output the time difference between every sensor being triggered, and since the distance between each sensor was known the velocity and acceleration of the shuttle could be calculated. The code used can be found in **APPENDIX A.A**.

Testing of the First Prototype

The Arduino was connected to a PC and the data gathered from the Arduino could then be directly streamed to Microsoft Excel to then later be worked on. The rig was first tested by dropping tennis balls down through the tube. The Arduino Uno would then output the time of when the ball passed each sensor in milliseconds, using the first sensor as a default zero for the other sensors to compare their times to. The distance between each sensor was 20 centimeters. Using the distance, and the time output from the Arduino the velocity of the ball as it passes each sensor can be calculated. For the data shown below the same tennis wall was dropped multiple times and its data collected and analysed.

Drop Nr./Sensor Nr.	1	2	3	4	5
1	0,0000	0,0917	0,1622	0,2223	0,2729
2	0,0000	0,1002	0,1784	0,2421	0,2951
3	0,0000	0,0999	0,1729	0,2347	0,2825
4	0,0000	0,0964	0,1681	0,2293	0,2769
5	0,0000	0,0930	0,1649	0,2256	0,2738
6	0,0000	0,0867	0,1560	0,2178	0,2650
7	0,0000	0,0919	0,1667	0,2240	0,2739
8	0,0000	0,0729	0,1438	0,2021	0,2498
9	0,0000	0,0763	0,1490	0,2087	0,2563
10	0,0000	0,0739	0,1468	0,2059	0,2542
11	0,0000	0,0934	0,1640	0,2185	0,2708

Table 5: Time of When each Tennis Ball Passed Each Sensor in Seconds.

The table above shows the time it took for the tennis ball to pass each of the five sensors with each drop. As previously mentioned the code is written in such way that the sensors start to count after the first sensor is triggered. The Arduino also outputs the times in milliseconds, however for the table the times have been changed to seconds instead. Using the values in the table above and the distance between each sensor (20 centimeters) the estimated velocity of the ball at each sensor was calculated, taking the total distance the ball has fallen and dividing it by the time value at each sensor. The results of this can be seen in the graph below.

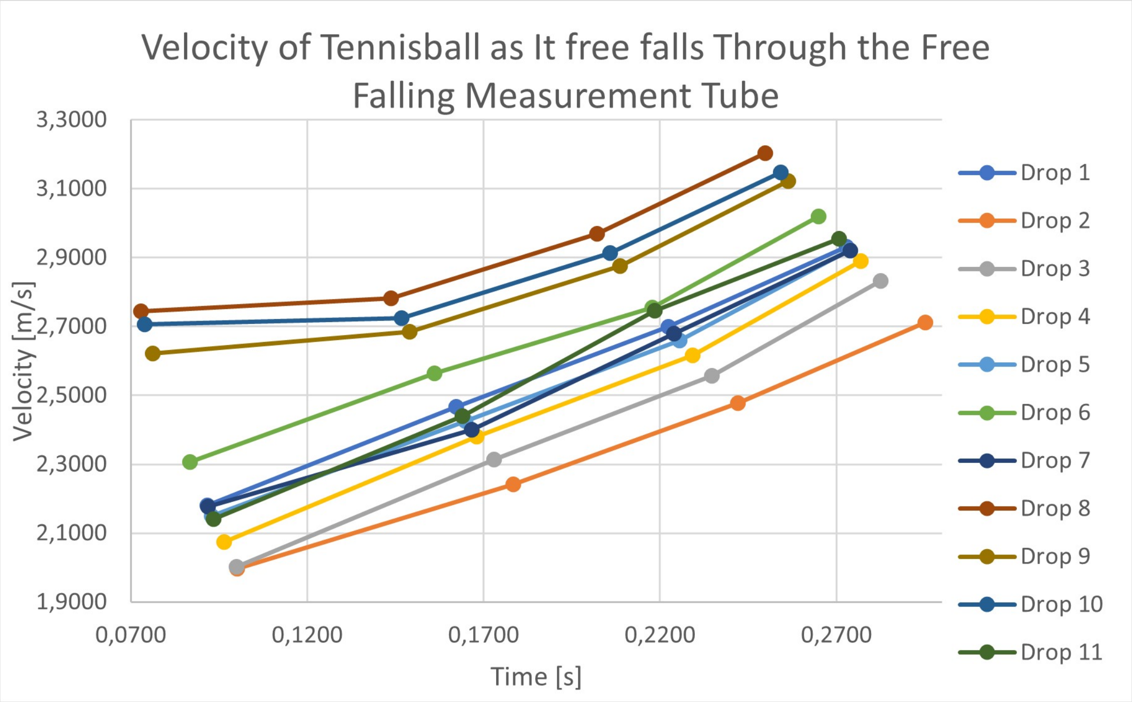


Figure 44: Velocity of Tennis ball as It Free Falls Trough the First Prototype

The graph above shows the velocity of the tennis balls over time as each time it is dropped down the free falling tube. The graph shows us that the increase in velocity and time between each sensor being triggered stays mostly consistent, with the increase in velocity being almost linear. This is expected as the velocity of the ball should theoretically increase linearly until terminal velocity is reached. The graph shows that the terminal velocity of the tennis ball was never reached.

There is a small variations on starting velocity, the largest difference being that between the eighth and the second drops. This difference is due to the fact that the ball was released by hand, and therefor there being a difference in initial velocity of the ball for each drop. As the Arduino is coded to use the first sensor trigger as being the start of time, this difference is expressed as a difference in initial velocity and a earlier detection by the second sensor. The balls were all released by hand at the approximately same position (10 cm +- 2cm from the first sensor), where they initially gather speed.

The table and graph above show that the tennis ball was dropped 13 times, however it was in reality dropped 20 times. The data for the seven ball drops not shown were removed either due to the ball hitting one of the sensors and bouncing outside of the free falling measurement tube, or one of the sensors giving inaccurate data due to it not being properly fixed after being hit by a previous tennis ball. The balls hitting the sensor as they fell revealed a problem with the first prototype. That being that the sensors were completely exposed to the falling objects they were meant to record. Due to this problem a second prototype was developed.

Second Prototype

The second prototype for the free falling measurement tube was based on a combination of the first and second designs presented in **3.2.2 Tube Design**.

The second prototype primarily consisted of four M6 threaded rods (each 1 meter long), a base, five 3D printed plates, five infrared obstacle avoidance modules, a mount for the microcontroller, and a PVC tube as well. The prototype is also constructed with multiple M6 nuts, M3 nuts and M3 bolts.

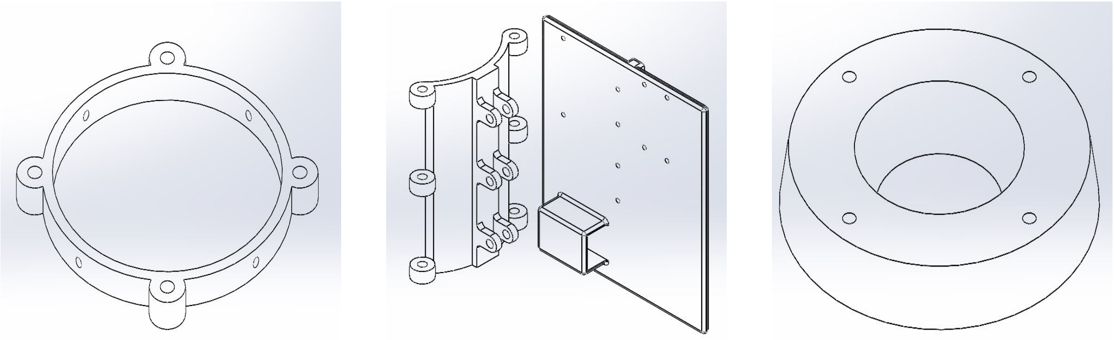


Figure 45: Second Prototype in SolidWorks: (1) Sensor Plate, (2) Controller Mount, and (3) Base

The 3D printed plates used in the second prototype are similar to the ones used in the first prototype, with the only differences being that the inner diameter has been increased to 104.5 millimeters so they can fit around the PVC tube, and that there are now four smaller holes on the walls of the plate. The holes were made smaller as it was decided to use the infrared obstacle avoidance modules as the sensors instead of the infrared-LED pair, and therefor the holes only need to fit M3 bolts instead of the whole LEDs. Due to the decrease in the hole diameter the use of washers to fasten the sensors were no longer needed.

The microcontroller mount was split into two parts. The first part was made to fit on the threaded rods, and has arms sticking out that can connect it to the second part of the microcontroller mount. The second part was a plate where the microcontrollers and other electronic components would be mounted. The mount plate had holes designed into it where the microcontrollers and the motor controller could be mounted with M3 bolts and nuts. It also had a large empty area for breadboards, and a compartment similar to the controller mount of the fifth prototype for the release mechanism, where a 9 volt battery could be placed. The extra space and the battery compartment were made because it was decided to try to keep all the electronics in a single area, and not spread them all over the device. The motors would still be fitted where they are needed, but the microcontrollers, the motor controller and all breadboards were now attached to the free falling measurement tube.

The new base was much smaller than the base used in the first prototype. After the first prototype was tested it was determined that there was little to no movement of the device, and therefor the base could be reduced significantly. Due to the base being smaller than the first prototype, it no longer required the opening on one side to gather the shuttles after testing.

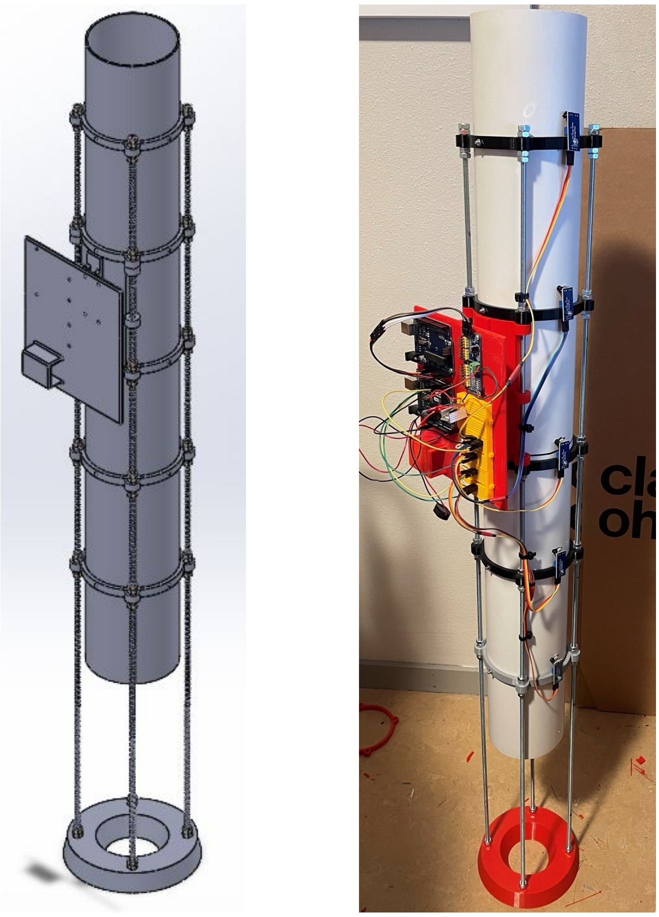


Figure 46: Prototype 2: (1) In SolidWorks, and (2) Finished Prototype

The prototype was constructed similarly to the first prototype, with the 3D printed sensor plates and the base fastened to the threaded rods with nuts, however the PVC tube was fastened to the prototype as well. The 3D printed sensor plates were fastened to the PVC tube by drilling 3 millimeter holes into the tube through the holes in the plates, and fastening the plates to the PVC tube with M3 bolts and nuts. Larger holes were drilled into the PVC tube above one of the 3D printed sensor plate holes. These holes were used so that the LEDs of the infrared obstacle avoidance modules could peek through and detect the passing shuttles.

The PVC tube is shorter than the threaded rods, being around 83 centimeters long. Due to the shorter length of the PVC tube, the base could be fastened to the bottom of the threaded rods, and there would be enough space for the sorting mechanism without it touching the ground. Due to the shorter length however the distance between each sensor had to be reduced from 20 centimeter to 15 centimeter. The PVC tube does however come with connections which allow more PVC pipes to be connected directly to them, which means that if needed the length of the PVC tube can be extended. For this prototype however these connections were used to fasten the releasing and the sorting mechanisms to the free falling measurement tube.

Placing the PVC tube, avoided the problem of having the falling objects hitting the sensors, or falling out of the prototype before getting measured, which the first prototype had. It also limited the effects of outside wind conditions interfering with the measurements.

4.3 Sorting Mechanism

The sorting mechanism did not go through any significant changes in its prototyping phase, but instead had a few smaller changes. The initial concept for the sorting mechanism was the wedge concept **(see 3.3 Sorting Mechanism)**. As the sorting mechanism did not go through any drastic changes in the prototyping phase, there will not be numbered prototypes, instead the main changes will be discussed directly.

This concept was chosen due to its simplicity, as the concept could be driven directly by a single motor, as well as not requiring an additional tube. The wedge concept was also chosen over the rotating bottom concept, as having the rotating bottom might introduce additional movement to the device which might result in the device needing a larger base to avoid falling over when driven. The wedge design did however mean that the sorting mechanism would not easily be made with PVC tubes, but instead the whole system, excluding the motor, would have to be 3D printed. This meant that if the tube design of the sorting mechanism would have to change the whole system would have to be re-printed, which could take a long time.

The sorting mechanism was simple, primarily only consisting of two parts, the tube, which connected to the free falling measurement tube and encased the entire sorting mechanism, and the wedge which was rotated by a motor, sorting the shuttles.

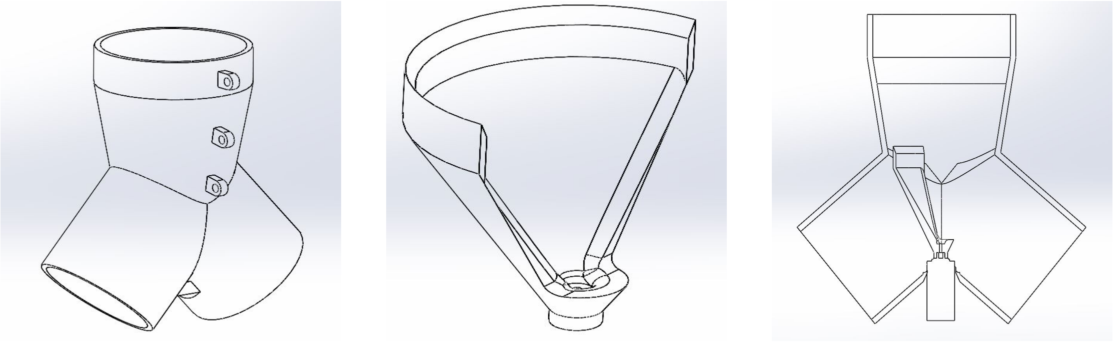


Figure 47: Sorting Mechanism in SolidWorks: (1) Tube, (2) Wedge, and (3) Split View of Assembly

The tube was a Y-shaped three way fork tube, where one opening was used as the entrance for the falling shuttles, and the other two openings were used as the exits, where the shuttles would fall through depending on how they were sorted. Between the two exit openings there was a motor mount, where a **Towerpro MG90S servo motor** was fitted. The tube was constructed by splitting the model, in a way where one of the exit openings was include in each split part, and then 3D printed. To fasten the two split parts, three arms with holes that M6 bolts could go through were added. After being printed, and the supports removed, the two split surfaces would be placed against each other, and fasted together with M6 bolts and nuts via the designed arms.

The wedge was constructed in a manner that it could be fastened to the **Towerpro MG996R servo motor**, by having a small opening on its bottom where the tip of the motor would slide in, as well as having a hole where a M3 bolt could be screwed through the wedge, and fasten inside the opening on the motor. As the primary purpose of the wedge was to sort the shuttles, it was designed so that it would block one of the exit openings on the inside of the tube and lead the shuttle through the other exit opening.

The tube component of the sorting mechanism had a few changes through the process of the prototyping phase.

Figure 48: All iteration of the Sorting Mechanism (From Left to Right)

Most of the changes to the tube component of the sorting mechanism were made to its shape and dimensions. The first tube had the same inner diameter for each opening, which was the same inner diameter as the free falling tube (10 centimeters).

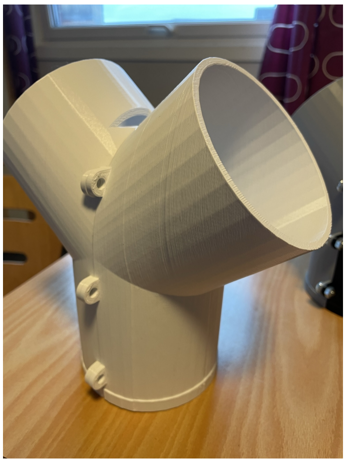


Figure 49: First Iteration of the Sorting Mechanism Prototype

The first iteration of the tube failed in the very start as the arms to fix the two split surfaces were to close to the tube, making it impossible to fix them together with bolts.

Figure 50: Second Iteration of the Sorting Mechanism Prototype

The second iteration fixed this mistake by extending the arms farther out. The problem that was found in the second iteration was that having all openings the same size did not work well as when the sorting mechanism fitted on the free falling tube, the two exit openings were larger than the distance between the threaded rods that were connected to the base, resulting in the rods bending away from each other and not being able to be fastened properly to the base.

Figure 51: Third Iteration of the Sorting Mechanism Prototype

The third iteration to the tube fixed this by keeping the same diameter for the entrance opening of the tube, but reducing the diameter of the two exit openings of the tube. The motor mount was also changed to become much simpler. The new design of the third iteration created a funnel like look to the sorting mechanism, with a larger entrance and smaller exits. The problem that arose with the third iteration was that now the exit openings were too small for the shuttle to fall through when they were being sorted.

Figure 52: Fourth Iteration of the Sorting Mechanism Prototype

The fourth iteration tried fixing the problem by changing the shape of the two exit openings from a circular hole to a oval or ellipse hole, keeping the same width so that the exit openings would fit between the threaded rods of the free falling measurement tube, but increasing the other radius to give the shuttles more space to fall through. The fourth iteration was not able to solve the problem, as the change in the radius was not enough and the shuttles still stopped when sorted.

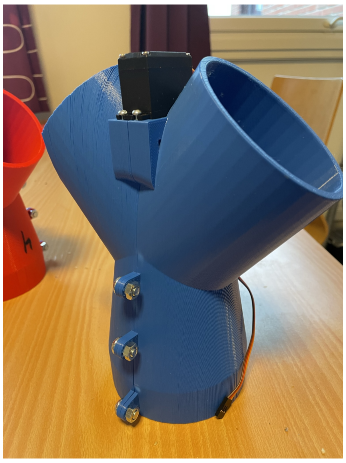


Figure 53: Fifth Iteration of the Sorting Mechanism Prototype

The fifth iteration kept the ellipse exit openings of the fourth iterations, but increased the radius slightly, and increased the angle between the exit openings and the entrance opening. This change solved the problem that the third and fourth iterations had, and the prototype worked as it should, being able to sort the shuttles through either of the two exit openings.

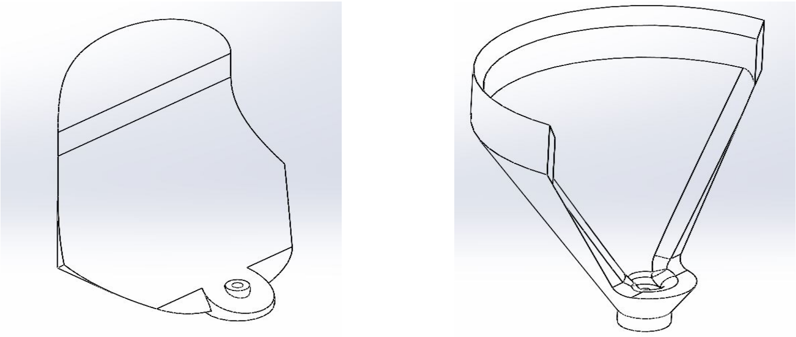


Figure 54: Prototypes of the Wedge in SolidWorks: (1) First Iteration, and (2) Second Iteration

The wedge only went through two iterations. The first iteration was somewhat bulky. It was changed with the third iteration of the tube, as the first iteration of the wedge was to large to be used with the newer smaller design of the third iteration of the tube. The second iteration of the wedge was a significant change to the first iteration. It kept a similar design to the first iteration with its connection to the motor, but over all looked much more like a funnel than the L-shape of the first iteration.

5 Results

In this chapter the final prototype will be presented, showing changes from the final prototypes of each component as well as the electronics. A description of the testing and the results from the testing of the final prototype are presented. The functions and factors mentioned in the introduction and the brainstorming chapter will be presented. It will be presented which of the functions and factors were implemented into the final prototype, with brief description on how they were implemented, with more details presented in the chapter **6.2 Functions and Factors**. Finally at the end of this chapter there will be a simple user guide on how to operate the final prototype.

5.1 Final Prototype

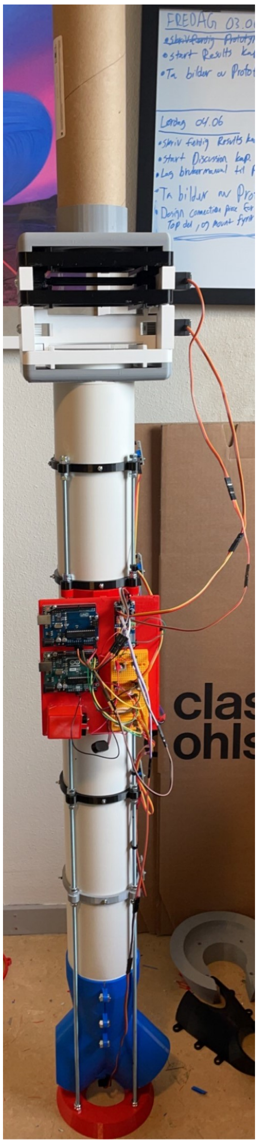


Figure 55: The Final Prototype

The image above shows the final prototype of the device for this thesis. The final prototype consists of the final prototypes of the release mechanism, the free falling measurement tube, and the sorting mechanism. The electronics used and how they were connected and implemented will also be shown. The technical drawing of each component used in the three primary parts of the prototype and how they were assembled can be found in **Appendix B.**

Release Mechanism

The release mechanism used in the final prototype is the same as the final prototype shown in **Prototyping: Release Mechanism**, with some minor changes. The final mechanism used for the release mechanism was the double gripper mechanism, and the feeding system chosen was the tube design.

Figure 56: Final Prototype Release Mechanism

The controller mount of the release mechanism prototype was removed due to all controllers and electronics being moved to a a controller plate mounted on the free falling measurement tube. Due to the removal of the controller mount, the tube mount was redesigned to be smaller as it no longer needed to mount the controller mount.

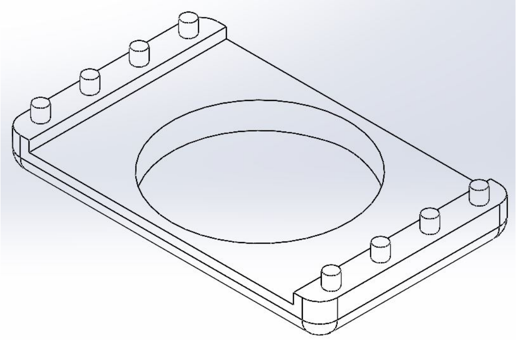


Figure 57: Release Mechanism Tube Mount in SolidWorks

The older tube mount was also designed to be fitted on to the free falling tube via threaded rods, as it mounted to the first free falling measurement tube prototype. As another design was used for the free falling measurement tube, the new tube mount was instead designed to be fitted to the free falling measurement tube with a connection piece that is fitted directly to a PVC tube.

The final prototype for the release mechanism also features a feeding system which was not present in the release mechanism prototype shown in **4.1 Release Mechanism**.

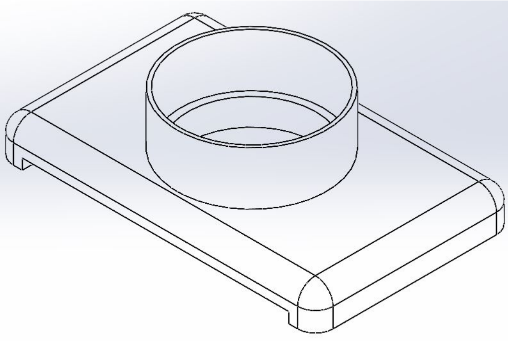


Figure 58: Release Mechanism Feeding Mechanism in SolidWorks

It was decided to use a simple paper tube, such as the ones used to ship artwork or papers, which were cheap and easy to get a hold of. The final prototype had a new top plate installed onto the top of the release mechanism which would allow the paper tube to be fitted comfortably and securely onto the new top plate. The new top plate and the paper tube would thereby be used as the feeding system for the final prototype, able to store multiple shuttles to be dispensed and analysed.

The release mechanism is operated with two **Towerpro MG996R servo motors**, which are controlled by an Arduino Uno through a motor controller. The code used can be found in **Appendix A.B**, and the motors and controllers are presented in the chapter **5.1.1 Electronics and Connections**.

Free Falling Measurement Tube

The free falling measurement tube used in the final prototype is the same as the final prototype shown in the **4.2 Free Falling Measurement Tube**. The final concept for the free falling tube was a combination of the tube and the threaded rod designs, and the sensors used in the final prototype were the infrared obstacle avoidance sensor modules.

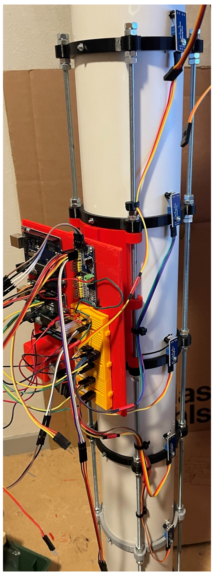


Figure 59: Final Prototype Free Fall Measurement Tube

All electronics excluding the servo motors and the sensors were embedded into a controller mount mounted on the free falling tube. The free falling measurement tube had five sensors embedded into the wall of the tube, with the distance between the first and last sensors being approximately 63 centimeters. The effectiveness of the sensors are shown in **5.2 Testing of the Final Prototype**.

Sorting Mechanism

The sorting mechanism of the final prototype was the same as the final prototype used in the **4.3 Sorting Mechanism**. The final concept of the sorting mechanism was the wedge concept.

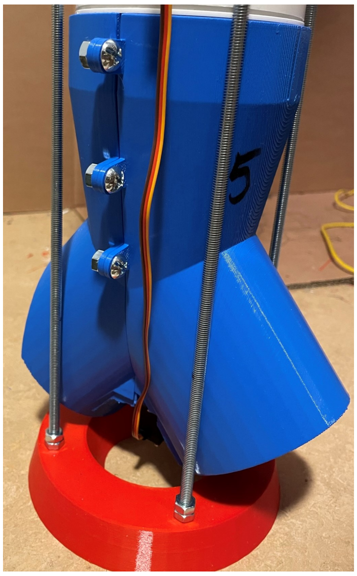


Figure 60: Final Prototype Sorting Mechanism

The sorting mechanism was fitted to the free falling measurement tube with a connection piece that was fitted snugly to one end of the PVC tube on the free falling measurement tube. The motor controlling the sorting mechanism is connected to the motor controller which is located on the free falling measurement tube, however the functions of the sorting mechanism were not implemented in code.

5.1.1 Electronics and Connections

All electronics and electronic components used in the final prototype, with the exception of the motors used in the release mechanism and the sorting mechanism, and the sensors used in the free falling measurement tube, are attached to a controller plate fitted to the free falling measurement tube.

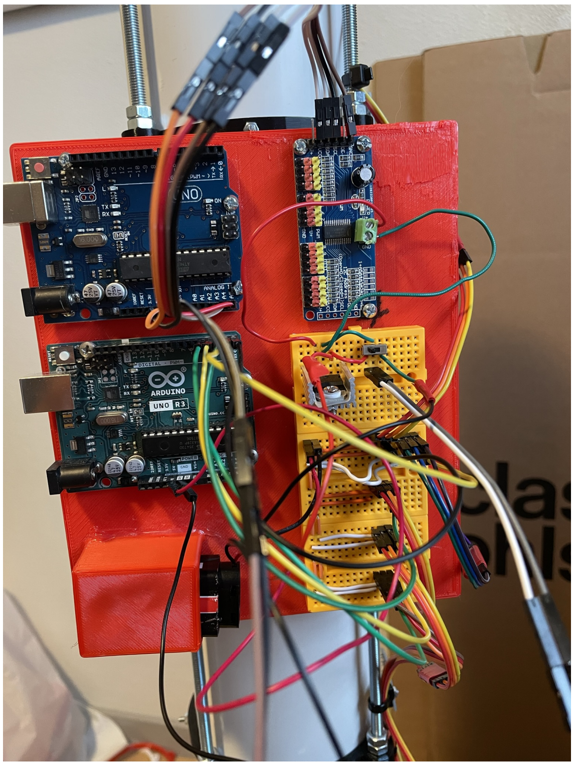


Figure 61: Close up Image of Controller Mount

The final prototype used two separate Arduino Uno microcontrollers. One Arduino Uno was connected to a motor controller and controlled the motors, while the other Arduino Uno was connected to each of the sensors of the free falling measurement tube, and received the signals from them when the shuttles fell passed them. To make it easier to refer to the two Arduino Unos, the top Arduino Uno was refer to as the blue Arduino Uno, and the bottom Arduino Uno as the green Arduino Uno

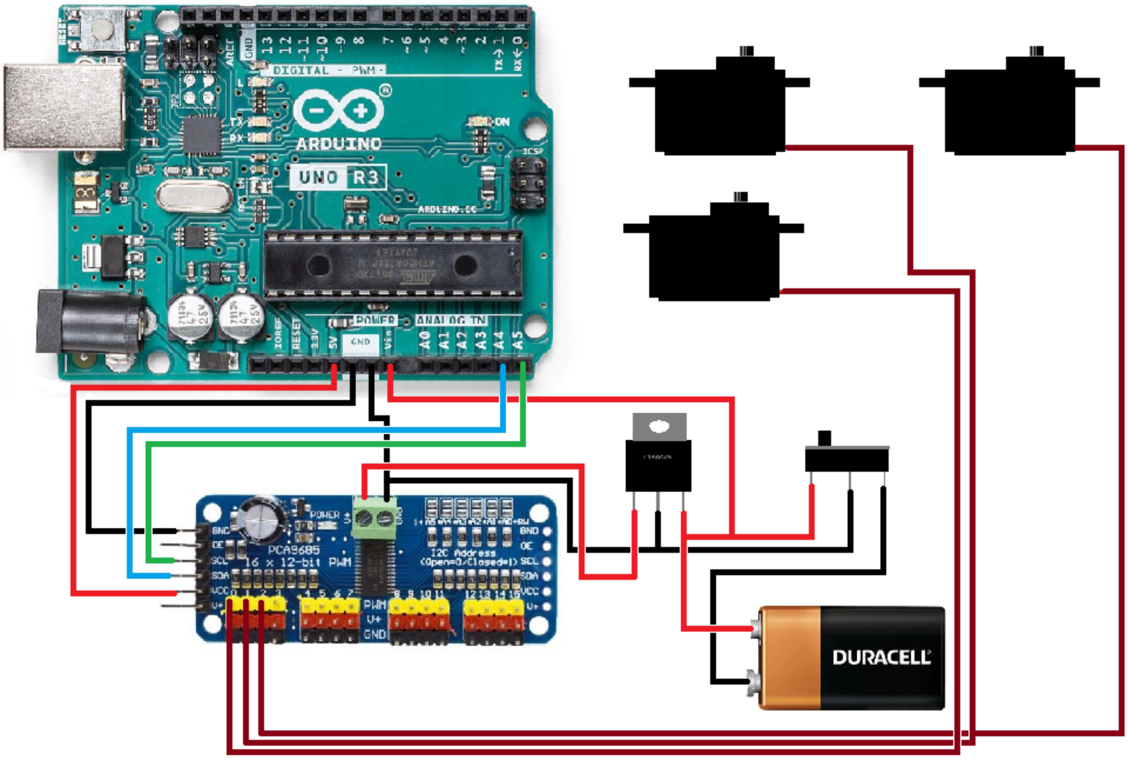


Figure 62: Circuit of Blue Arduino Illustrated

The Arduino Uno which sat on top (the blue Arduino Uno) was connected to the PCA9685 motor controller. The PCA9685 motor controller has six pins, however only four of them were used and connected to the Arduino Uno. The GND and VCC pins of the PCA9685 were connected to the GND and 5V pins of the Arduino respectively. The SCL pin on the PCA9685 was connected to analog pin 5 (pin A5) on the Arduino Uno and the SDA pin of the PCA9685 was connected to analog pin 4 (pin A4) on the Arduino Uno.

The PCA9685 used the 5 volts from the Arduino Uno to power itself and its logic, but required an additional external power source to drive the motors. A 9 volt battery was connected to a L7805CV linear voltage regulator through a 3 pin switch to supply 5 volts to the PCA9685 motor controller. A 3 pin switch was used to connect and disconnect the 9 volt battery from the voltage regulator, as even if the Arduino Uno was not be connected to the motor controller the voltage regulator would still be active, and it could get hot due to the current running through it from the battery. A heat sink was installed onto the voltage regulator to avoid damages due to heating.

The Towerpro MG996R servo motors used in the release mechanism and the sorting mechanism were connected to the PCA9685 motor controller. The two motors used in the release mechanism were connected to ports 0 and 1 on the motor controller, and the motor used in the sorting mechanism was connected to port 2. The code uploaded to the Arduino Uno can be found in **Appendix A.B**.

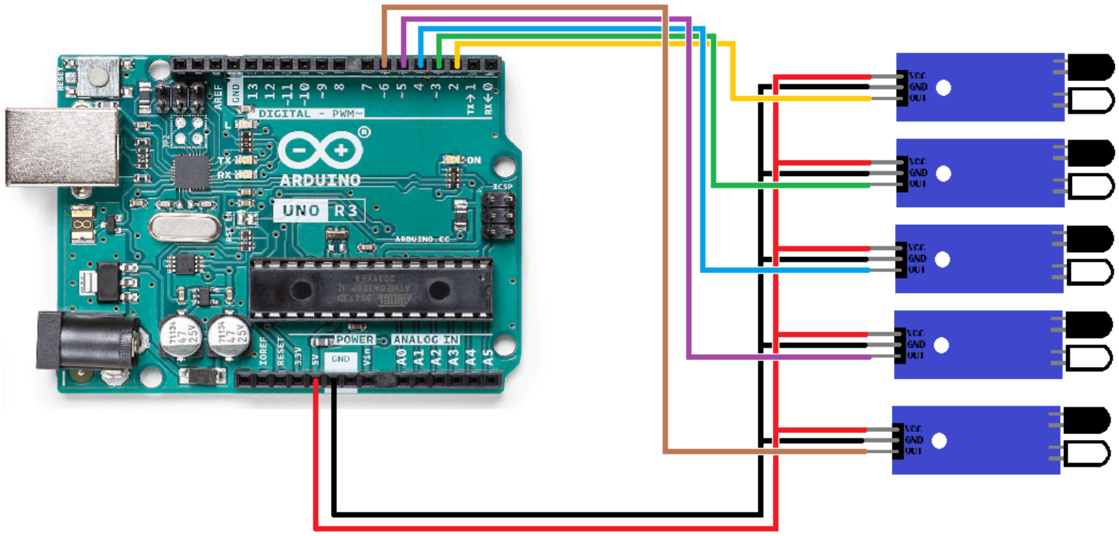


Figure 63: Circuit of Green Arduino Illustrated

The Arduino Uno which sat on the bottom (the green Arduino Uno) was connected to all the sensors used on the free falling measurement tube. There were five infrared object avoidance sensor modules connected to the free falling measurement tube, and each of the modules had three pins. All pins were connected to the Arduino Uno. To make it easier to connect all five modules to the Arduino Uno they were first connected to a breadboard, and then to the Arduino Uno. The VCC and GND pins of the modules were connected in parallel to the 5V and GND pins on the Arduino Uno. The OUT pins of the modules were connected to digital pins 2-6 on the Arduino Uno, with the OUT pin of the top module connected to digital pin 2 on the Arduino Uno, and the OUT pin of the bottom module connected to digital pin 6 on the Arduino Uno. The code uploaded to the Arduino Uno can be found in **Appendix A.A**.

When operating the final prototype the green Arduino Uno was connected to a PC, and the blue arduino was powered by the 9 volt battery by activating the three pin switch.

Further details on the operation of the final prototype are presented in the chapter**5.4 User Guide to the Final Prototype**.

5.2 Testing of the Final Prototype

After the final prototype was assembled it was tested. The reasoning for this test was to see if the results for each shuttlecock were consistent, if the velocity of the shuttles differed, and if the shuttles velocity of the shuttles increased linearly. In addition it was tested to see if the shuttles were dropped on its side gave differing results than dropping the shuttles with their corks pointing towards the ground. The test was performed with the final prototype and two shuttles previously used in the semester thesis *A Study on Shuttlecock Testing in Badminton*[2] (shuttles numbered 1 and 18).

Figure 64: Shuttles Used in Testing

Both shuttles belonged to the same speed class, however their condition and brand varied. The first shuttle (shuttle number 1) was a RSL Classic 78 shuttle and had some damages to some of its feathers, while the second shuttle (shuttle number 18) was a FZ Forza VIP 78 shuttle with two broken feathers.

Each shuttle was tested 15 times, with 3 results from each removed due to bad values (resulting from the shuttles not triggering certain sensors correctly), resulting in 12 data sets for each shuttle. Each time the shuttles were dispensed using the release mechanism of the final prototype. The first shuttle was tested six additional times using only the upper gripper of the release mechanism, using it to drop the shuttle three times as normal, with its cork facing the ground, and three times on its side.

Results

The data gathered from the testing showed that both the first and second shuttles showed that the final prototype was able to get consistent results from the shuttlecocks.

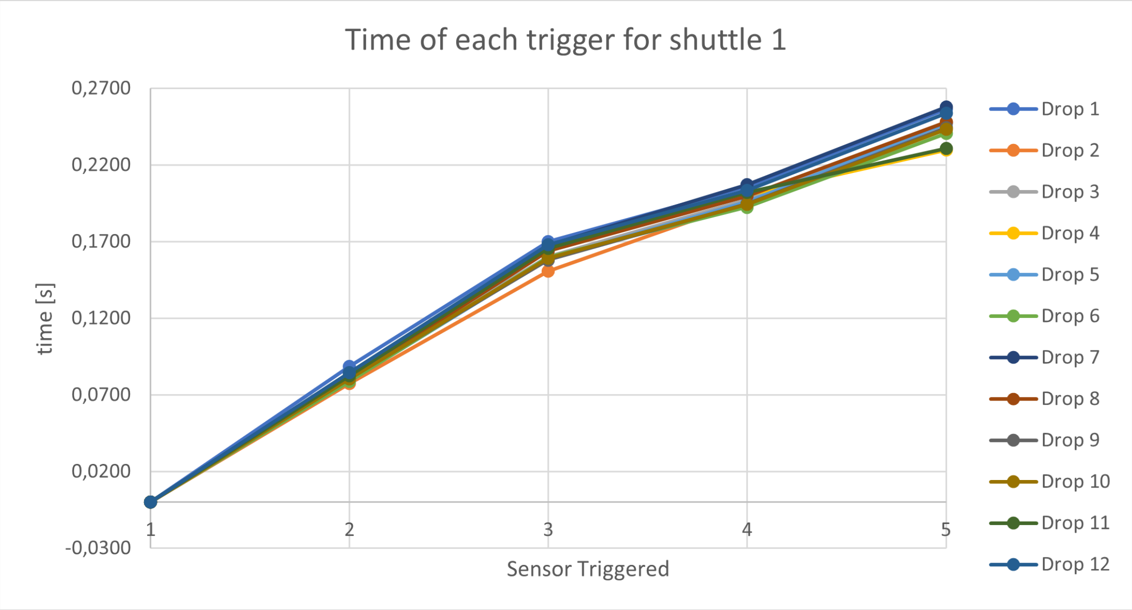


Figure 65: Elapsed time of fall for shuttle number 1

Figure 66: Elapsed time of fall for shuttle number 18

The graphs above show elapsed time between the first sensor and every other sensor being triggered with each drop of the two shuttlecocks. The graphs show that the increase in time is approximately the same with each drop. The time when each sensor was triggered was also very similar between both of the shuttles, with the difference in the average time between the first and last sensors being triggered being 7.3 milliseconds.

Using the elapsed time and the known distance between each sensor the calculated velocity of each shuttle can be plotted.

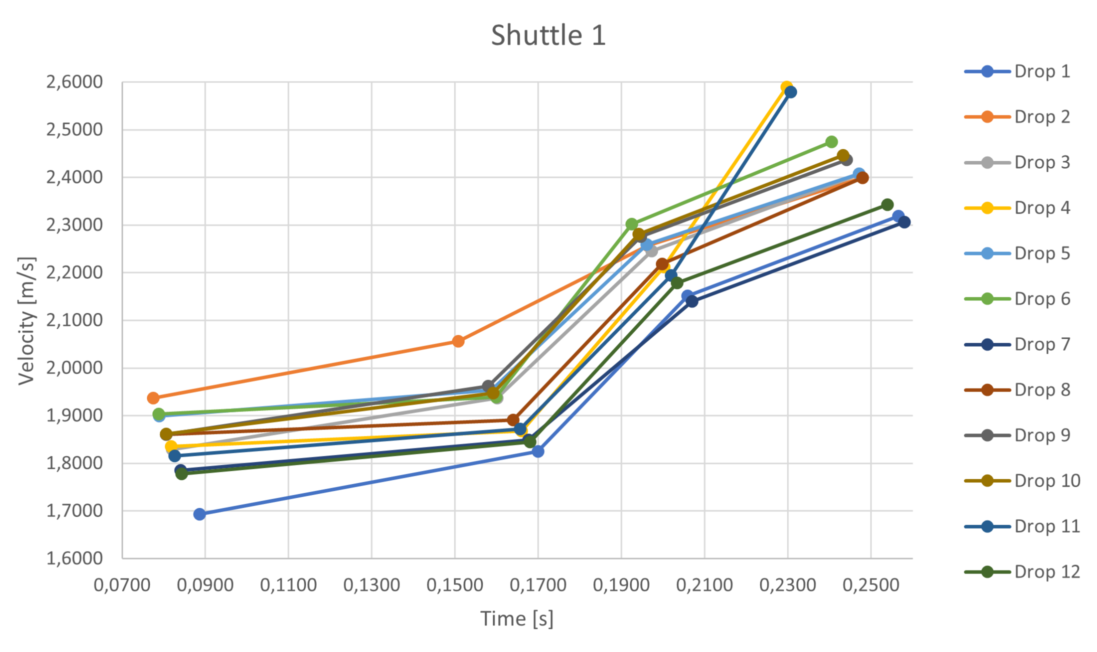


Figure 67: Velocity of shuttle 1

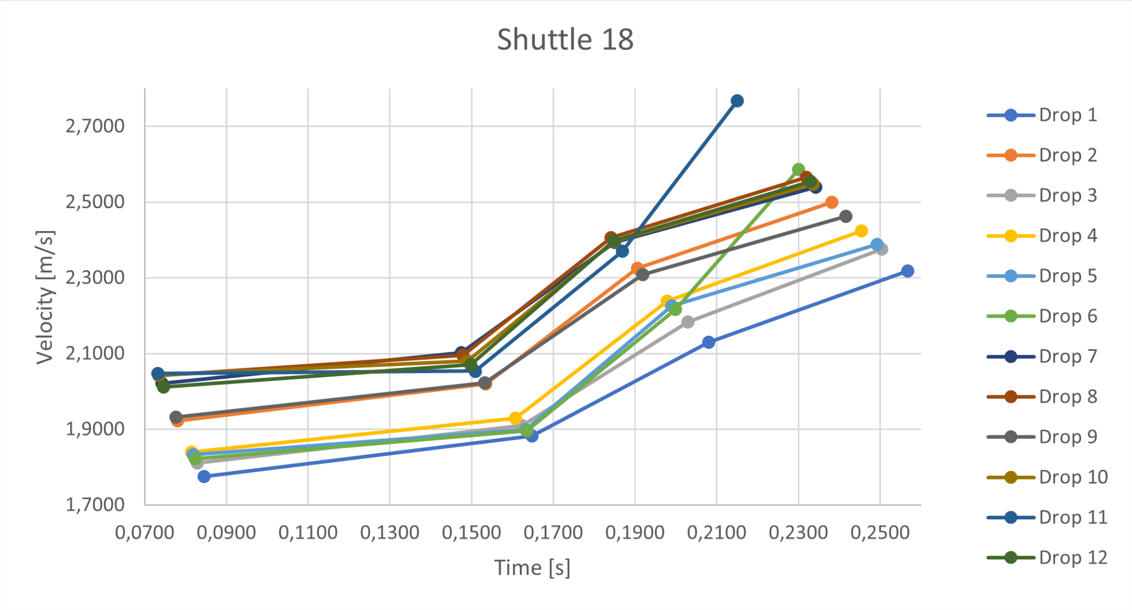


Figure 68: Velocity of Shuttle 18

The graphs above show the calculated velocity of the shuttles as they passed through the free falling measurement tube. The graphs show that the velocity of the shuttles did not increase linearly as was expected. The fourth and eleventh drop of the first shuttle, as well as the sixth and eleventh drop of the second shuttle, resemble an exponential increase in velocity, while the other drops more closely resemble linear increase in velocity. The reasoning to this is unknown, however the difference between the two types of velocity increase are most likely due to sensor error.

The second part of the testing was having a shuttlecock dispensed in different angles.

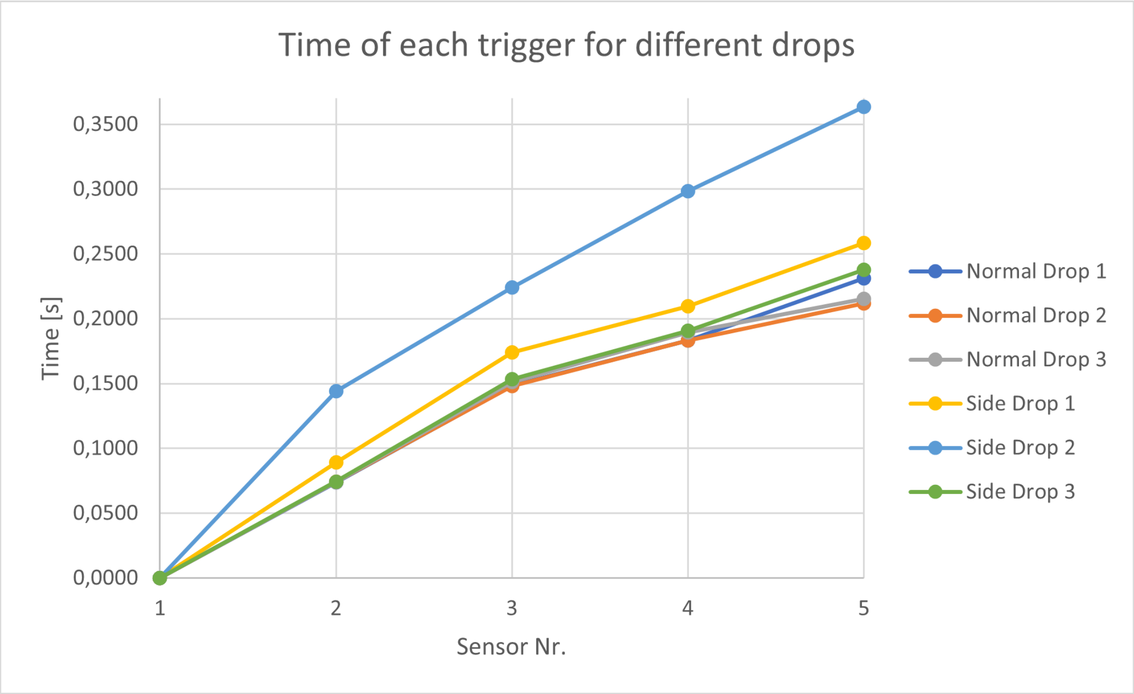


Figure 69: Elapsed time of shuttle dropped in different angles

The graph above shows the elapsed time between the first and last sensors being triggered with shuttles dropped with the cork facing the ground, and shuttles laying on their sides. This test had very limited samples taken with the shuttle only being dropped with the cork facing to the ground three times, and the shuttle on its side three times. The data gathered shows that the difference between the way the shuttle being dispensed being minimal, with the exception being the second drop with the shuttle on its side, which shows the shuttle being slower to trigger each sensor. The shuttle is constructed so that the cork will always lead the shuttle, and the difference between the angle in which the shuttle is dropped does not matter for the most part. In the case of the second side drop, the shuttle adjusted itself, however it bounced of the walls of the final prototype, which caused it to slow down.

5.3 Functions and Factors

In the chapter **1.2 Problem Description** the expected primary functions of the final device are presented, and in the beginning of the chapter **3 Brainstorming** preferred factors for the device were stated. Some of these functions have been implemented so far in the final prototype, and some of the factors are so far filled.

5.3.1 Functions from Introduction

In the chapter **1.2 Problem Description** there were some primary functions mentioned that the final device was supposed to be able to perform. It is important to mention that the final prototype is not the final device, as the device can and should be worked on further and improved to be able to be able to perform all of the final devices functions. The primary function of the final device was supposed to be analysing shuttlecocks to see if they were fit to be used in their current environment. The primary function was then split into multiple functions that together would fulfill the primary function. To be able to fulfil the primary function the device should be able to:

- **Shuttle Storage**: The final device should be able to store multiple shuttles. It should not be required to be hand fed a few shuttles at a time for analysis.
- **Dispense Shuttles**: The final device should be able to dispense shuttles one at a time. Only a singe shuttle should be analysed at a time.
- **Analyse Shuttles**: The final device should be able to analyse each shuttle, measuring any number of different aspects of the shuttle which could be used to see if it should be used or not.
- **Analyse Environment**: The final device should be able to analyse the its current environment, measuring any number of different environmental factors which could be used to determine what shuttles could be used.
- **Compare Data**: The final device should be able to compare the data gathered from the shuttles and the environment to determine which shuttles are fit to be used in the devices current environment.
- **Sort Shuttles**: The final device should be able to sort shuttles according to whether they were fit to be used in their current environment or not, physically separating the ones that are fit and the ones that are not.

The final prototype of this thesis was able to fulfill most of the functions mentioned. The functions that the final prototype was able to fulfill are presented in the table below.

Functions	Fulfilled	Details
Store Shuttles	Yes	The final prototype can store multiple shuttles in a feeding system connected to its release mechanism
Dispense Shuttles	Yes	The final prototype has a release mechanism which dispenses one shuttle at a time from the feeding system.
Analyse Shuttles	To a degree	The final prototype measures the velocity of shuttles as they fall through its free falling measurement tube, more work is recommended to see if it is enough to properly analyse the shuttles
Analyse Environment	No	The final prototype lacks environmental sensors to be able to analyse its current environment.
Compare Data	No	The final prototype has not been properly tested, and lacks data to be able to make the comparisons to properly sort the shuttles.
Sort Shuttles	To a degree	The final prototype has a sorting mechanism, where it is able to sort the shuttles, it however lacks the calibration of data to be able to do so properly.

Table 6: Final Prototype Functions Compared To Final Device

The table above gives some brief details of how these functions were implemented or not in the final prototype. Further details on each function are presented and discussed in the **6.2.1 Functions from Introduction**.

5.3.2 Factors from Brainstorming

In the beginning of the **3 Brainstorming** some factors were presented which the final device would preferably follow. These factors were mostly centered around that the final device should function as presented in **1.2 Problem Description** but that it would also be suited to be used for smaller badminton clubs. These physical factors were:

- **Sensors**: The device should have sensors to analyse the shuttle and its current environment.
- **Mobility**: The device should neither be very heavy nor very large. It should be able to be moved by the average badminton player without additional equipment such as a lift, and it should be able to be store easily in most badminton clubs.
- **Cost**: The device should not be expensive to construct, it should preferable be open source. It should be cheap, either to be able to be mass produced for cheaper prices, or be cheap for smaller badminton clubs to construct and assemble themselves.
- **Speed**: The final device should preferably be faster to analyse the shuttles than it takes a badminton player to test the shuttles themselves.

The final prototype was able to follow most of the factors mentioned above, however as some functions of the final device had not been implemented to the final prototype some of the factors could not be properly fulfilled. The factors that the final prototype was able to fulfill are presented in the table below.

Factors	Fulfilled	Details
Sensors	To a degree	The final prototype has sensors implemented to be able to measure the shuttles free falling velocity, however sensors to analyse its environment are not yet implemented.
Mobility	Yes	The final prototype is mobile. The height was 1.29 meters tall (or 1.9 meters tall with the tube inserted into the feeding system) and it weighed approximately 3 kilograms. It is easy to and carry and can, if wished, be broken down into separate parts.
Cost	Yes	The cost of the final prototype was low, assuming the creator had access to a 3D printer. Most of its part were 3D printed, and other parts such as the sensors, PVC tube and threaded rods can be found for cheap as well.
Speed	No	It was unable to measure the effective speed of the final prototype, as the environmental sensor had not been implemented, and therefor the final prototype was unable to properly sort shuttles by comparing data.

Table 7: Final Prototype Factors Compared to Final Device

The table above gives some brief details of how these factors were implemented or not in the final prototype. Further details on each function are presented and discussed in the **6.2.2 Factors from Brainstorming**.

5.4 User Guide to the Final Prototype

In this chapter a brief description of how the final prototype works when operated, and a brief guide on how to operate the final prototype. Before operating the final prototype it is expected that both Arduino Unos have the codes found in **Appendix A**, uploaded to the respected Arduino Uno microcontrollers, and that all components are connected as referred to in the previous chapters. It should be noted that both Arduino codes found in **Appendix A**, are written and uploaded to the Arduino Unos with the open-source Arduino software IDE (integrated development environment). The Arduino software IDE can be installed for free from Arduinos website (https://www.arduino.cc/en/software, accessed 08.06.22). The code for the blue Arduino Uno uses an additional software package to be able to control the motor controller. Instructions on installing the additional software package required can be found in a guide on Steemit (https://steemit.com/utopian-io/@drencolha/adafruit-pca9685-pwm-servo-driver-setup-arduino-library-use-shown-with-an-example-project-tutorial, accessed 08.06.22). When uploading the code to the blue Arduino Uno it is important to disconnect the Vin pin, as otherwise the Arduino will not connect properly to the PC.

The first step to operate the final prototype is to power it on. The final prototype uses two Arduino Unos and both need to be powered. Like in the previous chapter, the two Arduino Unos will be referred to as the blue Arduino Uno (the top one connected to the motor controller), and the green Arduino Uno (the bottom one connected to the sensors).

First connect the green Arduino Uno to a PC. This Arduino will output the time of when each sensor is triggered. The data can be seen when the code is uploaded in the Arduino software IDE, or to be able to save and work on the data outputted by the green Arduino Uno it is possible to use the Data Streamer function in Microsoft Excel, which streams the output of the Arduino Uno Directly into a Microsoft Excel worksheet.

To Power on the motor controller and the blue Arduino Uno, simply flick the switch found on one of the breadboards. This switch connects the 9 volt battery to both the Arduino Uno and the voltage regulator (which powers the motors connected to the motor controller).

After the blue Arduino Uno is powered up it will start running its code, and start dispensing shuttles. It is therefore important to power on the green Arduino Uno up first, and having it ready to upload its data in the Microsoft Excel worksheet. Next place shuttles into the feeding system at the very top of the final prototype, and watch the release mechanism dispense one shuttle at a time down the free falling measurement tube, and the data from the shuttle being printed in the Microsoft Excel worksheet.

6 Discussion

There are some different things that need to be discussed about the final prototype.

6.1 Shuttle Factors

In the chapter **2.2.1 Shuttle Factors** different aspects of the shuttle were mentioned that could be used to analyse the shuttle. The final prototype used the speed of the shuttle as it free fell through the free falling measurement tube as the sole aspect of the shuttle that would be used to sort the shuttle, however many of the aspects presented in the theory chapter could have been used instead or alongside the speed of the shuttle.

The velocity and acceleration of the shuttles was chosen due to the simplicity of retrieving the data as multiple different sensors could be used to measure the velocity of the shuttles, and it was chosen to measure the velocity of the shuttles during free fall as it was the cheapest method. It would have been possible to launch the shuttles and thereby more easily measure the velocity of the shuttles closer to terminal velocity, however the final prototype would have ended up being much larger and heavier if a launcher had to be developed and constructed.

A factor that could have been used to analyse the shuttle during free fall could have been looking at the rotation of the shuttle during free fall, and looking to see if the shuttle fell straight down or if its trajectory varied. These factors would have required a camera to be either fitted at the bottom of the device or at the bottom of the release mechanism to be able to film the shuttle fall down. The device would then require to have computer vision implemented to recognize how the shuttle was falling and use the data gathered from the fall of the shuttle to sort it. This would make the device more complicated and expensive and was therefor not implemented.

Another factor that could have been used to analyse the shuttle was its weight. Shuttles were sorted into speed classes based on their weight before, and the weight of the shuttle as well as the center of mass of the shuttle effects how the shuttle will fly in the air. To weigh the shuttle a scale could have been implemented, for example in the release mechanism, where before the shuttle is release it was weighed, and its weight used alongside other aspects of the shuttle used to analyse it. This factor was considered, however it was never implemented due to time restraints.

In the end only the velocity and acceleration of the shuttles was used to try to analyse the shuttles, however the process of using the sensor for analysing was only briefly tested (as can be seen in **4.2 Free Falling Measurement Tube**), and more work needs to be done to see if the velocity of the shuttles is enough to sort the shuttles efficiently.

6.2 Functions and Factors

As mentioned in the chapter **5.3 Functions and Factors**, the desired functions and factors introduced in the chapters **1.2 Problem Description** and **3 Brainstorming** which were or were not implemented in the final prototype will be discussed in further details in this chapter.

6.2.1 Functions from Introduction

In the chapter **1.2 Problem Description** there were some functions mentioned, and in the chapter **5.3.1 Functions from Introduction** it was briefly described how these functions were or were not implemented in the final prototype. Each function will be addressed and described in further detail where it is needed.

Store Shuttles

One of the functions desired for the device was the ability to be able to store multiple shuttles at a time. This was so that the person operating the device would not have to hand feed the device one shuttle at a time, but could instead place multiple shuttles, and let the device take care of the rest. The final prototype implemented this function in the form of a feeding system on top of the final prototype. This feeding device, as presented in **5.1 Final Prototype** was simply composed of a paper tube, the type which is used to store and ship larger papers such as technical drawings or artwork. The inner diameter of the paper tube is larger that the inner diameter of the typical tube in which shuttles are stored, so when shuttles are placed into the tube they will fall to the bottom of it. The paper tube is also somewhat large, being approximately 63.5 centimeters tall, and can theoretically store up to 21 shuttles at a time (bottom shuttle will fall into the releasing mechanism, calculated with approximately 3 centimeters of the next shuttle sticking out of the bottom one, and therefor 61 / 3 = 21).

Dispense Shuttles

A function desired for the device was the ability dispense shuttles one by one, as only a single shuttle should be analysed at a time. This function was connected to the previous function, the ability to store multiple shuttles, as even when the shuttles are tested by players, only a single shuttle is tested at a time. This was also due to analyse and sort a single shuttle at a time, as dropping all the shuttles at once would make it impossible to analyse and sort the shuttles appropriately. The final prototype implemented this function in the form of a release mechanism, which was the top part of the final prototype. The feeding system was placed on top of the release mechanism, and feeds the stored shuttles to the release mechanism, so that shuttles do not need to be fed one by one to the release mechanism by hand. The design used for the release mechanism was a double gripper mechanism (described in **3.1.1 Release Mechanism**) and the release mechanism for the final prototype is shown in **5.1 Final Prototype**.

Analyse Shuttles

A function desired for the device was the ability to analyse the shuttles, measuring any number of different aspects of the shuttle which could be used to see if it was fit to be used or not. Different factors which were theorised to possibly be analysed were presented in the **2.2.1 Shuttle Factors**, however for this thesis the aspect of the shuttle that was picked was its speed and acceleration during free fall. Discussion around the shuttle aspect chosen is discussed in a later chapter. The final prototype implemented this function in the form of the free falling measurement tube. The shuttles would be released from the release mechanism and fall down the free falling measurement tube. As the shuttles fell sensors embedded in the walls of the free falling measurement tube would record the time it took the shuttle to fall certain distances, and using the data recorded the velocity and acceleration of the shuttle could be calculated. The reason for the table shown in **5.3.1 Functions from Introduction** claiming that the function of analysing shuttles was fulfilled to a degree was due to after testing the free falling measurement tube it was not clear if measuring the velocity and acceleration of the falling shuttle would give enough data about the shuttle to properly be able to analyse or sort it. In the details given in the same detail it is recommended to be able to give an educated answer to whether the data is enough to make the decision of if the shuttle is fit to be used or not.

Analyse Environment

A function desired for the device was the ability to analyse the environment in which the device was present in. Different environmental factors which could effect the shuttles, and could to possibly be be used to analyse the shuttles were presented in the **2.2.2 Environmental Factors**, with the most prominent factor theorised being the environments being the air pressure, and the environments geographical altitude effecting the air pressure most. The final prototype did not implement environmental sensors. This was mostly due to time constraints, with most of the time going into designing and developing the rest of the device. The possible future implementation and possible recommendations on how to analyse the environment will be presented in the **6.3 Improvements and Further Work**.

Compare Data

A function desired for the device was the ability to compare the data gathered from the shuttles and the environment to previous gathered and tested data to determine whether the shuttles being tested were fit to be used in the devices current environment. The idea was to have the device used in different areas with multiple different players. The device would be tested in one environment, gathering data on shuttles and the environment. Then a set of consistent players would test the same shuttles in a manner that the shuttles are tested today, to see which shuttles were fit to be used according to the rules specified in *the Laws of Badminton*[1]. The final prototype did not implement this function, as it lacked the function to analyse the environment. This was also due to time constraint, as the prototype was not finished with enough addition time to test it with multiple players in different areas. The possible future implementation and recommendation on comparing the data is be presented in a the **6.3 Improvements and Further Work**.

Sort Shuttles

The last function desired for the device was the ability to sort shuttles on whether they were fit to be used in their current environment or not. The idea was to have the device gather data on its current environment and the shuttle being tested, compare the data gathered to previous data gathered and determine whether the shuttle was fit to be used in its current environment. It would then sort all shuttles into two groups: a group of shuttles fit to be used in their current environment, and a group of shuttle not fit to be used in their current environment. The final prototype implemented this function in the form of the sorting mechanism. The shuttles would fall through the free falling measurement tube and into the sorting mechanism. The sorting mechanism had a motor which would rotate depending on the result of the shuttle, sorting the shuttle by letting it fall through one of two openings at the bottom of the sorting mechanism. The final design used for the sorting mechanism was the wedge concept presented in the **3.3 Sorting Mechanism**, and the sorting mechanism for the final prototype is shown in detail in the **5.1 Final Prototype**. The reason for the table shown in **5.3.1 Functions from Introduction** claiming that the function of sorting shuttles was fulfilled to a degree was due to the sorting mechanism being able to sort the shuttles through its two openings, but the final prototype lacking the data to be able to determine in which way the shuttle should be sorted.

6.2.2 Factors From Brainstorming

In the beginning of the chapter **3 Brainstorming** there were some factors presented which the device was desired to fulfill. These factors mostly focused around the use and the construction of the device. It was briefly described which factors were fulfilled with the final prototype and how they were fulfilled in the chapter **5.3.2 Factors from Brainstorming**. This chapter will go more into detail about the results shown in the table found in **5.3.2 Factors from Brainstorming**.

Sensors

A factor that the device was preferred to have was sensors. The sensors were an essential part to use as they served to perform the primary function of the device, sorting the shuttles, by using the sensors to gather data on the shuttles tested and the devices environment. The final prototype implemented sensors in the free falling measurement tube part of the final prototype. The free falling measurement tube had five infrared obstacle avoidance sensor modules embedded in its walls, which were used to calculate the velocity and acceleration of the shuttles that fell through it. The reason for the table shown in **5.3.2 Factors from Brainstorming** claiming that the factor of sensors was fulfilled to a degree was due to the final prototype only implementing sensors to analyse the shuttle, but not implementing sensors to analyse the environment. This was previously discussed on the last page.

Mobility

A factor that the device was preferred to have was mobility. The device was not to be too large for a smaller badminton club to store or use, nor too heavy for the average badminton player to be able to move it without the assistance of a trolley or a lift. The final prototype was able to fulfil the desired factor of mobility. The final product stood at 1.29 meters, or 1.9 meters if the feeding system was installed, and could be easily broken apart and re-assembled into smaller parts without the need of tools. The final prototype weight approximately 3 kilograms with the feeding system installed, which should be light enough for most badminton players to easily lift and move it around.

Cost

A factor that the device was preferred to have was low cost. The device was preferred to be cheap, either so that it could easily be mass produced, or so that smaller badminton clubs could be able to buy all the components themselves without breaking their bank. The final prototype was able to fulfil the desired factor of cheap cost, assuming that the person buying the components and assembling the prototype had a free access to a 3D printer, cables, nuts and bolts.

Part	Quantity	Cost pr unit	Total Cost	Acquired from
PVC Tube	1	139	139	Biltema
Threaded Rods	4	100	400	Biltema
Servo Motor	3	47	141	Omega Verksted NTNU
Arduino Uno	2	55	110	Omega Verksted NTNU
Motor Controller	1	30	30	Omega Verksted NTNU
9 Volt Battery	1	35	35	Omega Verksted NTNU
Voltage Regulator	1	10	10	Omega Verksted NTNU
Sensors	5	6	30	Omega Verksted NTNU
Total Cost			894,96	

Table 8: Overview of Final Prototype Cost

All costs in the table above are given in Norwegian Kroner (NOK). Without counting the potential cost of the nuts, bolts, cables and the 3D printed components the approximated cost for the final prototype was 895 NOK, with the detailed cost of each component being shown in the table above. The costs shown in the table above reflect that the prototype was built at NTNU in Norway in the year of 2022, as the cost may change on where the components are acquired from and over time.

Speed

A factor that the device was preferred to have was speed. The idea was that the device should be able to analyse and sort more shuttles faster than it would take a badminton player to test the shuttles in the traditional manner. The final prototype did not fulfil this factor as it had not been developed to the point of it being able to sort the shuttles by the data it gathered. This detail has been discussed earlier in this chapter, with the biggest reason being that the environmental sensors had not yet been implemented.

6.3 Improvements and Further Work

The final prototype is complete, however as mentioned before there are some things that the final prototype is missing to be fully operational and some things that can be improved in future prototypes.

First, features of the device which the final prototype is missing need to be implemented. These are mainly implementing the environmental sensors, which could either be a digital sensor for air density, or a mix of sensors which could measure the relative humidity, temperature and geographical altitude. When the environmental sensors are implemented and functional, the sorting mechanism has to be implemented in the code. To have it implemented properly testing would have to be done. The author suggests a test which requires gathering a few good and consistent badminton players to test multiple shuttles, from different speed classes and brands, in different areas. The players would test the shuttles, and the device would be used to gather information from the shuttles and its environment. The data from the device and the data from the players would then be collected, documented, and a possible library with statistics of the shuttles could be established. This library could contain an approximate tolerance for the factors of the shuttles, so that when shuttles are later tested in the device, the device could compare the data from the shuttle to the library and see if the data from the shuttle lies within the tolerance given for the current environment.

After the device has become operable other components could be added or worked on. An example of a component that could be worked on is the free falling tube. Additional sensors could be added to gather more data on shuttles. Examples of additional sensors were discussed in **6.1 Shuttle Factors**. The length of the tube and total number of sensor could also be changed and tested, to see at which length the device can gather the best data, and how many sensors are needed to gather enough data to properly analyse the shuttle, while not over analysing or gathering additional not needed data.

Additional components can be added onto the prototype to fix possible problems. An example is if the device is not able to analyse the shuttle within the time it takes the shuttle to fall through the tube before getting sorted, a stopping mechanism or a smaller release mechanism could be added between the free falling measurement tube and the sorting mechanism, which would stop the shuttle after it had fallen the complete length of the free falling measurement tube, hold it there until the microcontroller has determined how the shuttle should be sorted, then the sorting mechanism would move according to a signal from the microcontroller and finally the stopping mechanism would release the shuttle to be further sorted by the sorting mechanism.

After the device has become operational, and components added to fix potential problems, it is recommended to start optimising the device. Find if different designs for the different components will make the device more efficient. It is also recommended to change from using the Arduino Uno to a separate microcontroller. The Arduino Uno has many different functions and features that are not required to operate the device, making it slightly over engineered. Find a microcontroller which is able to perform the functions of the device, but do not over engineer it. The final prototype uses two separate Arduino Unos to perform two separate tasks, however it should be able to function properly with a single Arduino Uno.

7 Conclusion

This thesis aimed to develop a solution to the problem of inaccurate shuttlecock testing in tournaments, as presented in the semester thesis *A study on Shuttlecock Testing in Badminton*[2]. The solution came in the form of a device which could more accurately test shuttlecocks. The thesis presented functions that the device should be able to perform, as well as factors that the device should be built around. The thesis also presented different aspects of the shuttles and the environment which could effect the results from shuttlecock testing. The device was divided into separate components which could fulfil specific functions of the device. Different concepts for each component was presented, and certain concepts were tested and iterated on until a functioning prototype was built.

The final prototype was able to store multiple shuttles at once, dispensing one shuttle at a time down a tube with sensors embedded in its walls. The time between each sensor was measured, and using the known distance between each sensor the velocity of the shuttles could be calculated. The final prototype also included a sorting mechanism, however due to time restraints environmental sensor were not implemented and therefore the prototype could not properly sort the shuttlecocks.

In the end the final prototype was able to fulfil many of the set requirements for the device, however environmental sensors have to be implemented, as well as more testing done for the device to function as intended.

It is recommended that environmental sensors are to be implemented, and the device be uploaded to the internet to make the project open-source, so that badminton clubs can improve on the design, construct the device cheap and implement it in their clubs.

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Appendix

A Arduino Code

A Free Falling Measurement Tube Code

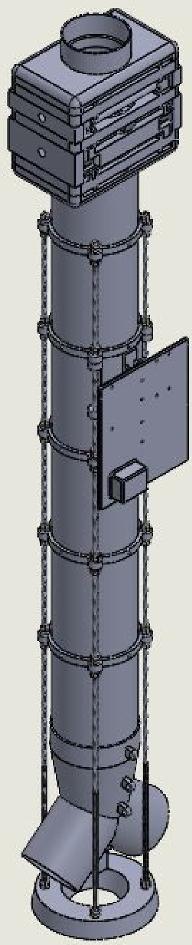
```
const int sens1 = 2;
const int sens2 = 3;
const int sens3 = 4;
const int sens4 = 5;
const int sens5 = 6;

int tr1, tr2, tr3, tr4, tr5 = HIGH;       // Triggers for each Sensor.

unsigned long t1, t2, t3, t4, t5 = 0;         //Time values.

int dist = 200;                           //distance between each sensor is 40 cm = 400 mm.
float el1, el2, el3, el4 = 0;            // Elapsed Time.
float v1, v2, v3, v4, v5;                 // Velocities.

 void setup() {
      pinMode(sens1, INPUT);
      pinMode(sens2, INPUT);
      pinMode(sens3, INPUT);
      pinMode(sens4, INPUT);
      pinMode(sens5, INPUT);

      Serial.begin(9600);
    }

    void loop() {

      tr1 = digitalRead(sens1);
      while(tr1 == LOW){
        t1 = micros();
        tr1 = digitalRead(sens1);
        }

      tr2 = digitalRead(sens2);
      while(tr2 == LOW){
        t2 = micros();
        tr2 = digitalRead(sens2);
        }

      tr3 = digitalRead(sens3);
      while(tr3 == LOW){
        t3 = micros();
        tr3 = digitalRead(sens3);
        }

      tr4 = digitalRead(sens4);
      while(tr4 == LOW){
        t4 = micros();
        tr4 = digitalRead(sens4);
        }
```

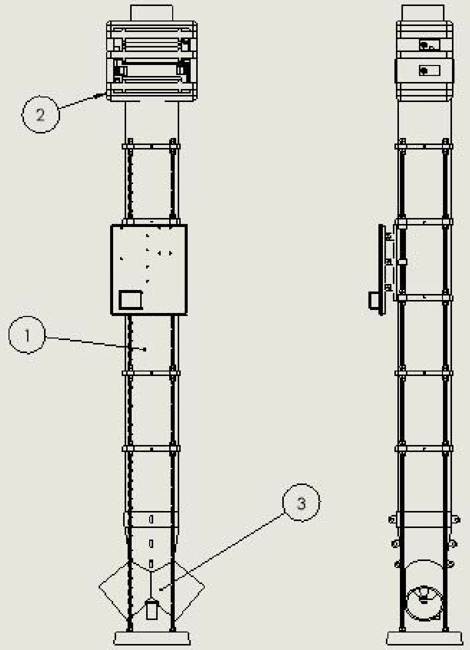
```
    tr5 = digitalRead(sens5);
    while(tr5 == LOW){
      t5 = micros();
      tr5 = digitalRead(sens5);
      }


    el1 = t2 - t1;
    el2 = t3 - t1;
    el3 = t4 - t1;
    el4 = t5 - t1;

    while (t5 != 0){
      Serial.print(0);
      Serial.print(", ");
      Serial.print(el1);
      Serial.print(", ");
      Serial.print(el2);
      Serial.print(", ");
      Serial.print(el3);
      Serial.print(", ");
      Serial.println(el4);
      delay(100);
      t5 = 0;
    }
  }
```

B Release Mechanism Code

```
#include <Wire.h>
#include <Adafruit_PWMServoDriver.h>

Adafruit_PWMServoDriver srituhobby = Adafruit_PWMServoDriver();

byte upper_gripper = 0;
byte lower_gripper = 1;

void setup() {
  Serial.begin(9600);
  srituhobby.begin();
  srituhobby.setPWMFreq(60);
}

void loop() {

// Opening and Closing the upper gripper
  for (int pulse = 150; pulse < 600; pulse++) {
    srituhobby.setPWM(upper_gripper, 0, pulse);
  }
  delay(100);
  for (int pulse = 600; pulse > 150; pulse--) {
    srituhobby.setPWM(upper_gripper, 0, pulse);
  }
  delay(100);


// Opening and Closing the lower gripper
  for (int pulse = servoMIN; pulse < 400; pulse++) {
    srituhobby.setPWM(lower_gripper, 0, pulse);
  }
  delay(500);
  for (int pulse = 400; pulse > servoMIN; pulse--) {
    srituhobby.setPWM(lower_gripper, 0, pulse);
  }
  delay(500);

// Letting the shuttle fall, and waiting a little bit befor starting on the next shuttle
  delay(1000);

}
```

B Technical Drawings





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	REFERENCE
1	Free Falling Measurement Tube		1	SHEET 14
2	Release Mechanism		1	SHEET 2
3	Sorting Mechanism		1	SHEET 19

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	[illegible]		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:
FINAL PROTOTYPE

MATERIAL:
PLA

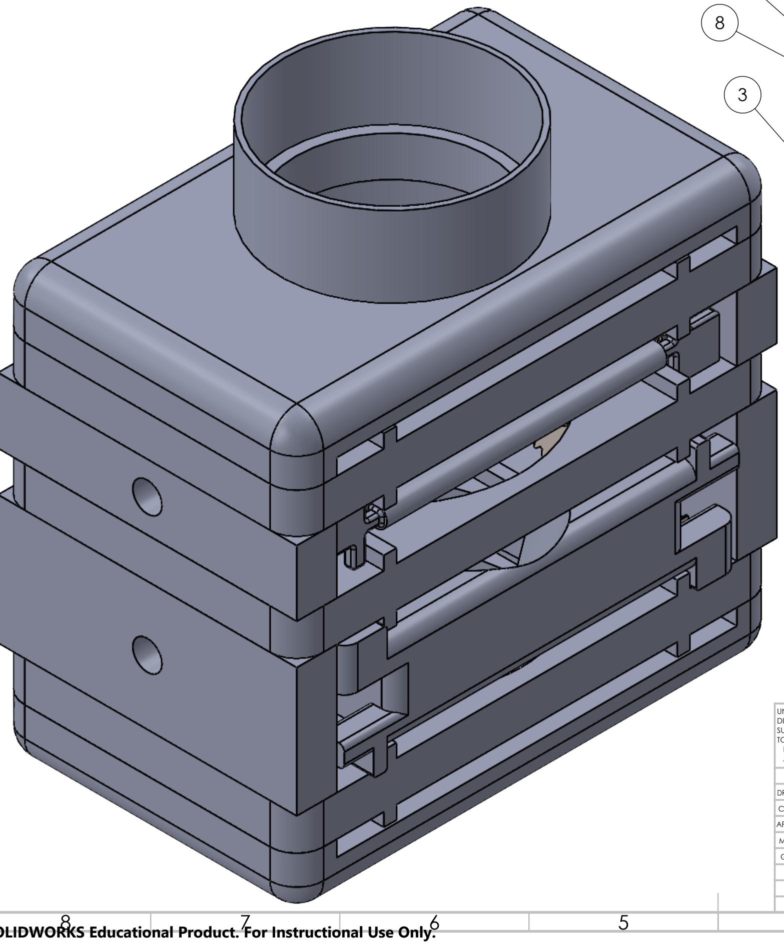
DWG NO.
Final Prototype

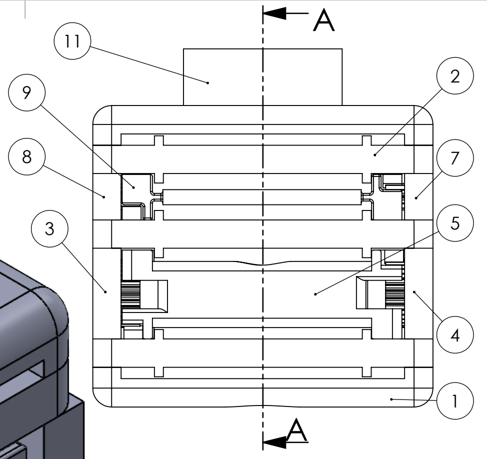
A3

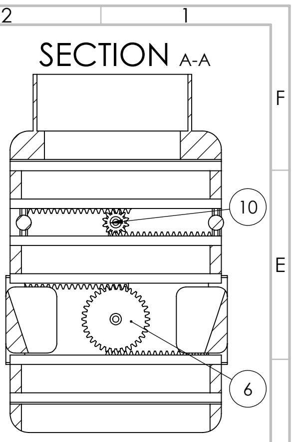
WEIGHT:

SCALE:1:10

SHEET 1 OF 21







SECTION A-A

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	REFERENCE
1	Tube Mount		1	SHEET 9
2	Plate		3	SHEET 4
3	Lower Wall		1	SHEET 7
4	Lower Wall with Motor Mount		1	SHEET 8
5	Lower Gripper		2	SHEET 12
6	Lower Gear		2	SHEET 13
7	Upper Wall with Motor Mount		1	SHEET 6
8	Upper Wall		1	SHEET 5
9	Upper Gripper		2	SHEET 10
10	Upper Gear		2	SHEET 11
11	Feeding System		1	SHEET 3

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:
PLA

WEIGHT:

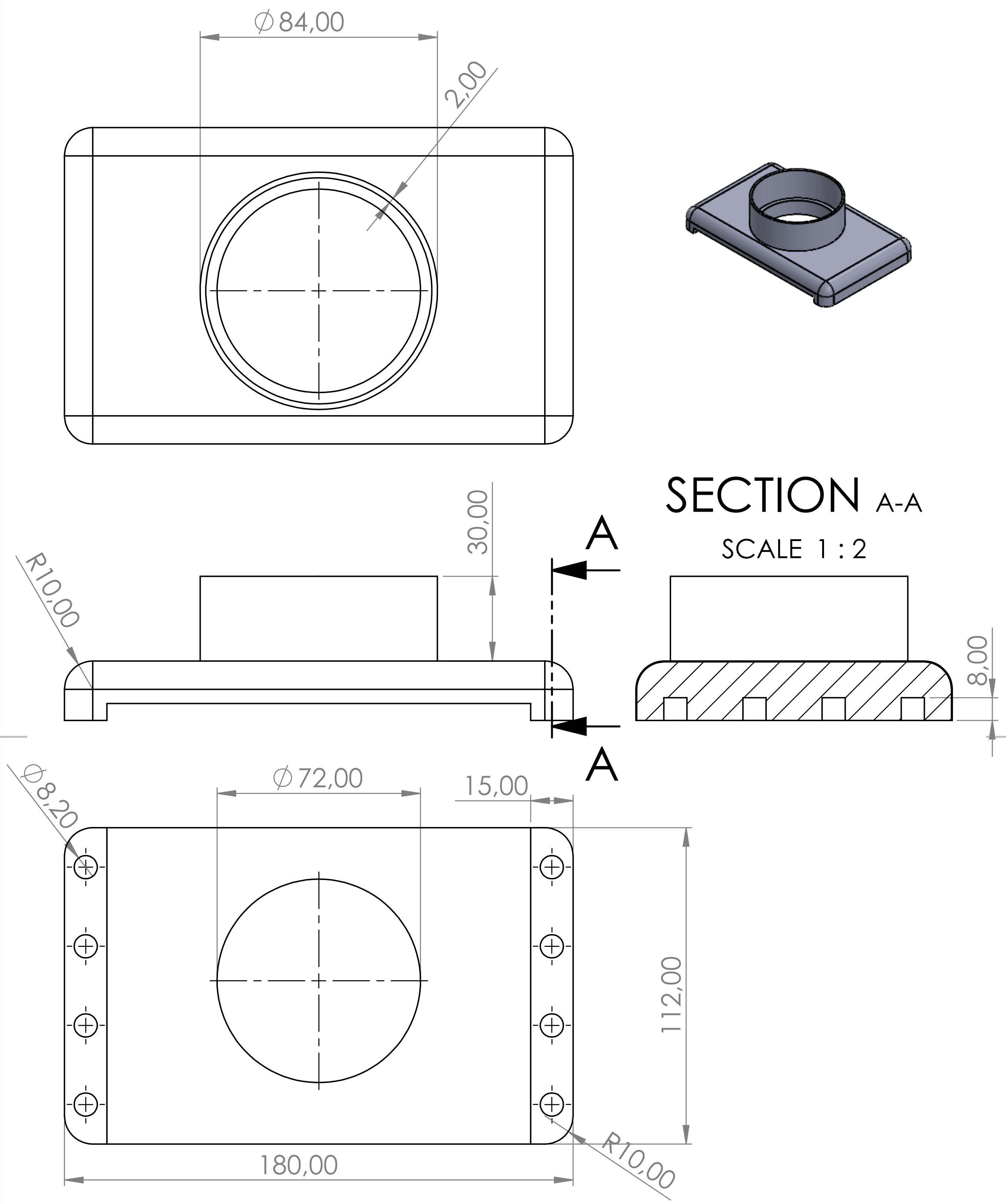
TITLE:
Final Prototype

DWG NO.
Release Mechansim

A3

SCALE:1:2

SHEET 2 OF 21



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:
PLA

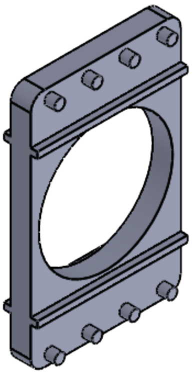
DWG NO.
Feeding System

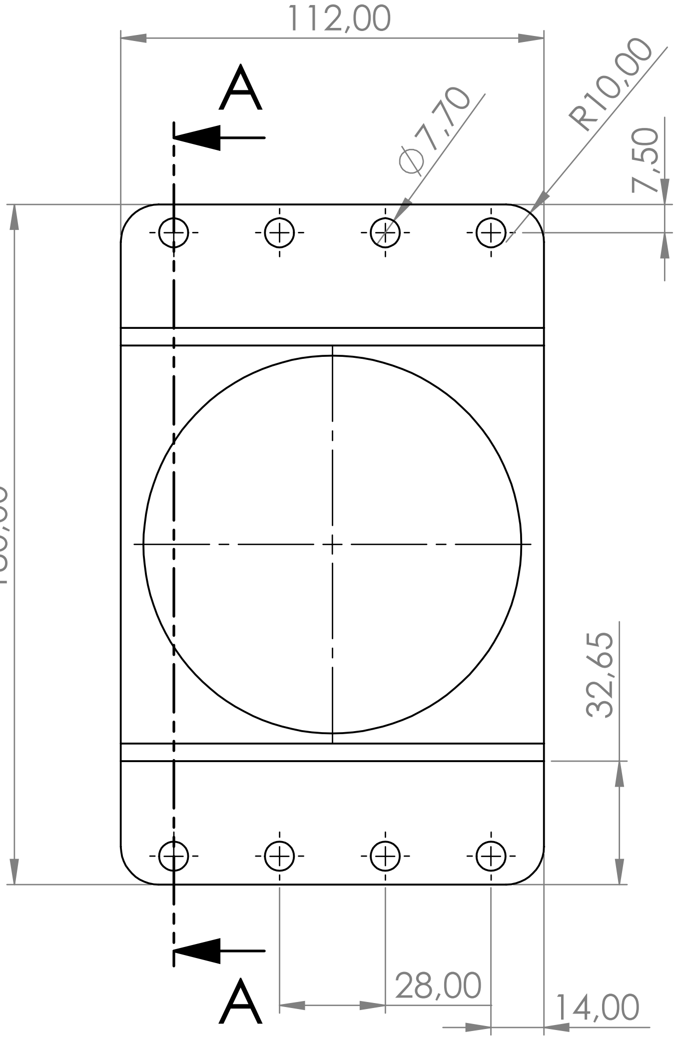
A4

WEIGHT:

SCALE:1:5

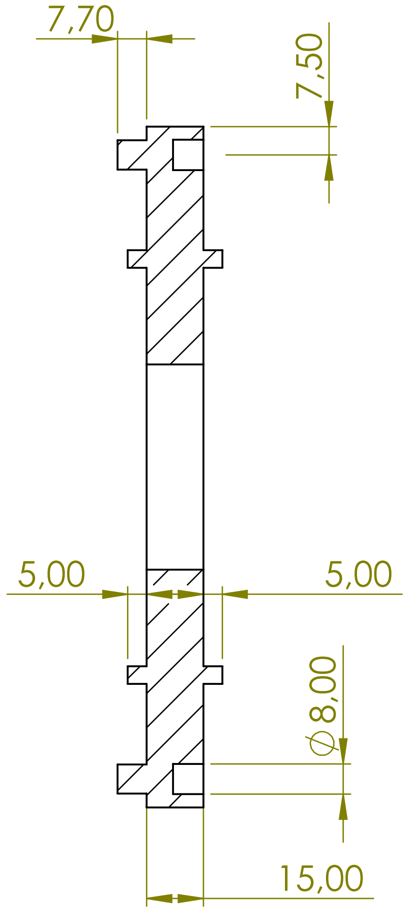
SHEET 3 OF 21





SECTION A-A

SCALE 1 : 2



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:
PLA

DWG NO.

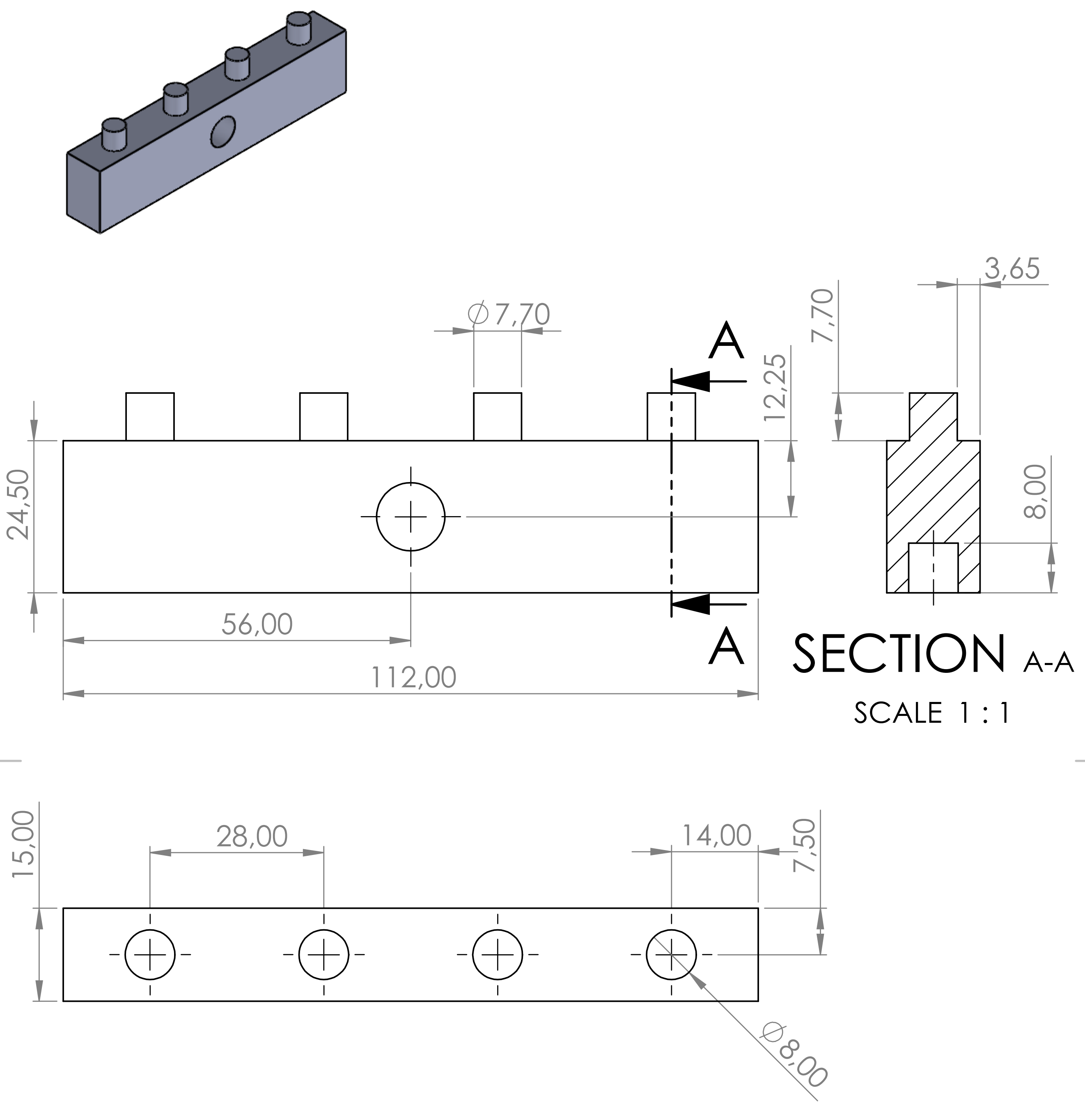
Plate

A4

WEIGHT:

SCALE:1:5

SHEET 4 OF 21



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:

DWG NO.

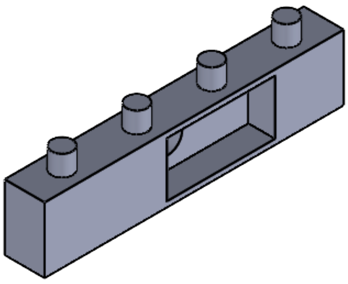
Upper Wall

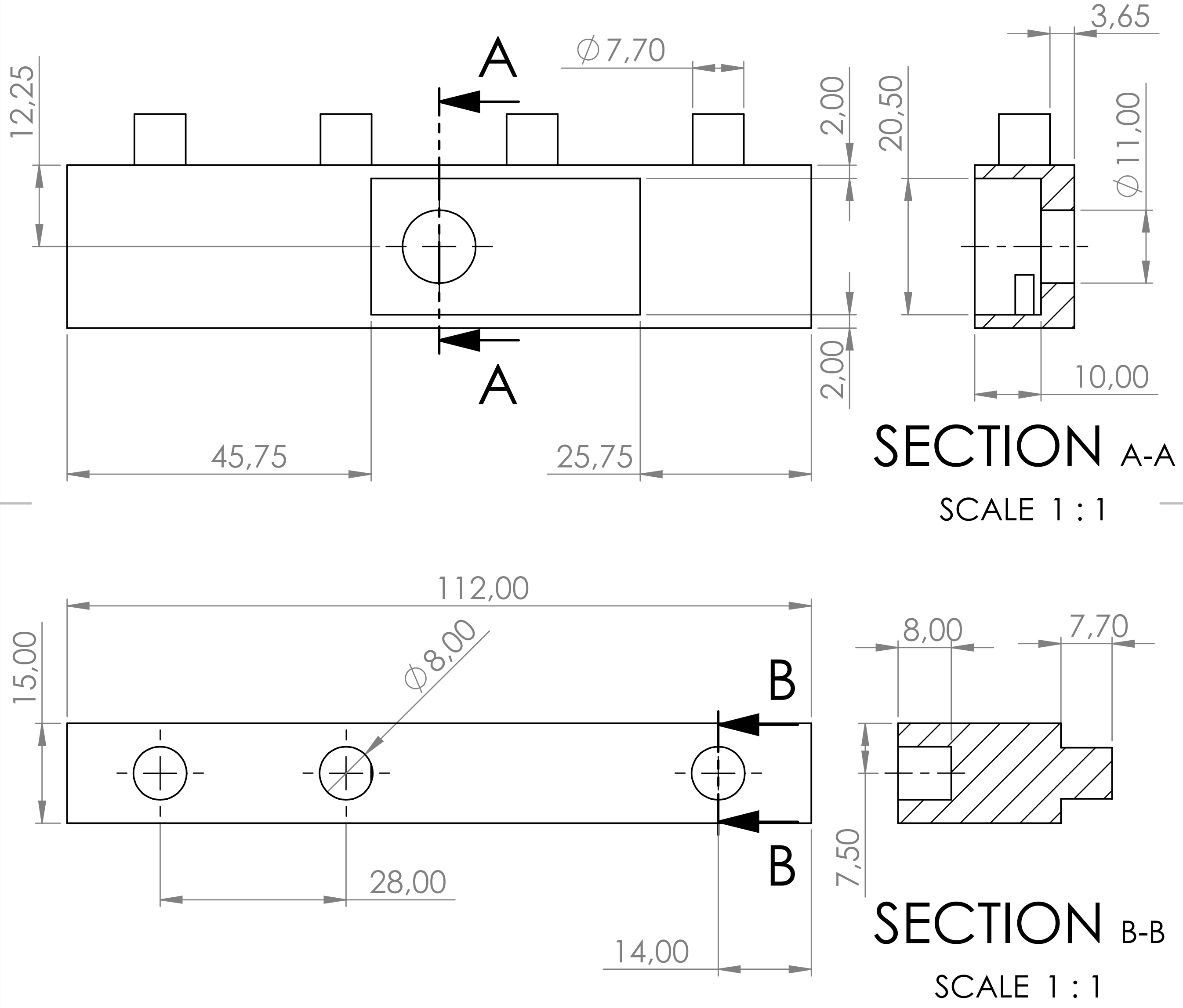
A4

WEIGHT:

SCALE:1:2

SHEET 5 OF 21





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL: PLA

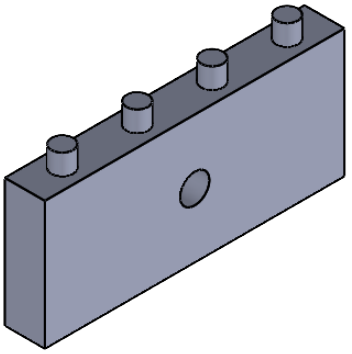
DWG NO. Lower Wall with Motor Mount

A4

WEIGHT:

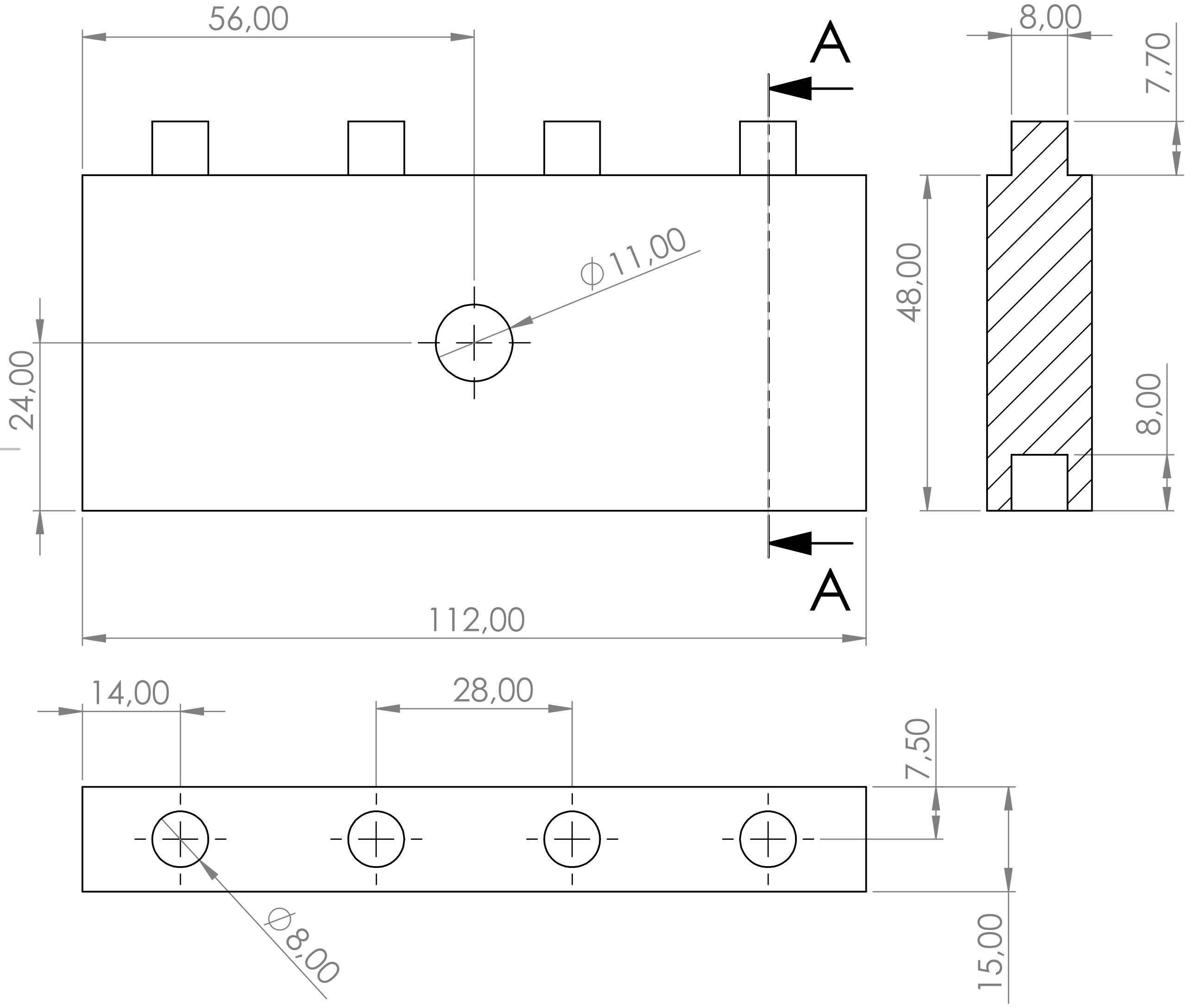
SCALE:1:2

SHEET 6 OF 21



SECTION A-A

SCALE 1 : 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:
PLA

DWG NO.

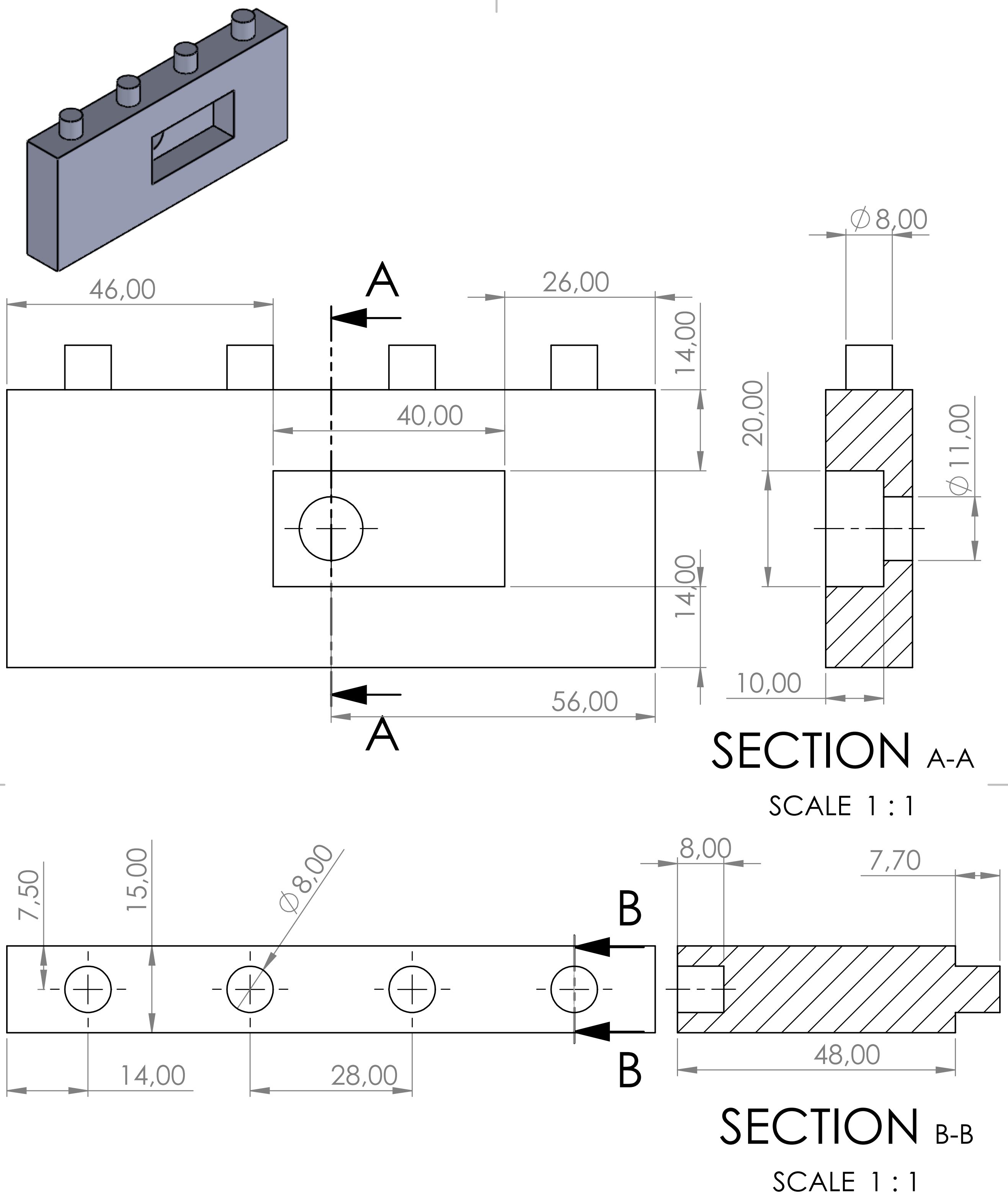
Lower Wall

A4

WEIGHT:

SCALE:1:2

SHEET 7 OF 21



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL: PLA

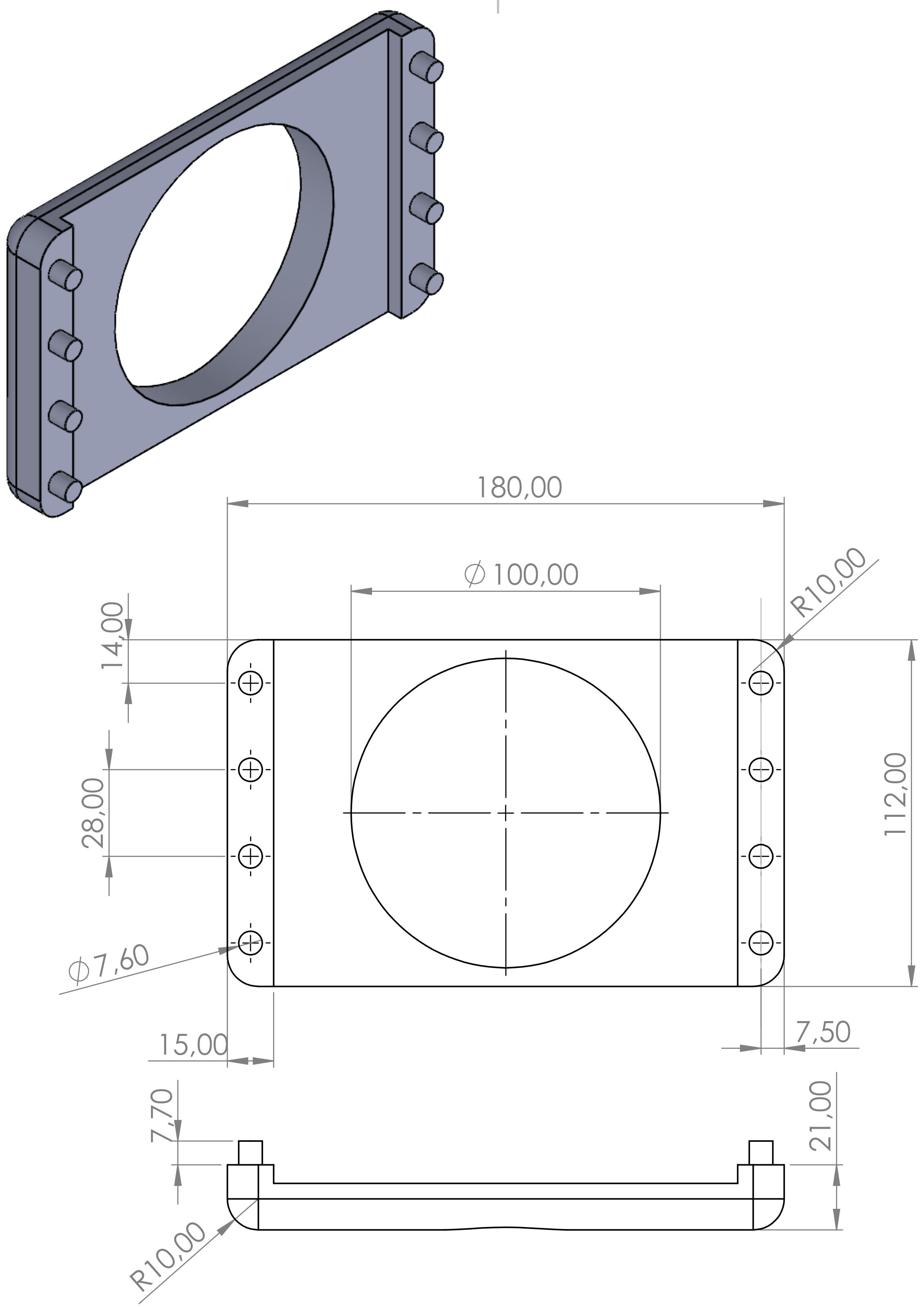
DWG NO. Lower Wall with Motor Mount

A4

WEIGHT:

SCALE:1:2

SHEET 8 OF 21



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:
PLA

DWG NO.

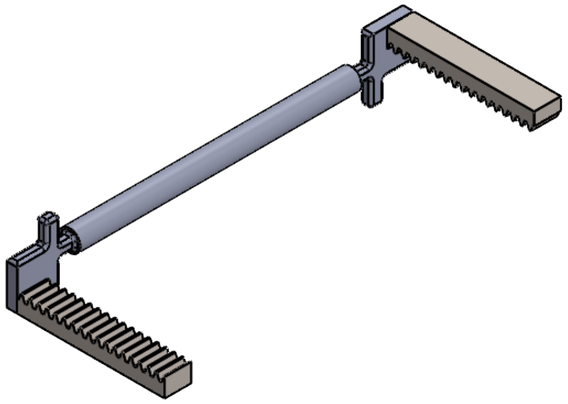
Tube Mount

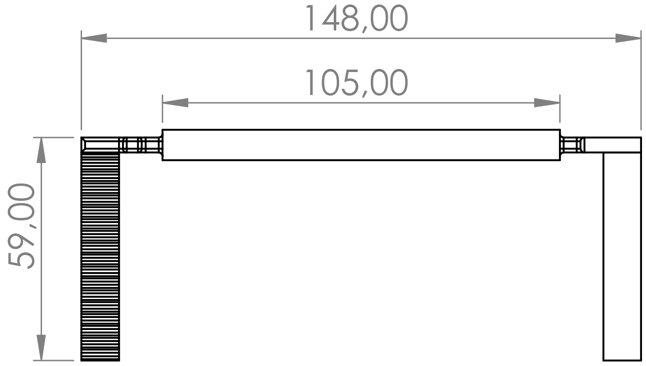
A4

WEIGHT:

SCALE:1:5

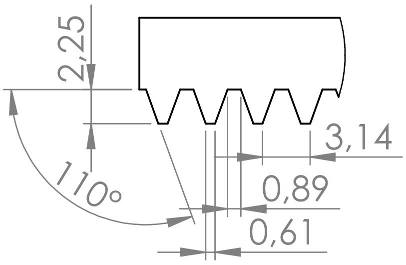
SHEET 9 OF 21

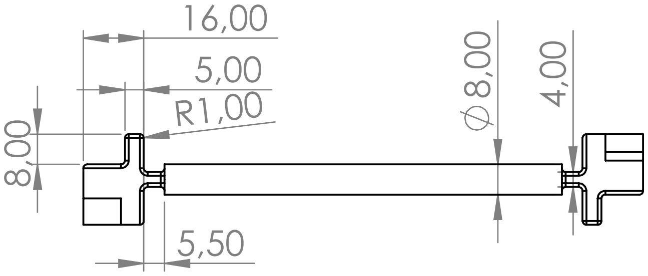


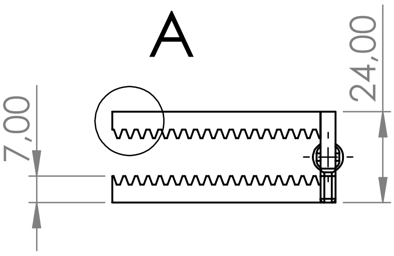


DETAIL A

SCALE 2 : 1







UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:

PLA

DWG NO.

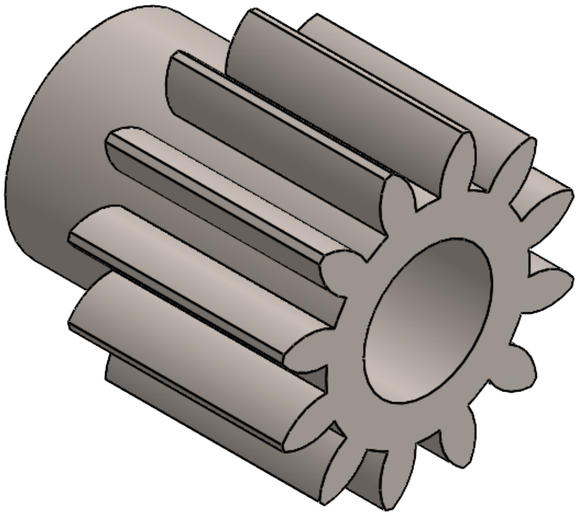
Upper Gripper

A4

WEIGHT:

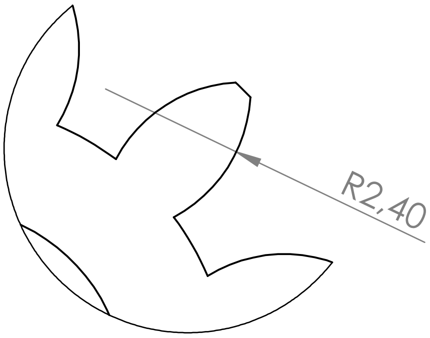
SCALE:1:2

SHEET 10 OF 21



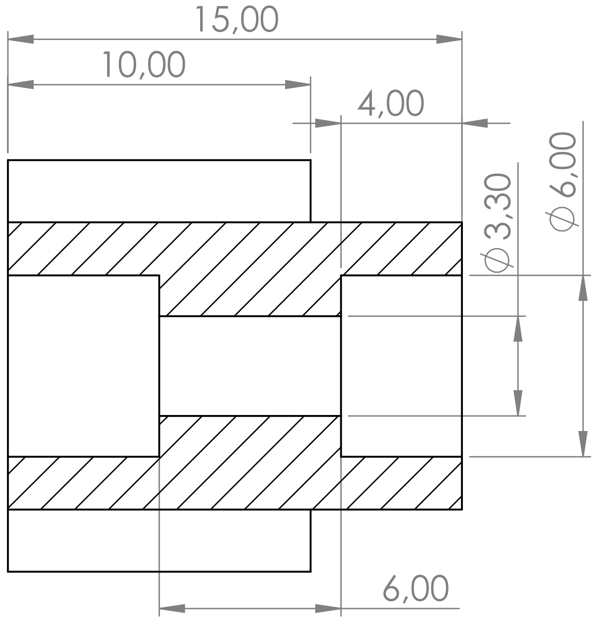
DETAIL B

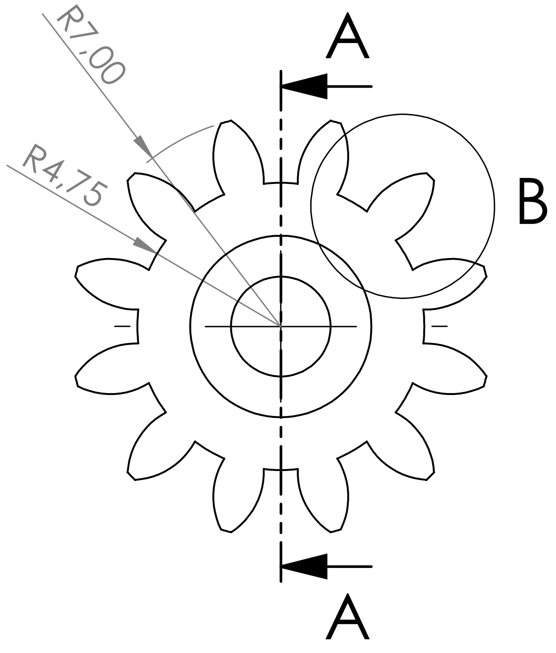
SCALE 8 : 1



SECTION A-A

SCALE 4 : 1





Gear Specification	
Module	1
Number of Teeth	12
Pressure Angle	20

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:

PLA

DWG NO.

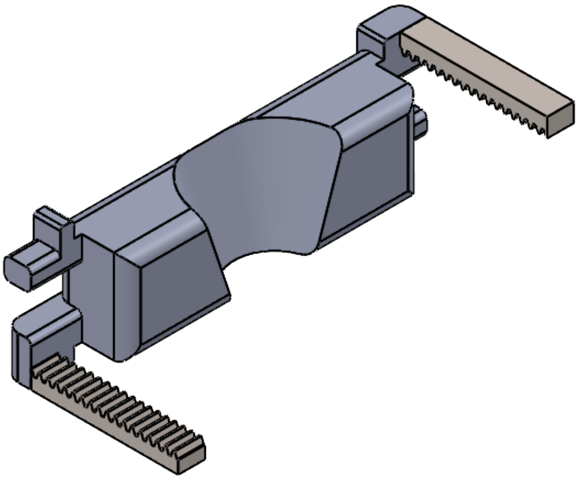
Upper Gear

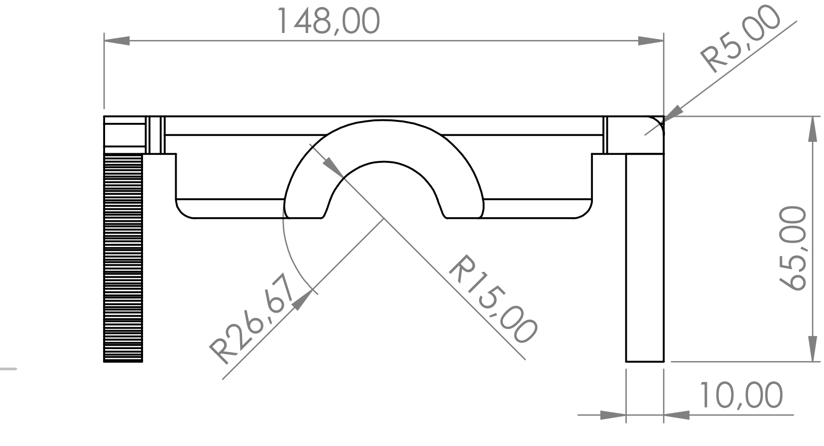
A4

WEIGHT:

SCALE:2:1

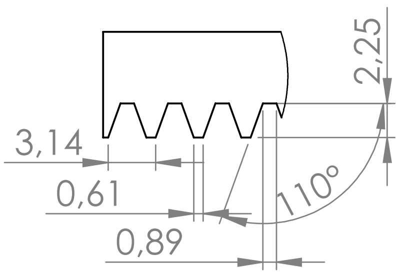
SHEET 11 OF 21

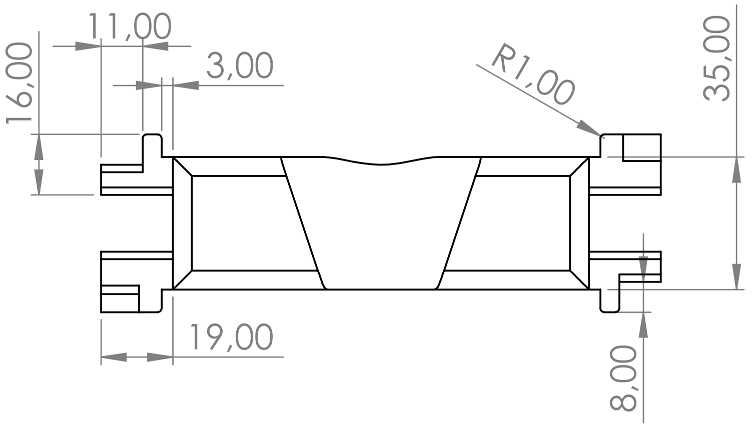


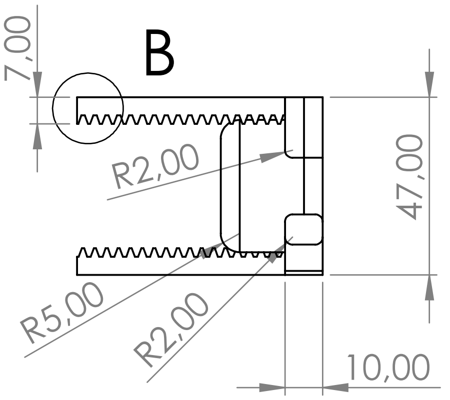


DETAIL B

SCALE 2 : 1







UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:
PLA

WEIGHT:

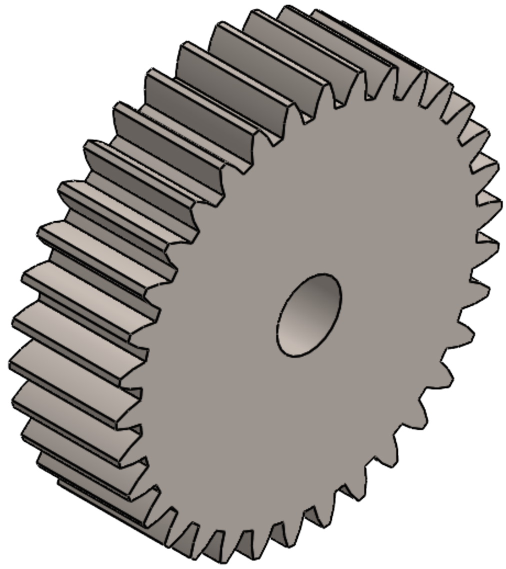
TITLE:
Final Prototype

DWG NO.
Lower Gripper

A4

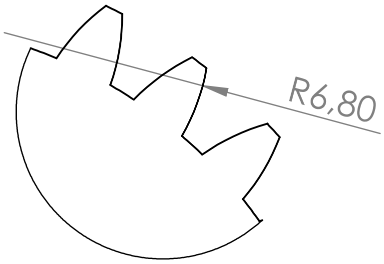
SCALE:1:2

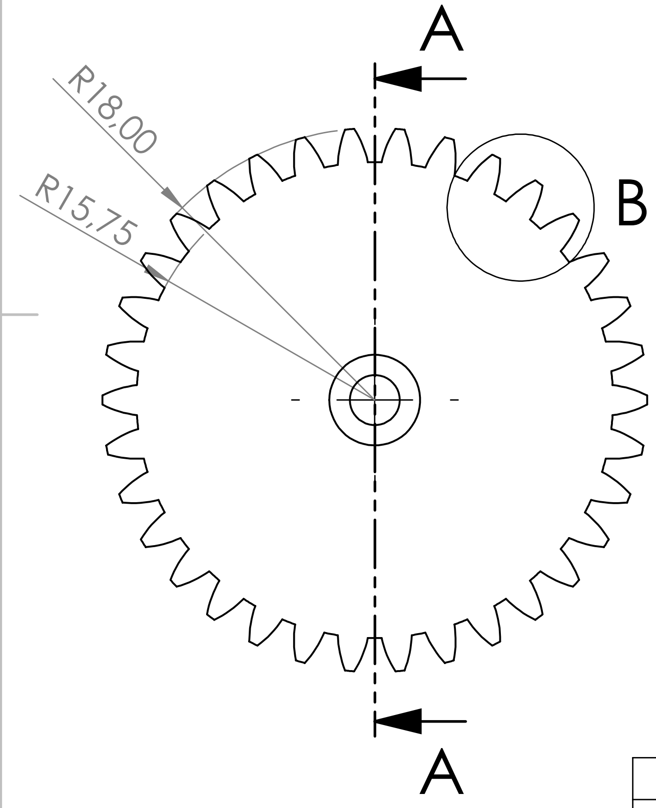
SHEET 12 OF 21



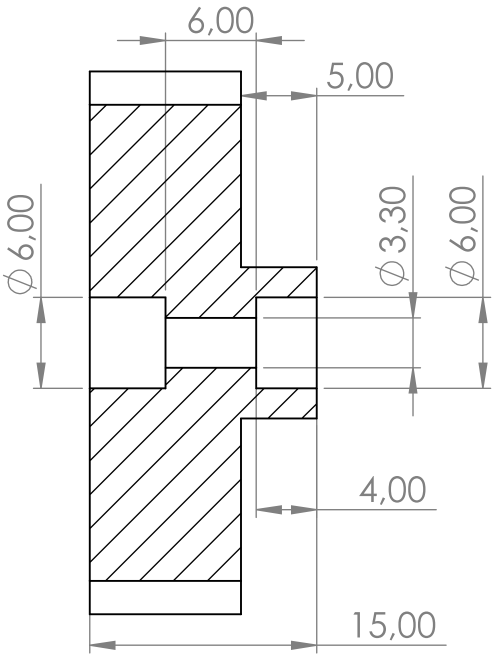
DETAIL B

SCALE 4 : 1





SECTION A-A



Gear Specification	
Module	1
Number of Teeth	34
Pressure Angle	20

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:
PLA

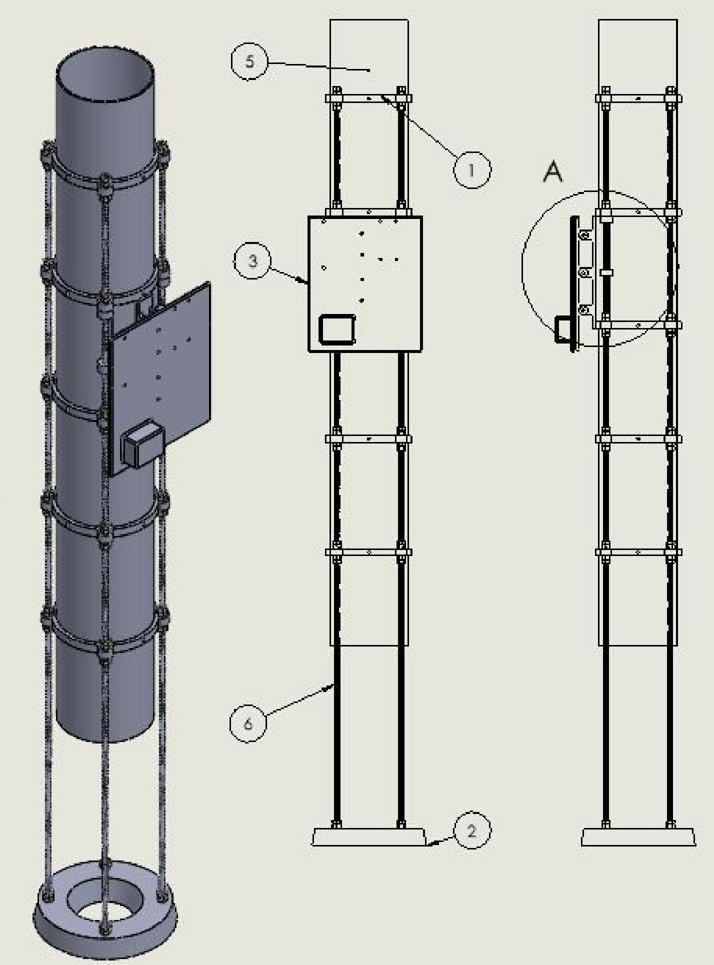
DWG NO.
Lower Gear

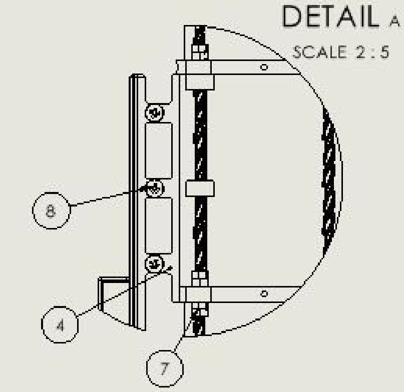
A4

WEIGHT:

SCALE:2:1

SHEET 13 OF 21





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	REFERENCE
1	Sensor Plate		5	SHEET 15
2	Base		1	SHEET 18
3	Controller Mount		1	SHEET 16
4	Controller Mount Link		1	SHEET 17
5	Tube	PVC Ø100 x 830 mm	1	
6	Threaded Rod	EN 14592, M6 1000 mm	4	
7	ISO - 4032 - M6 - D - N	ISO metric hexagon nut, C-1008	99	
8	ISO 7045 - M6 x 25 - Z - 25N	ISO metric Hexagon pan head screw, C-1008	3	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	[illegible]		28.05.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Final Prototype

MATERIAL:
PLA

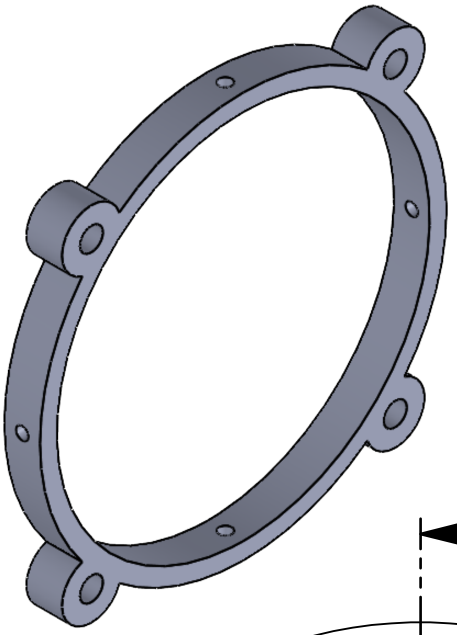
DWG NO.
Free Falling Measurement Tube

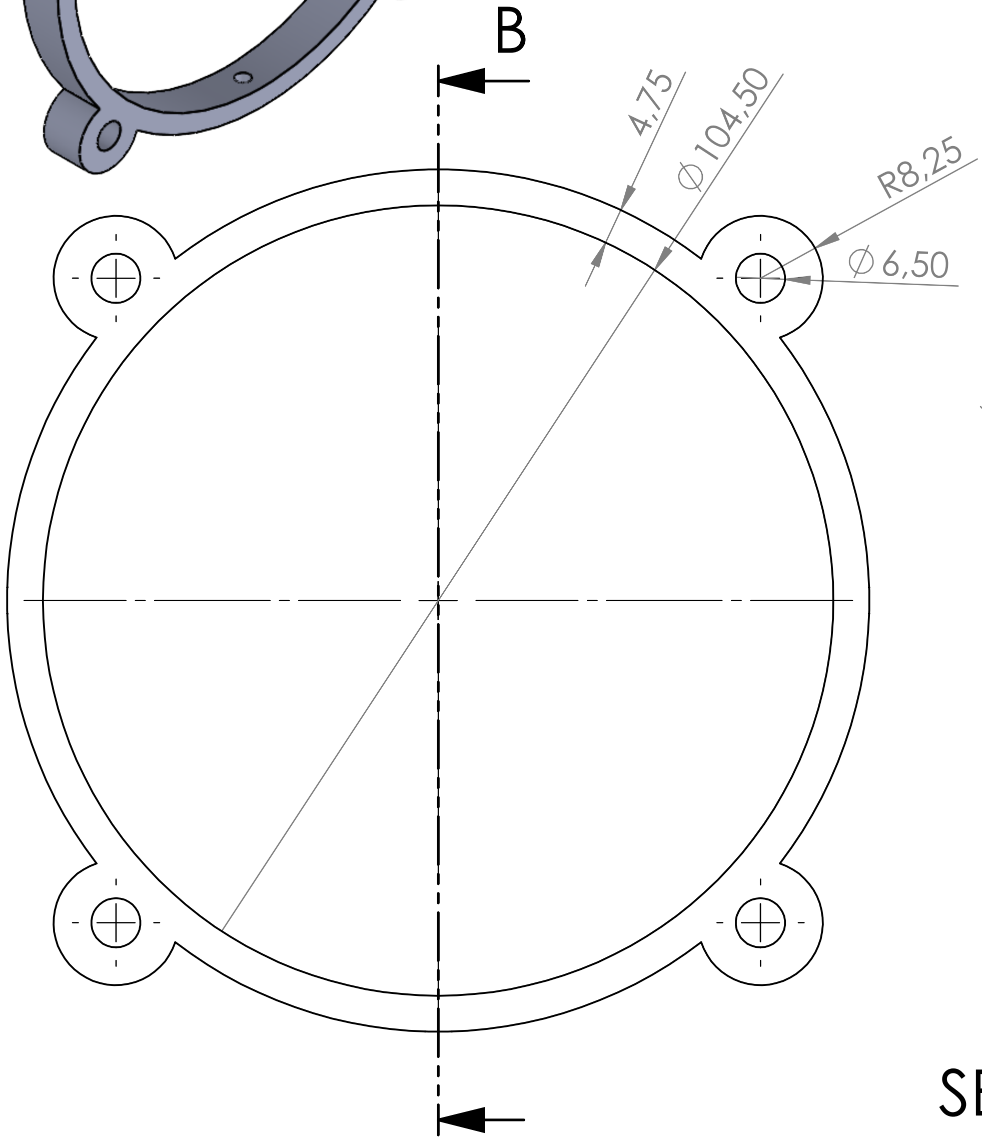
A3

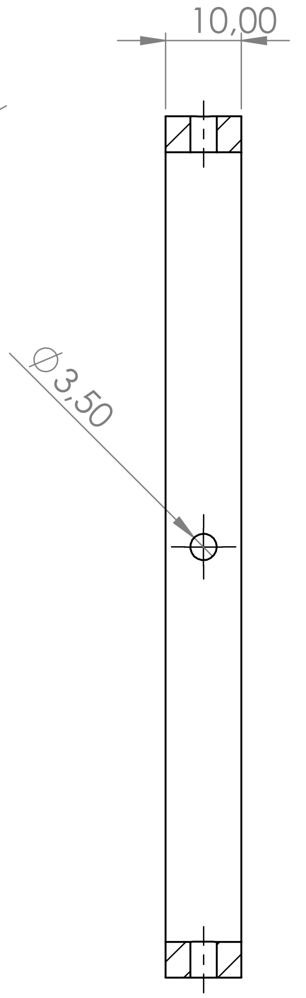
WEIGHT:

SCALE:1:10

SHEET 14 OF 21







SECTION B-B
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Hafsteinn Einar		08.06.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:
Final Prototype

MATERIAL:
PLA

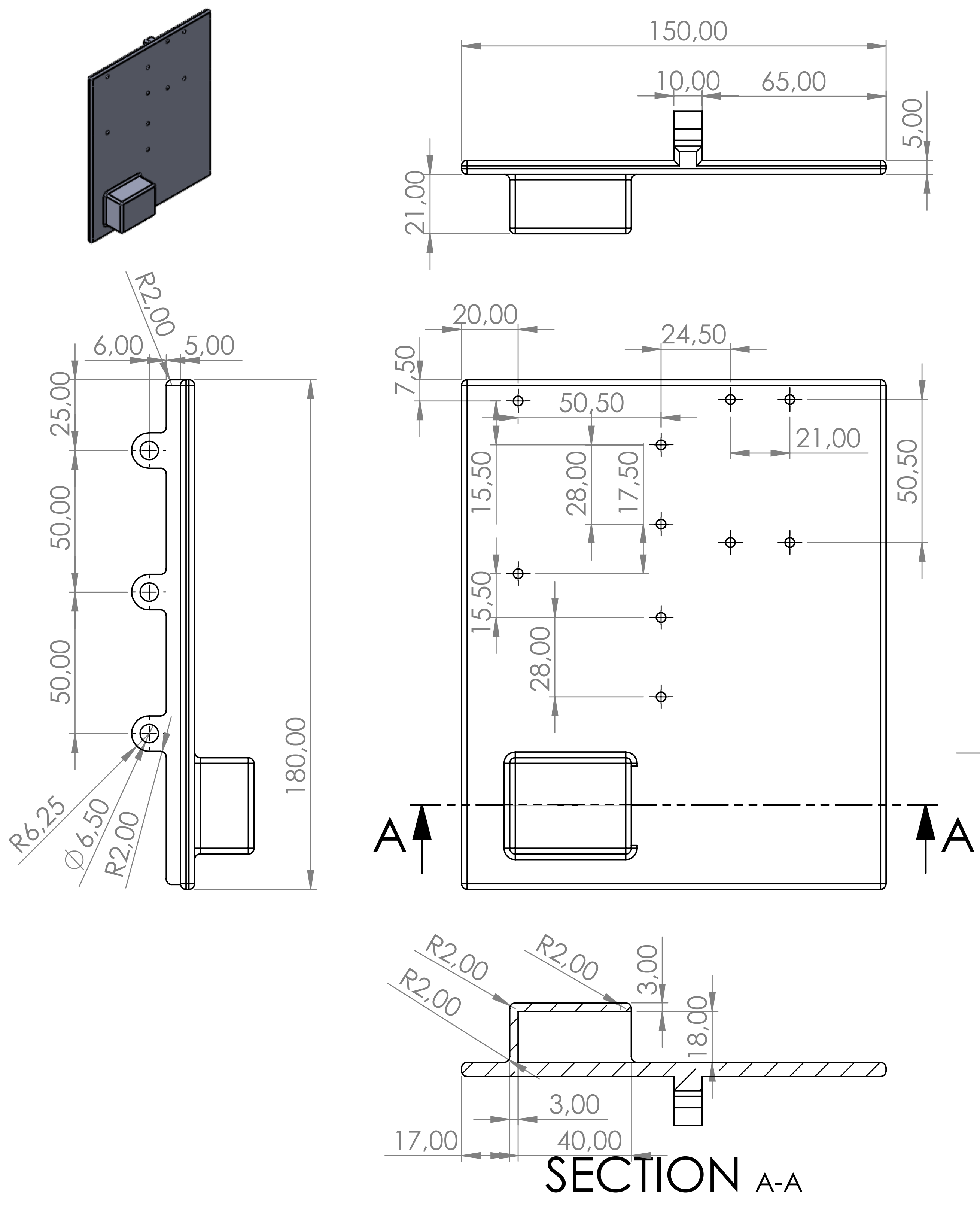
DWG NO.
Sensor Plate

A4

WEIGHT:

SCALE:1:2

SHEET 15 OF 21



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
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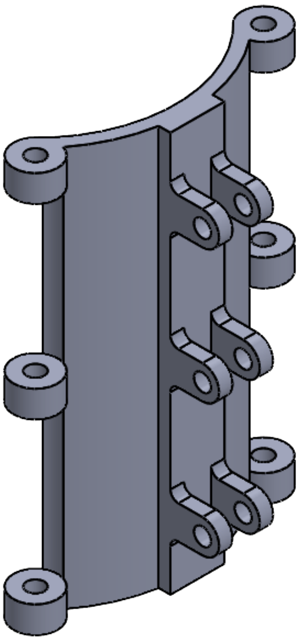

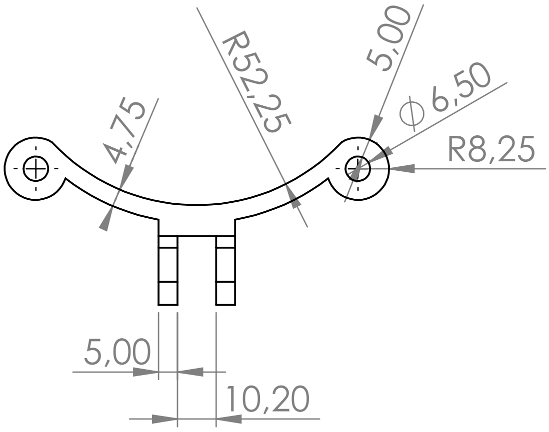

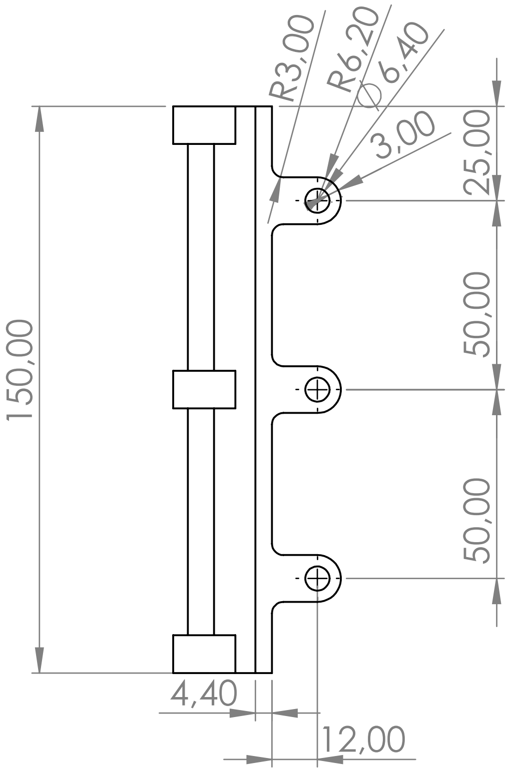

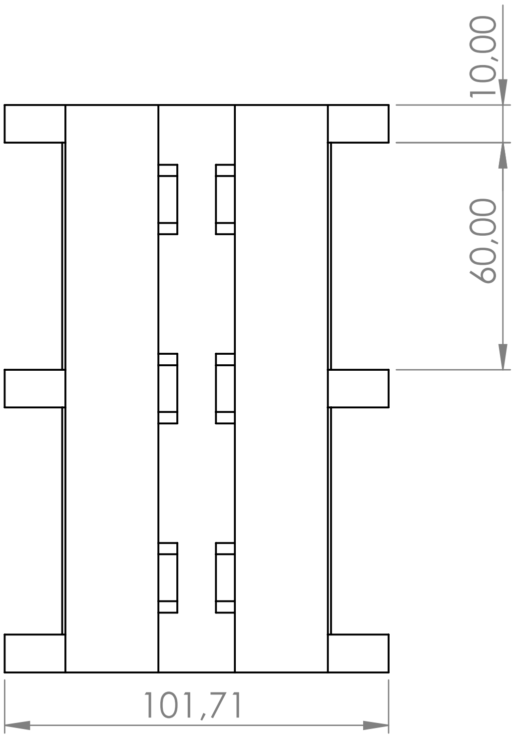

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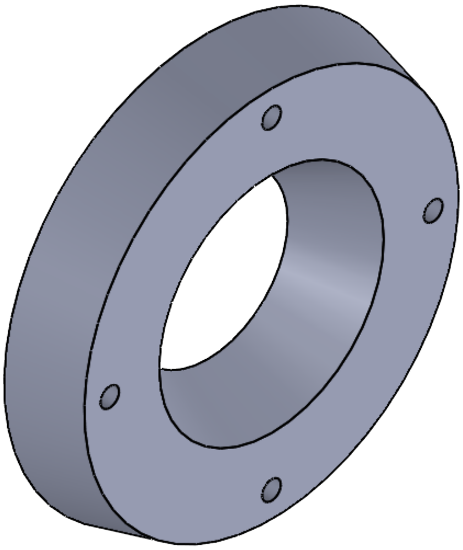

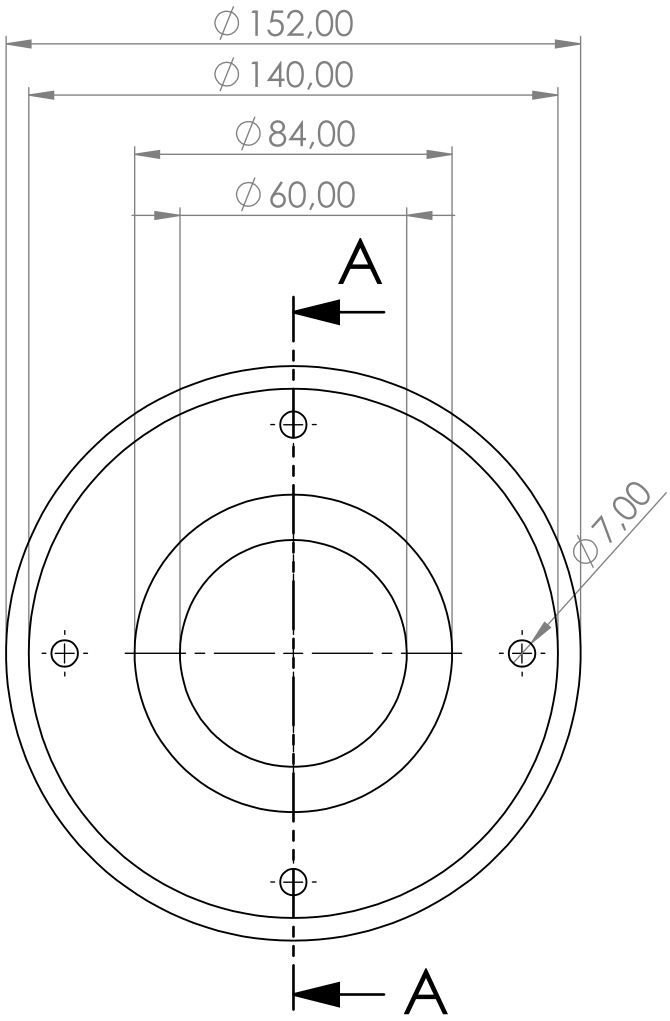

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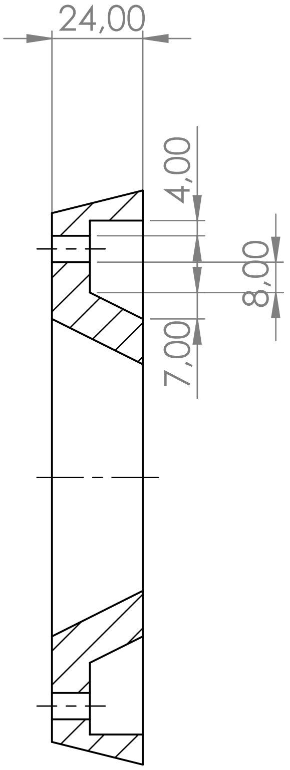

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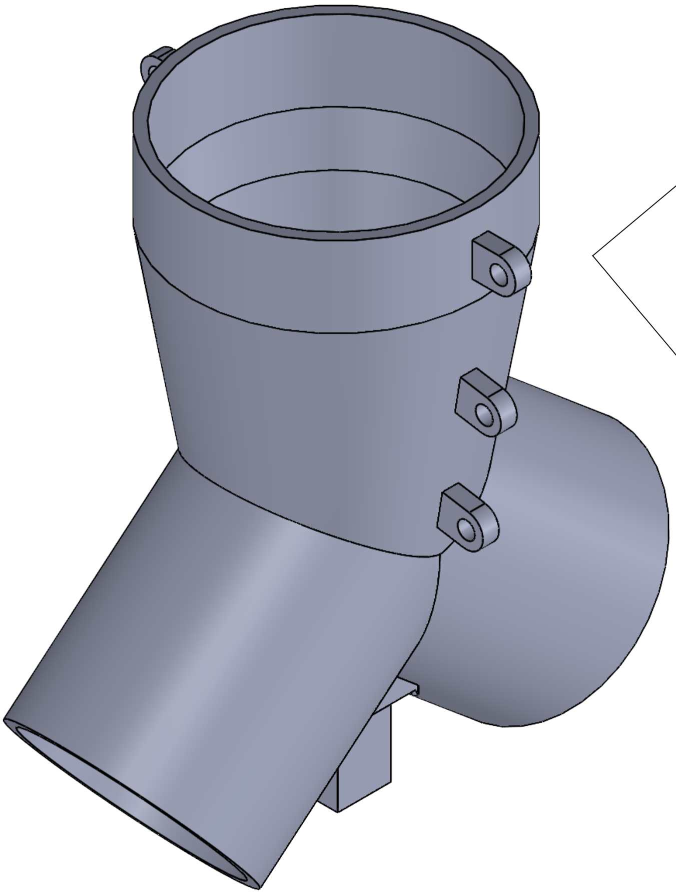

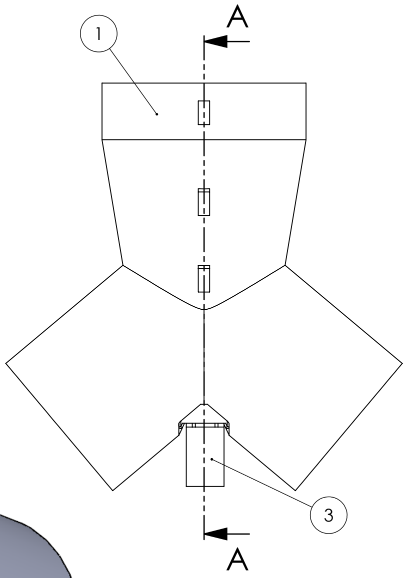

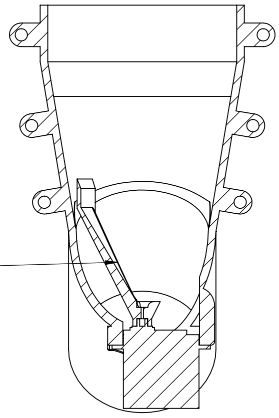

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2	Wedge		1	SHEET 21
3	Servo Motor	Towerpro MG996R	1	

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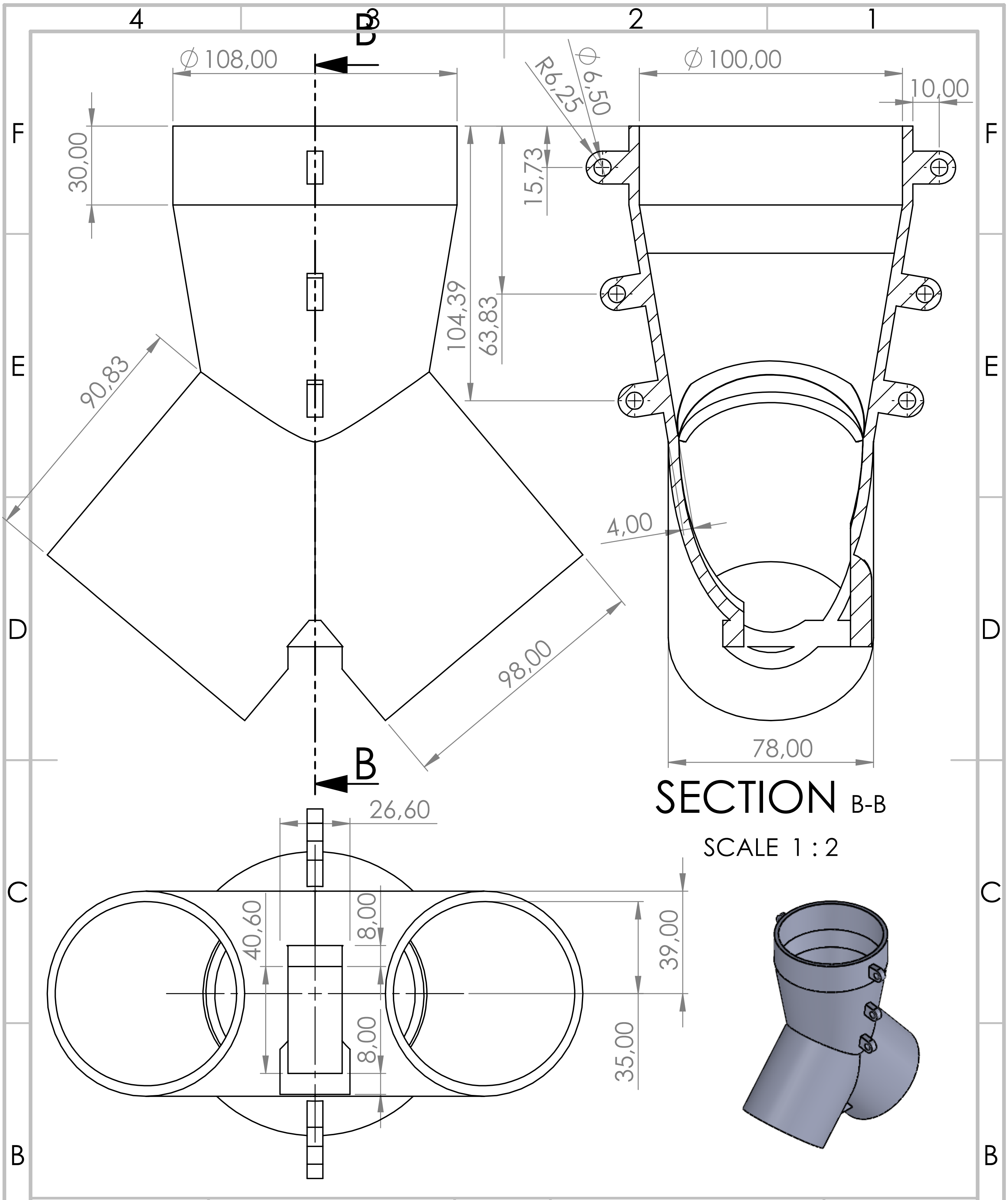

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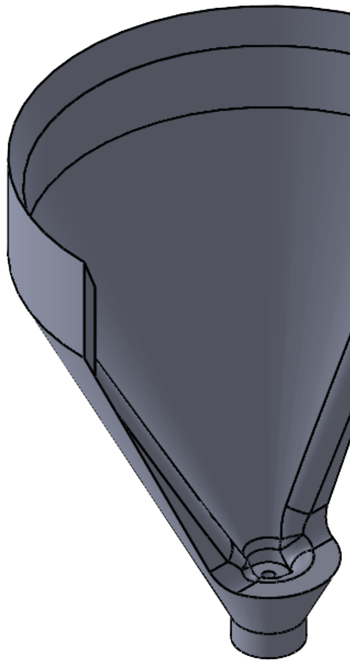

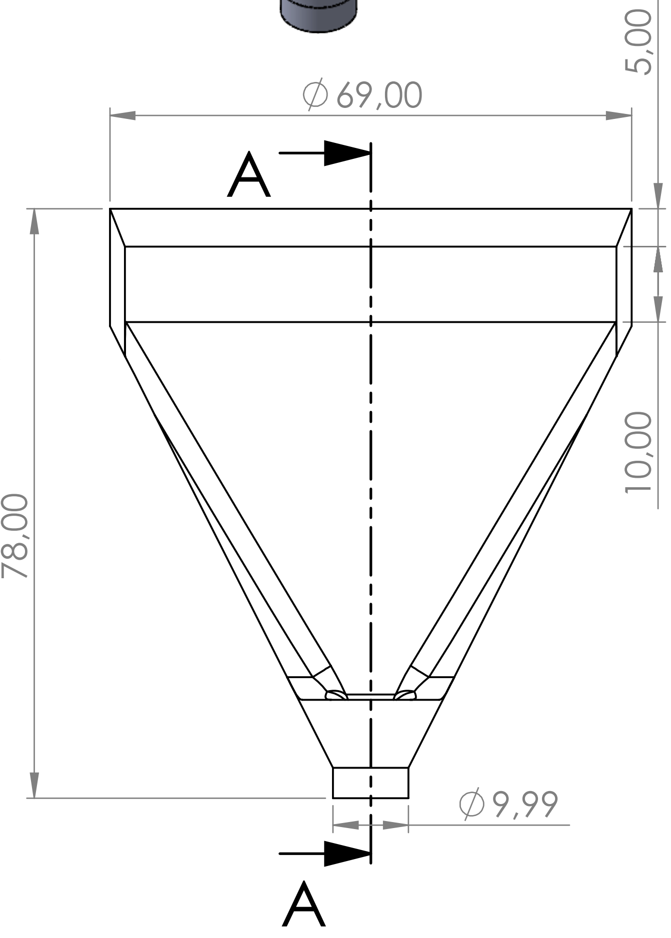

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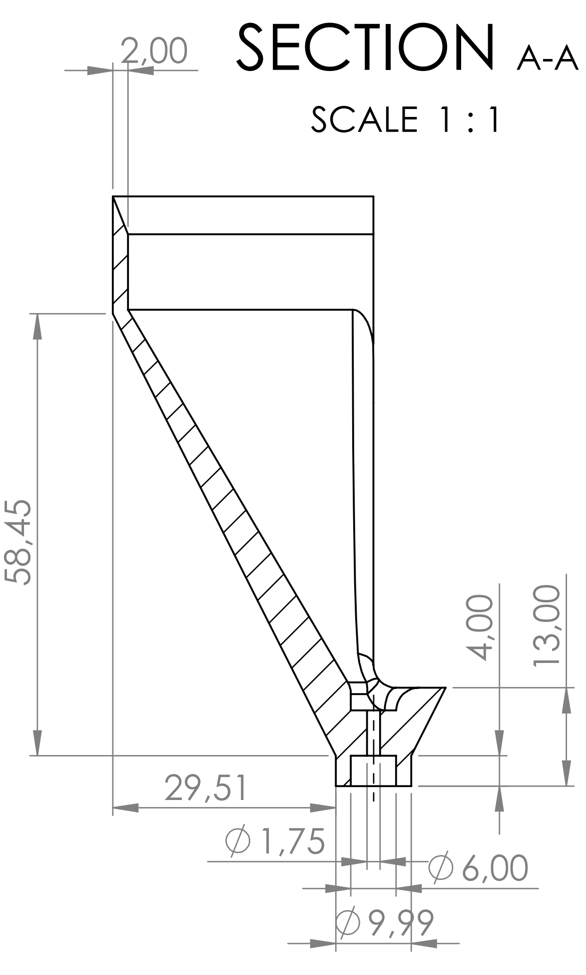

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TITLE:

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MATERIAL: PLA

DWG NO.

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SHEET 21 OF 21

C Semester Thesis

NTNU
Kunnskap for en bedre verden

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

TPK4560 - ROBOTTEKNIKK OG AUTOMATISERING, FORDYPNINGSPROSJEKT

A Study on Shuttlecock Testing in Badminton

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Main Supervisor:
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December, 2021

I Summary

Badminton is a very popular racket sport that utilizes shuttlecocks instead of balls. Shuttlecocks are complex objects with unique aerodynamic properties and individual traits. Shuttlecocks are sorted into different speed classes, and it is important to select the correct speed class for the environment that you will be playing in. Testing of shuttlecocks is done in large tournaments, but in local tournaments testing might be skipped. It is important to test shuttlecocks so that the correct shuttlecock speed is selected. Players all play differently and it might be smarter to have a machine sort the shuttlecocks to see if they are fit to be used in tournaments.

This thesis aims to see if the current way of testing shuttlecocks is effective or subjective and should be automated. The thesis will do this by performing an experiment during a local tournament, to see how different players attending the tournament test the shuttlecocks, and comparing the data gathered to data from other players.

26 different players took part in the experiment, however there were some factors of the experiment that did skew the data, such as some players being unfamiliar with testing shuttlecocks, shuttlecocks not being in ideal condition, and simplified measurements. Even with the skewed data it is obvious that the process of testing shuttlecocks should be automated, or changed in some way as the results from the players testing differed considerably.

It would be recommended if data is to be used from different players that the experiment be redone, however it is clear that the process should be automated. The thesis recommends that a concept for automation of shuttlecock testing should start, and a prototype be made.

II Sammendrag

Badminton er en veldig populær idrett som bruker fjerballer i stedet for baller. Badmintonballene er komplekse objekter med unike aerodynamiske egenskaper og individuelle karakteristikker. Badmintonballer er sortert i forskjellige fartsklasser, og det er viktig å velge riktig fartsklasse for miljøet du skal spille i. Testing av badmintonballer er gjort under store turneringer, men under lokale turneringer kan testing bli hoppet over. Det er viktig å teste badmintonballene slik at riktig hastighetsklasse blir valgt. Alle spillere spiller forskjellig, og det kan være smartere å la en maskin sortere badmintonballene for å se om de er egnet til å brukes i turneringer.

Hensikten med oppgaven er å se om dagens måte å teste badmintonballer er effektiv eller subjektiv og bør automatiseres. Oppgaven vil gjøre dette ved å utføre et eksperiment under en lokal turnering, for å se hvordan forskjellige spillere som deltar i turneringen tester badmintonballer, og sammenligne dataen som er samlet med data fra andre spillere.

26 forskjellige spillere deltok i eksperimentet, men det var noen faktorer ved eksperimentet som kunne skjevt dataene, slik som at noen spillere var ukjente med å teste badmintonballer, det at badmintonballene ikke var i ideell tilstand, og forenklede målinger. Selv med de skjeve dataen er det åpenbart at prosessen med å teste badmintonballer bør automatiseres, eller endres på en eller annen måte, da resultatene fra spillertestingen var betraktelig forskjellig.

Det vil bli anbefalt hvis individuell data skal brukes videre at eksperimentet gjøres på nytt, men det er åpenbart at prosessen bør automatiseres. Oppgaven anbefaler at et konsept for automatisering av badmintonball testing bør starte, og en prototype lages.

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1 Introduction

This thesis is the conclusion of a semester project which will lead into a master project for the Department of Mechanical and Industrial Engineering at NTNU in Trondheim, Norway. The semester project is pre-work for a development of a device which can test and categorize shuttlecocks into different speed classes. This project worked on finding flaws within the current procedure for shuttlecock testing, and gathering data on the testing of shuttlecocks, as currently there is little to no published data on the subject. The data was gathered from an experiment. The experiment was done during a badminton tournament, where players were taken aside between games and perform shuttlecock testing on some shuttlecocks, and the distance of the shuttles served was documented. The data was then analysed and discussed.

1.1 Problem Description

The problem description of this thesis is:

Ideally, shuttlecocks should fly perfectly and their speed classes work for their assigned environments. The properties of shuttlecocks change over time, as temperature and humidity changes effect the shuttlecock. This results in that not all shuttlecocks from the same tube might uphold their assigned speeds. This is why shuttlecock testing is important. For tournaments some shuttles are tested by some players to establish whether the speed class chosen is suitable for the tournaments environment. All players play differently and therefor the testing of shuttlecocks might be biased to their play-style and strengths. Not all shuttlecocks are tested either so there might be some shuttles that do not adhere to the same standards as the tested shuttles. This thesis aims to point out flaws in the current way shuttlecocks are tested, so that further work can be done on finding a solution in automating the shuttlecock testing process.

As there is little published research and data on shuttlecock testing, this thesis will also attempt to fill in some of the gaps in data when it comes to testing of shuttlecocks.

Some of the bigger factors when it comes to testing shuttlecocks lies with the players testing and the shuttlecocks, therefor this thesis will also ask and attempt to awnser questions such as:

- Are the differences in results from testing shuttlecocks by different players significant?
- Are most players consistent enough to test shuttlecocks effectively?
- Is the difference between each shuttle in a tube considerable?
- Is there a large difference between shuttlecock brands?
- Is the difference between where the shuttles first impact the ground and where they stop moving considerable?

1.2 Thesis Structure

This chapter presents what will be discussed in the other chapters.

Background Theory: This chapter will discuss the background of badminton and shuttlecocks, as well as discussing the procedure of shuttlecock testing, how it is currently performed and some flaws that are in it. It will also contain some discussion of previous studies within the field.

Methodology: This chapter presents and discusses the method of obtaining the data necessary. Presenting and describing the experiment, and the equipment used in the experiment. Discussing the simplified measurements used, as well as data adjustment after the experiment, and how consistency will be chosen from the data. Finally discussing how the data

Results: This chapter will present the data from the experiment, as well as how it has been analysed. The data found in during the experiment will be analysed, discussed, and used to attempt to answer the questions posed in **1.1 Problem Description**.

Discussion: This chapter presents and discusses some different factors that might have effected the final results of the experiment, as well as how some decisions under and before the experiment might have altered the final results.

Conclusion: Conclusion of the thesis, final conclusion of the data, and recommendations for further work.

Appendix: In the Appendix all gathered data from the experiment can be found. That includes tables of documented data, tables from data gathered from the videos, images of where all shuttles ended up, as well as all recordings from the experiment.

2 Background Theory

2.1 Badminton

Badminton is a racquet sport played either by two opposing players (in singles) or by two pairs of opposing players (in doubles). The game is played on a court with the dimensions 13.41 meters by 5.18 meters (length by width), and is divided by a 1.55 meter tall net in which is place in the middle of the length of the court and spans the width of the court. For doubles games the width of the court is extended from 5.18 meters to 6.1 meters (image shown below).

Where other racquet sports (such as tennis and squash) hit balls with their racquets, badminton instead uses shuttlecocks.

Each side may only strike the shuttlecock once before it passes over the net, and points are scored by striking the shuttlecock over the net and landing it within the opponents side of the court. A rally ends once the shuttlecock impacts the ground or a player commits a fault. A game ends when a player has reached 21 points or more with a two point lead or the first that scores the 30th point. A match is determined by the best of three games.

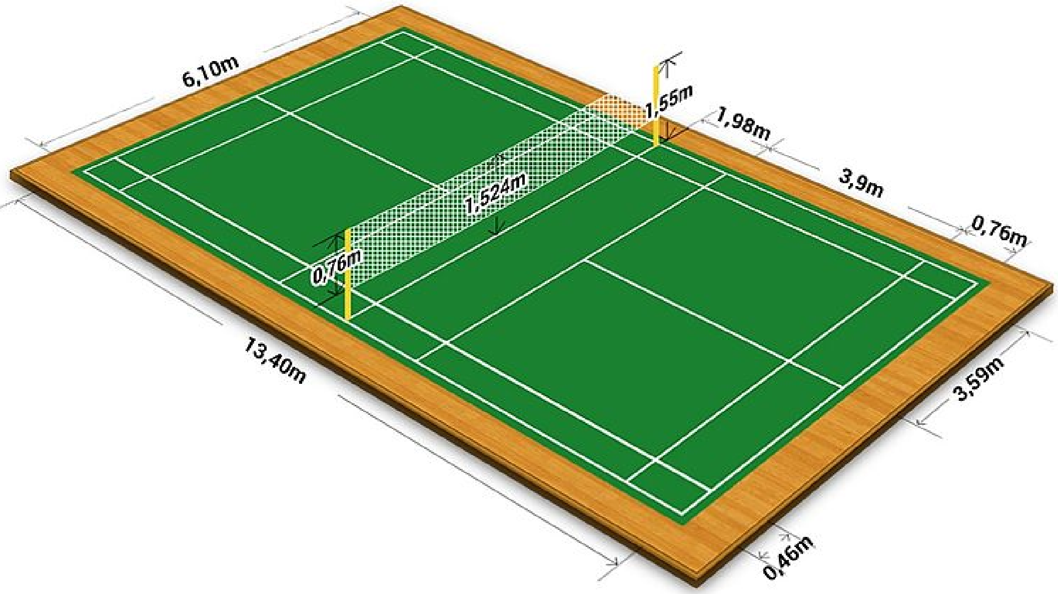


Figure 1: Badminton Court with Dimensions

2.2 Shuttlecocks

The shuttlecock has a unique design: A rounded leather covered cork base embedded with 16 feathers formed into an open conical shape. The feathers are usually those of geese (sometimes duck), but can be replaced by plastic or an synthetic alternative formed in an open conical shape.

The design leaves the shuttlecock very aerodynamically stable, and exposes the shuttlecock to more drag slowing it down while in air. Due to the different materials composing the shuttlecock it is non-homogeneous resulting in the cork tip to always leading the shuttlecock.

The feathered shuttlecocks are often the preferred choice of more serious badminton players due to them having a greater initial speed without travelling outside the court and they the parachute like trajectory. Due to their substantial initial speed players can also smash the shuttlecock faster, giving their opponent less time to react.

The synthetic and plastic shuttlecocks are more beginner friendly. They are more durable and economical than feathered shuttlecocks, and they travel in a more normal trajectory instead of the feathered parachute trajectory. In the research journal ”The physics of badminton” [2] it is discussed how the trajectory differences between the plastic and feathered shuttlecocks is due to the increased mass of the plastic, however cutting into the skirt longitudinally of the plastic shuttlecock alters its trajectory to be more similar to that of the feathered shuttlecock. The article also mentions that due to the trajectory difference between the feathered and plastic shuttlecocks, the plastic shuttlecock will travel farther, which might be more suitable for junior players.

A recent study showed that the feathered shuttlecocks are also more stable in air, and has a shorter oscillating period when turning around after impact with a racket[5].

The Badminton World Federation has approved the use of synthetic feathered shuttlecocks in international tournaments of all levels from 2021[6]. These synthetic shuttlecocks are not the same as used in the previously named article, but new ones developed by Yonex and approved by the Badminton World Federation. This is done to try to increase the durability of the shuttlecocks, lower the prices of shuttlecocks and reduce the carbon footprint by the badminton sport.

2.3 Shuttlecock Testing

When the shuttlecocks are being constructed they are tested for speeds and sorted accordingly into tubes (usually containing 12 shuttles each). This testing is usually done by launching the newly constructed shuttlecock from a shuttlecock launcher and the shuttlecock landing on a conveyor belt marked with the speed value. There will also be a worker to hit the shuttlecock out of the way if it sees that the shuttlecock looks unstable while in the air. Feathered shuttlecocks are sorted into five different speed classes, which reflect on where the shuttlecocks should be used. The table below shows the different feather shuttlecock speed classes.

International	Metric Wgt	Grain	Speed
1	48	75	Slow, for use in highland
2	49	76	Medium slow, for use in hotter area
3	50	77	Medium, most sea level area
4	51	78	Medium fast, cold area
5	52	79	Fast, cold area, below sea level

Table 1: Speed classes for feathered shuttlecocks

On the graph above ”International”, ”Metric Wgt” and ”Grain” are all different classifications for the same speed classes. Which one is used is dependent on the brand, however the ”Metric Wgt” is seen as an older system, and the ”Grain” is more often used to replace it.

This is the extent of the shuttlecock being tested by the producers. The tubes of shuttlecocks will later be marked with the shuttle speeds, driven to distributors and later to the consumers (badminton clubs etc.). With the passing of time, and change in temperature and air pressure the quality and the individual properties of the shuttlecocks have a chance to change to a certain degree, and therefor their speed might also change. This will result in a club buying a tube of shuttlecocks of a certain speed, and having some of the shuttles not having the qualities of their corresponding speed class. This is why it important to test the shuttles before using them for play.

In professional or larger tournaments a few players might be picked out to test a few shuttlecocks to see if the speed class is suitable for the conditions in the room where the game is being played. The testing is not done on all shuttlecocks used, and is often not done in smaller or local tournaments.

The current laws on how a shuttlecock should be tested are specified in the Laws of Badminton[3] under section **3. Testing a shuttle for speed**:

- **3.1**: To test a shuttle, a player shall use a full underhand stroke which makes contact with the shuttle over the back boundary line. The shuttle shall be hit at an upward angle and in a direction parallel to the side lines

- **3.2**: A shuttle of correct speed will land not less than 530 mm and not more than 990 mm short of the other back boundary line as in the figure below.

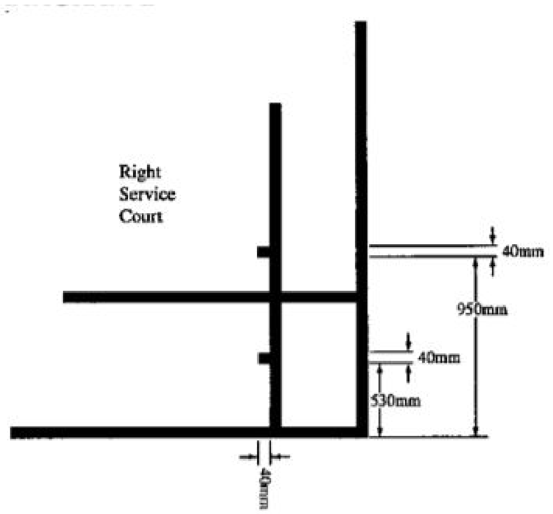


Figure 2: Illustration of the valid zone on badminton court

These laws are specified well, however due to the process of testing requiring a player to be done it can introduce problems.

These problems come in the form of inaccuracies, as all players play differently, not all players will test the shuttlecock with the same amount of force, and the angle of impact between the shuttlecock and racket will differ slightly between each player. These inaccuracies may result in players needing to adapt their play-style, or avoid certain techniques or strokes, since they might result in the shuttlecock going outside the legal boundaries, as in either not making it over the net, or going outside the court.

When a player is testing shuttlecocks he will only take into account where the shuttles come to a complete stop. When the shuttles are served and impact the ground they will bounce, which will most of the time create some distance between the location of the shuttles initial impact spot and the shuttles final resting location. This will then lead to some shuttles that might have either landed in the valid zone and bounced out, or landed outside the valid zone and bounced in.

There are also other factors that might effect the testing of shuttles, such as environmental factors like temperature, altitude, and humidity, or even factors relating to the shuttlecocks, like age, brand, and dryness of the feathers.

Testing might need to be done more often over the course of a tournament if the humidity and temperature of the tournament environment (stadium, gymnasium, etc.) is not regulated. An example can be seen with the 2021 Denmark Open where near the end of a session the shuttles had to be replaced by shuttles of a lower speed class, going from a speed class of 78 down to 77[4].

2.4 Previous Studies

There have been multiple studies on shuttlecocks, mostly on their aerodynamic features and trajectory, however there is little documented knowledge on the testing of shuttlecocks.

It is documented how the procedure of testing shuttlecocks in the Laws of Badminton [3], as well as videos on how it should be performed. There is a study by Yonex posted on their website where different experiments were performed on their shuttles[7]. One of these experiments used the procedure of testing shuttlecocks to compare their brand against two unnamed brands. The data from the experiment might seem unreliable as it concluded that their shuttles were more accurate than the other brands. The unreliability stems from the experiment being performed by the producers themselves.

Although most published research focuses on the aerodynamic properties of shuttlecocks some research papers have suggested that a scientific method to test shuttlecocks should be developed instead of the traditional and subjective method currently in use[1].

3 Methodology

An experiment was conducted to attempt to answer the questions posed in **1.1 Problem Description**. The experiment will be used as data to determine the accuracy of the shuttlecocks being tested, and if the differences between players is significant then there will indicate that the automation of the testing process would be beneficial.

3.1 Experiment Description

The experiment was conducted at Sit Dragvoll fitness center during a the Norwegian under 23 badminton championship hosted by the NTNUI Badminton club over the weekend of the 23rd and 24th of October 2021.

Players were gathered between their matches, and taken to the gymnasium nearby used for the experiment. Each player tested 12 shuttlecocks, serving them from a marked line on the ground (representing the backline of the court), toward a mat in the gymnasium some distance away (representing the other side of the court).

Players were asked to test the shuttlecocks, however the players who were not familiar with testing shuttles were told to perform an underhand serve directed towards the mat on the other side of the court, and to try to hit the shuttle so that it impacts their racket over the dark line marked on the floor.

The distance from the player to where the shuttlecock impacted the ground were thereafter measured and documented. Cameras were placed to see if the shuttles were properly served, and to see if the distance was correctly measured post experiment, as well as where the shuttles initially impacted the ground. The data from each player and shuttle were later compared and worked on.

The illustration below shows how the experiment was set up, with the numbers marked on the illustration corresponding to: (1) the marked line, (2) the player testing the shuttles, (3) camera number 1 (GoPro Camera), (4) backline location, (5) the measuring mat, and (6) camera number 2 (Ipad).

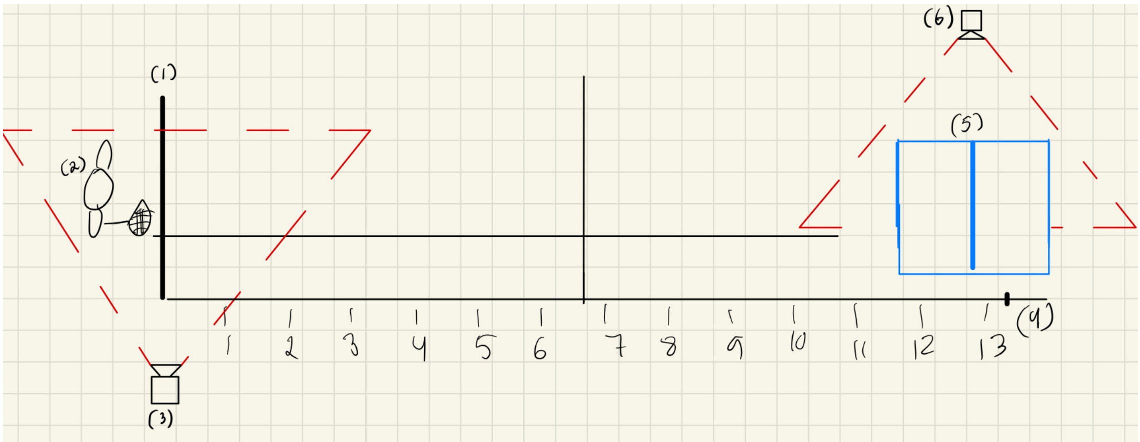


Figure 3: Illustration of the setup of the experiment

3.2 Experiment Equipment

3.2.1 Mat

A paper mat was made with the dimensions of 2.4 meters by 2 meters. Lines were drawn parallel to each other, with a distance of 10 centimeters between each line as shown in the illustration below. These were made to simplify the measuring of where the shuttles land. During the experiment the mat was taped to the ground so that the center of the mat (1.2 meters) was located 60 centimeters from the backline opposing the player testing. A paper mat was chosen as it was light and easily transportable, cheap, and because the amount of cushioning or dampening effect it would have on the shuttle would be negligible, making it so that as if the shuttle had impacted the ground directly as it would normally when testing shuttles.

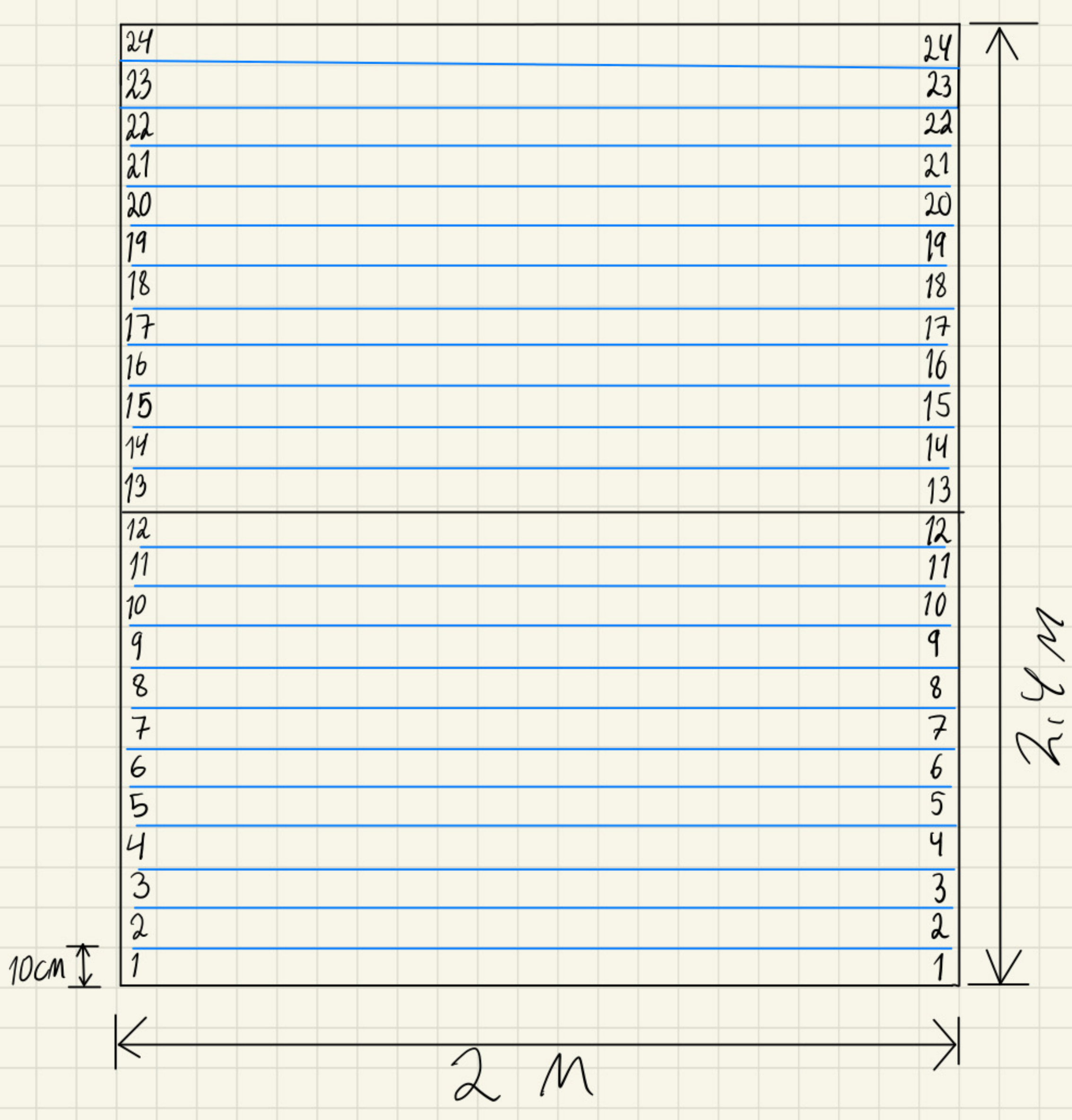


Figure 4: Illustration of the mat

3.2.2 Shuttlecocks

Two tubes of feathered shuttles were gathered for this experiment, and each shuttle was given a number and marked. The shuttles marked 1 - 12 were RSL Classic 78 shuttles, while the shuttles marked 13-24 were FZ Forza VIP 78.

The RSL Classic shuttles were bought from NTNUI Badminton, the club hosting the tournament, and were the same shuttles as the ones used in the tournament.

The FZ Forza shuttles where borrowed from another local Trondheim badminton club. This allowed the comparative between different shuttles as well as the two brands.

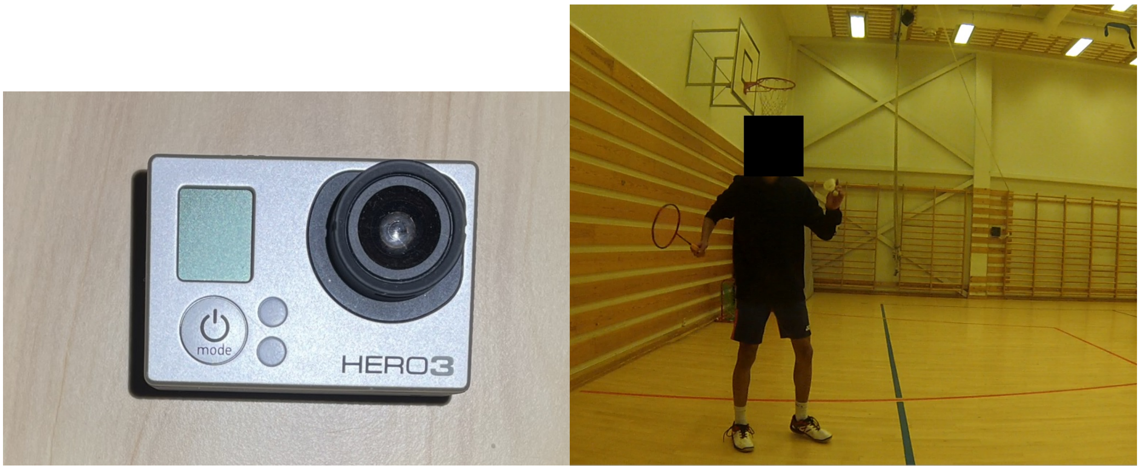
During the experiment six shuttles of each brand were tested by each player. The shuttles were mixed so that it would be more difficult for the players to distinct the different brands.

After the first ten players the shuttles were switched with the the other six shuttles of each brand. The first 12 shuttles were later used to supplement the ones that got lost or broke.

3.2.3 Cameras

Two cameras were used during the experiment. These cameras were:

- **GoPro HERO 3 Silver**: The GoPro camera was placed close to where the players would test the shuttles. It sat on a tripod standing 1.15 meters tall and angled parallel to the ground, angled slightly as to be able to view the players entirely. The view from the GoPro showed where the shuttle impacted the racket when a player tested the shuttles. The player, the shuttle and the marked line on the ground were all clearly visible from the GoPro camera.



[redacted]

Figure 5: (Left) GoPro Hero 3 Silver camera, (Right) View from the GoPro camera

- **Ipad 10.2"**: The Ipad was was placed on the other side of the badminton court. It sat on a tripod standing 1 meter tall and angled in a downward angle. The view from the Ipad was the entire mat. The mat, the lines on the mat and the numbers on the mat were all visible from the Ipad. The view from the Ipad can be seen in the image below.

Figure 6: (Left) Ipad 10.2", (Right) View from the Ipad camera

These cameras were chosen due to availability. The cameras are not optimal for some parts such as measuring the distance from where the racket impacts the shuttle relative to the backline, but to keep the cost of the experiment to a minimum, cameras that were available at hand were used. Even though neither camera is suited for slow-motion video, it can be seen approximately where the shuttles land, and where the racket impacts the shuttle.

3.3 Simplified Measurements

Measurements gathered during the experiment were simplified to save time during the experiment. Parallel lines were marked on the mat with space of 10 centimeters between each, and ranges defined between lines, marked numerically from 1 to 24 (since the mat was 2.4 meters long). These numbered ranges will be hereby be referred to as measurement zones.

The measurement for each shuttle was marked as the number of the measurement zone it landed within, or marked out if the shuttle did not land on the mat.

The mat was placed with its center 60 centimeters from the backline of one side of the badminton court. This results in measurement zone 1 being between 11.61 and 11.71 meters from where the player serves. The valid landing zone, as described in **2.3 Shuttlecock Testing**, which would be 12.41 - 12.87 meters from the player serving, or within measurement zones 7 through 12.

Shuttlecocks that did not reach the mat are marked with a "U". If a shuttle is laying right outside of measurement zone 1, then it is over 80 centimeters from the valid landing zone, which is far from being valid.

3.4 Data

After the experiment was finished, the data was gathered and analysed. The videos from the GoPro were reviewed and it was noted whether the players racket impacted their shuttlecocks behind, over or beyond the line marked on the ground. The videos from the Ipad were review to see where the shuttlecocks first impacted the ground, as well as if there were inconsistencies with the written shuttlecock landing values and the video.

3.4.1 Data Adjustments

To adjust the stats the distances of the shuttles was adjusted according to the videos of each players serve. It was explained to each player that it was desired that the shuttle be served in a manner so that the shuttle would impact the racket over the marked line. In the serving videos from the GoPro camera it can be seen whether the shuttle impacted the racket behind, above or beyond the marked line. Whether the shuttle impacted the racket above or beyond the marked line were documented, and the final distance of that shuttle was adjusted. The adjustment was simplified in a manner so that if the shuttle had impacted the racked behind the line, the final distance of the shuttle would be moved one measurement zone (10 centimeters) forward (farther), and if the shuttle impacted the racket over (beyond) the line the final distance of the shuttle would be pushed one measurement zone (10 centimeters) backwards (closer to the player).

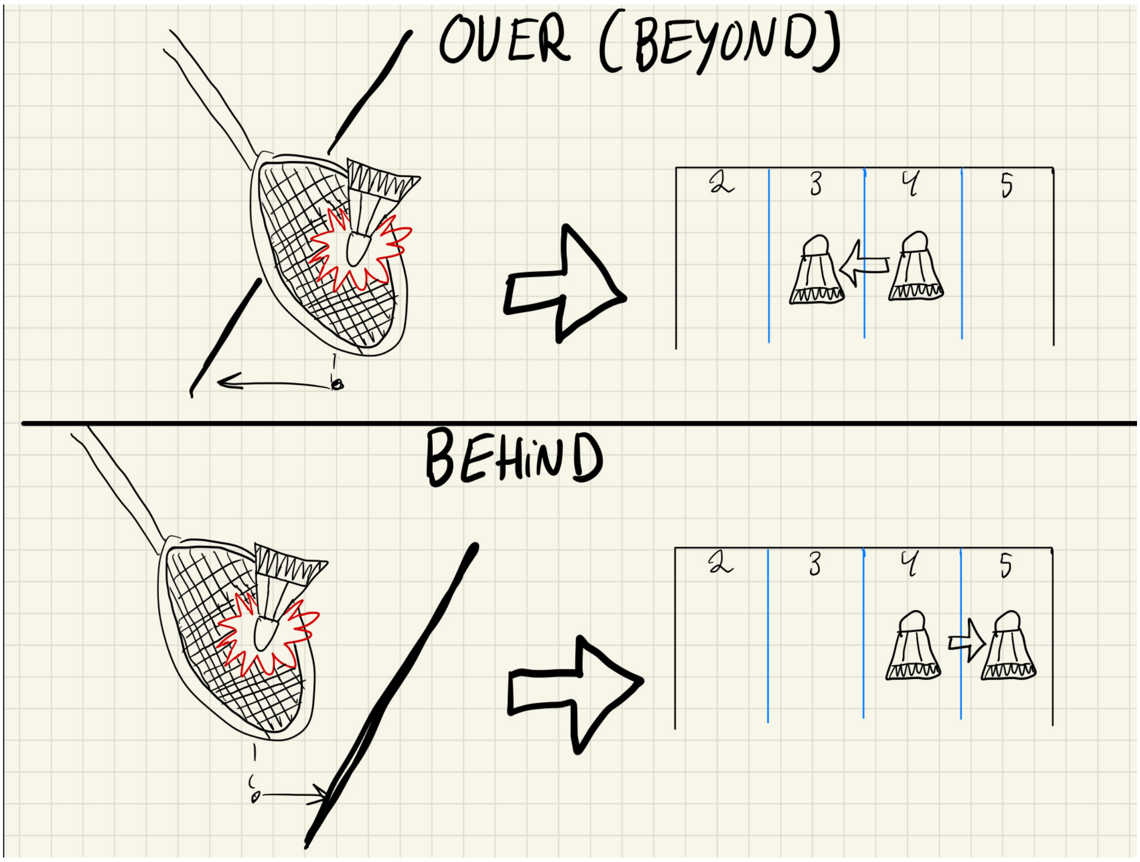


Figure 7: Illustration of data adjustments

3.4.2 Data Consistency

Due to there being many different players testing the shuttles, there was bound to be variations between the skill level of the players. The stats of all players could be used, however some might find that mixing the results from a higher ranking player with a lower ranking one would result in skewed or bad data. This only depends however on what you want to know from the data. When it came to viewing the differences between players then all the data was used, but when it came to viewing the differences in shuttles only the data from the more consistent players was used. When it came to finding the more consistent players some comparisons had to be made. The factors in choosing the more consistent players were:

- **Range:** The player was able to serve their shuttles so that they were concentrated within one area, and that they were not spread all over. Seeing that a larger portion of the shuttles all lay within a special range determined by the average distance the player tested the shuttles.
- **Distance:** Seeing that a larger portion of the shuttles landed on the mat, as the shuttles that did not make it onto the mat were only marked as out and did therefor land far away from the valid zone.

As not all players tested the same amount of shuttles (due to lack of time or, damaged or lost shuttles) the value of both these factors were instead set to percentages. The range is set to three measurement zones (30 centimeters) forward and backward from the players average shuttle distance. This is simply a conservative number, as the valid landing zone is approximately 46 centimeters long. The amount of shuttles that need to be within that range are set to a minimum of two thirds (67%), and the amount of shuttles outside the measure area are set to no more than one third (33%).

Players that fulfil the data consistency requirements were added to a separate group that will hereafter be referred to as the consistency group. The data from the consistency group is used as data for the shuttles.

4 Results

The experiment was performed at Dragvoll, Trondheim which is located 160 meters over sea level, and the temperature inside the gymnasium was 18 degrees Celsius. A total of 26 different players took part in the experiment.

4.1 Data from the experiments

Some decisions had to be made when it came to analysing the simplified measurements. When it came to calculating average distances for the shuttles there was a question: What about the shuttles that landed outside the mat? Those shuttles were marked as out or with a ”U”. As those shuttles ended up being some distance away from the valid zone (at minimum 80 centimeters away) their distance did not seem too important. Giving the value of ”U”, or out, a numerical value would not make alot of sense either, as the distances for the shuttles that landed outside the mat varied greatly. For those reasons it was decided that the amount of shuttles out would be documented, but when it came to working with averages and distances they would be left out. This ended up reducing the sample size of some analyses. The total sample size is still large, being reduced from 288 shuttles tested to 131 shuttles instead, and the sample size from the consistency group being reduced by much less from 76 shuttles down to 63 instead. The sample size however for the individual shuttles the sample sizes can be reduced to a factor that makes their results inaccurate and unusable.

The table below shows the data from the experiment after being adjusted as discussed in **3.4.1 Data Adjustments**. Data before adjustments can be found in **Appendix A**. In the table below ”Shuttle Nr.” refers to the number of the given shuttle as mentioned in **3.2.2 Shuttlecocks**, and ”Distance” refers to where the shuttle had landed on the mat. Distances marked with a ”U” refer to the shuttle not reaching the mat, and shuttle numbers and distances marked with a ”X” refer to the player not testing 12 shuttles, and the ”X”s are then marking that that shuttle number is blank. To give the players anonymity their names have been excluded and instead each player was given a number to differentiate them from each other.

The table below shows all data documented during the experiment, and can therefor be somewhat more difficult to read. It is placed below so that anyone can use that data for their own studies. To make it easier to read, the data will be cut down and specific questions answered in the next chapters and sub chapters.

The table below only shows where the shuttles came to a complete stop after testing. Data on where the shuttles first impacted the ground after testing is discussed in **4.4 Landing Differences**, and shown in **Appendix B**.

Player Nr.		1	2	3	4	5	6	7	8	9	10	11	12
1	Shuttle Nr.	4	1	15	6	5	18	17	16	3	14	13	2
	Distance	U	U	2	U	2	1	2	U	4	4	4	1
2	Shuttle Nr.	1	2	6	16	15	4	3	5	17	14	18	13
	Distance	U	U	U	U	U	U	U	U	U	U	2	3
3	Shuttle Nr.	13	14	18	3	5	17	16	15	4	2	1	6
	Distance	U	1	3	5	1	4	1	4	4	U	7	5
4	Shuttle Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
5	Shuttle Nr.	1	22	18	10	8	21	17	19	12	23	11	20
	Distance	U	8	9	5	6	7	6	10	13	10	4	5
6	Shuttle Nr.	1	19	11	10	17	8	21	22	18	23	12	20
	Distance	U	2	U	U	U	U	U	U	U	U	U	U
7	Shuttle Nr.	5	6	1	18	3	4	2	15	14	16	17	13
	Distance	3	U	3	2	U	U	U	U	2	U	U	U
8	Shuttle Nr.	16	18	14	5	1	6	3	15	2	13	4	17
	Distance	4	5	11	4	U	3	5	9	3	2	3	2
9	Shuttle Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
10	Shuttle Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
11	Shuttle Nr.	4	2	6	1	13	3	18	5	17	14	15	16
	Distance	U	2	5	9	5	11	11	7	11	9	9	U
12	Shuttle Nr.	16	1	17	18	3	14	5	15	4	2	13	6
	Distance	U	U	3	U	U	1	U	1	2	U	U	U
13	Shuttle Nr.	20	23	17	11	12	10	X	X	X	X	X	X
	Distance	U	5	1	7	5	6	X	X	X	X	X	X
14	Shuttle Nr.	21	8	9	7	22	19	X	X	X	X	X	X
	Distance	U	U	8	U	1	9	X	X	X	X	X	X
15	Shuttle Nr.	7	8	9	23	19	22	20	17	21	10	12	11
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
16	Shuttle Nr.	12	11	10	8	9	19	23	21	17	20	22	X
	Distance	U	U	9	10	6	4	4	3	U	4	2	X
17	Shuttle Nr.	10	8	12	9	20	23	19	21	22	11	17	X
	Distance	U	U	U	U	U	U	U	9	8	U	5	X
18	Shuttle Nr.	20	8	12	9	10	23	19	11	17	22	21	X
	Distance	U	4	U	7	U	4	4	U	2	U	3	X
19	Shuttle Nr.	20	12	9	8	23	21	17	22	19	11	10	X
	Distance	16	U	U	1	8	2	1	4	U	3	4	X
20	Shuttle Nr.	20	23	22	10	11	21	8	17	19	9	12	X
	Distance	U	1	2	1	4	5	2	U	6	4	4	X
21	Shuttle Nr.	20	19	21	9	11	12	8	22	23	10	17	X
	Distance	U	3	U	U	U	U	1	1	4	1	2	X
22	Shuttle Nr.	23	8	9	21	12	11	20	22	10	17	19	X
	Distance	1	U	1	1	4	U	9	8	1	3	8	X
23	Shuttle Nr.	22	23	17	20	8	11	21	10	19	12	X	X
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
24	Shuttle Nr.	22	23	17	20	8	11	21	10	19	12	X	X
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
25	Shuttle Nr.	22	21	20	19	12	8	17	23	18	10	1	11
	Distance	U	U	U	U	U	3	5	7	3	2	U	U
26	Shuttle Nr.	20	17	23	8	11	10	19	22	21	1	12	X
	Distance	2	2	5	4	U	1	2	2	3	U	3	X

Table 2: Adjusted results from experiment

4.2 Players

As mentioned before the skill level of the players did vary. As mentioned in the **2.3 Shuttlecock Testing**, during tournament play, certain number of players of considered average skill level for the tournament, are chosen to test shuttlecocks and determine whether the speed class is adequate for that tournaments environment.

4.2.1 Player Distances

A few players served the shuttles farther onto the mat, while others could not hit a single one onto it. We can condense **table 2** to make it easier to read the data on the players, removing unnecessary data such as shuttle numbers. This gives us the table below.

Player Nr	Average distance	Total Outs	Shuttles	In [%]
1	2,5	4	12	66,67%
2	2,5	10	12	16,67%
3	3,5	2	12	83,33%
4	0	12	12	0,00%
5	7,55	1	12	91,67%
6	2	11	12	8,33%
7	2,5	8	12	33,33%
8	4,64	1	12	91,67%
9	0	12	12	0,00%
10	0	12	12	0,00%
11	7,9	2	12	83,33%
12	1,75	8	12	33,33%
13	4,8	1	6	83,33%
14	6	3	6	50,00%
15	0	12	12	0,00%
16	5,25	3	11	72,73%
17	7,33	8	11	27,27%
18	4	5	11	54,55%
19	4,88	3	11	72,73%
20	3,22	2	11	81,82%
21	2	5	11	54,55%
22	4	2	11	81,82%
23	0	10	10	0,00%
24	0	10	10	0,00%
25	4	7	12	41,67%
26	2,67	2	11	81,82%
Average:	3.19	6	11	46,56%

Table 3: Average distance data from all players

In the table "average distance" is measured in measurement zones (2,5 would be somewhere within measurement zone 2, close to measurement zone 3), "total outs" refers to how many shuttles landed outside the mat, and "Shuttles" refers to how many shuttles that player tested.

The table shows that the average distance of most players does not lie within the valid shuttle testing range, which has been established previously as measurement zones 7 - 12. The only players that had an average distance within the valid zone were players numbered 5 and 17, however player numbered 17 only hit three of his shuttles onto the mat, so the sample size is too small to count.

Out of the 288 shuttles tested 156 landed outside of the mat. This means that approximately 54.2% of the shuttles tested did not reach the mat, and that the players testing had an average of 6 shuttles outside the mat. This is of course skewed due to some players not hitting any shuttles onto the mat, as seen on the table above, 6 of the players (players numbered 4, 9, 10, 15, 23, and 24) did not hit any shuttles onto the mat. No player hit all of their shuttles onto the mat, the best being players numbered 5, 8, and 13, which only hit a single shuttle outside the mat.

From the data shown in the table we can see that the average distance and percentage of shuttles hit onto the mat vary considerably. This data should be sufficient to answer the question set forth in **1.1 Problem Description**:

"Are the differences in results from testing shuttlecocks by different players significant?"

The data gathered from the players attending the Norwegian under 23 championship, their serving distances varied significantly, and therefor we can recognize that shuttles that one player might find to be fit to be used after testing, might not be a good fit for another player.

4.2.2 Consistency Group

As mentioned the number of shuttles every player hit outside the mat also varies greatly. This can skew the average distance data for each player, as it is calculated only with the data from the shuttles that landed onto the mat. It is therefor important to recognize which players were the most consistent. This is done by considering the factors discussed in **3.4.2 Data Consistency** to separate the more consistent players into a separate group called the consistency group. This results in the most consistent players being players numbered: 1, 3, 5, 8, 13, 20, and 26. The consistency group is extracted from **table 2** and **table 3** into the following tables below.

Player Nr.		1	2	3	4	5	6	7	8	9	10	11	12
1	Shuttle Nr.	4	1	15	6	5	18	17	16	3	14	13	2
	Distance	U	U	2	U	2	1	2	U	4	4	4	1
3	Shuttle Nr.	13	14	18	3	5	17	16	15	4	2	1	16
	Distance	U	1	3	5	1	4	1	4	4	U	7	5
5	Shuttle Nr.	1	22	18	10	8	21	17	19	12	23	11	20
	Distance	U	8	9	5	6	7	6	10	13	10	4	5
8	Shuttle Nr.	16	18	14	5	1	6	3	15	2	13	4	17
	Distance	4	5	11	4	U	3	5	9	3	2	3	2
13	Shuttle Nr.	20	23	17	11	12	10	X	X	X	X	X	X
	Distance	U	5	1	7	5	6	X	X	X	X	X	X
20	Shuttle Nr.	20	23	22	10	11	21	8	17	19	9	12	X
	Distance	U	1	2	1	4	5	2	U	6	4	4	X
26	Shuttle Nr.	20	17	23	8	11	10	19	22	21	1	12	X
	Distance	2	2	5	4	U	1	2	2	3	U	3	X

Table 4: Adjusted data from the consistency group

Player Nr	Average Distance	Total Outs	Sample Size
1	2.5	4	8
3	3.5	2	10
5	7.55	2	11
8	4.18	1	11
13	4.8	1	5
20	3.11	2	9
26	2.67	2	9
Average:	4.13	1.86	10.86

Table 5: Data from consistency group

In this table "Average Distance" again refers to the average measurement zone of the shuttles that landed on the mat, "Total Outs" refers to the number of shuttles the player landed outside the mat, and "Sample Size" refers to the number of shuttles the player hit onto the mat. This table shows us that from the most consistent players, only one had an average distance within the valid zone. The distances of the players still varies considerably, however the sample size and number of shuttles landed outside the mat stays mostly consistent.

The tables show that only seven of 26 players, or approximately 27 percent of the players, were deemed consistent. From this it can be concluded that the part of the players attending the experiment, most are not fit to test shuttlecocks.

The data can be used to to answer one of the questions put forth in **1.1 Problem Description**:

"Are most players consistent enough to test shuttlecocks effectively?"

The data gathered from the experiment most of the players who both attended the experiment, and the Norwegian under 23 Championship could not be considered consistent enough to test the shuttlecocks sufficiently, due to considerable differences in average shuttle serving distances.

It should be mentioned that the players deemed most consistent only includes players that hit most of their shuttles onto the mat. There were also some players that were consistent, and hit most of their shuttles close to each other, but landed all, or most, of their shuttles outside the mat. The ceiling height of the gymnasium was also lower than of the stadium where they were used to playing badminton, so some of the shuttles crashed into the ceiling and fell straight down and landing outside the mat. Some players that might normally be consistent were not due to this environmental factor.

4.3 Shuttles

Even though the experiment and the questions in the thesis mostly revolve around the player factor of when it comes to the testing of shuttlecocks, it can still be interesting to take a look at the shuttles tested themselves. As mentioned in **2.3 Shuttlecock Testing**, shuttles will alter over time, and all shuttles within the same tube are slightly different. This can result in some shuttles changing over time, resulting in them no longer filling the requirements for their assigned speed class anymore. Trying to analyse that data on the shuttles may prove more difficult since they are mixed with the data of each player. For this reason it might be smarter to only use the data from the consistency group for most of the analyses done on the shuttles.

4.3.1 Brands

When looking at the data for the two brands used (FZ Forza and RSL Classic) only the results from the consistency group are considered. The consistency group tested 76 shuttles in total, where 36 were RSL Classic shuttles, and 40 were FZ Forza shuttles. Out of the 76 shuttles tested 13 landed outside the mat. These 13 shuttles have been removed from the calculations done with the consistency group data, leaving 35 FZ Forza shuttles and 28 RSL Classic shuttles. Plotting the data from the consistency group into a box plot makes it easier to view the differences between the two brands.

Figure 8: Box plot of distances of each shuttle brand

The box plot above shows the different spreads of distances for each shuttle brand, based on the data gathered from the consistency group. From the simplified distances, the RSL Classic shuttles reached the average distance of 4.04 and the FZ Forza shuttles had an average distance of 4.2. This means that the shuttles from both brands traveled on average somewhere between 11.91 - 12.01 meters, but the FZ Forza shuttles travel slightly farther. It can also be seen from the box plot that the FZ Forza shuttles had a larger spread than the RSL Classic shuttles tested, however the one dot above the RSL Classic shuttles shows that the shuttles that traveled the farthest was a RSL Classic shuttle. This one case says little about the brands and is most likely just due to the player serving. It should be noted that there is a difference in sample size for each brand, and this can change the outcome somewhat.

Another effect of the FZ Forza shuttles being more spread, and traveling somewhat further is that there were more FZ Forza branded shuttles within the valid zones. From the consistency group nine shuttles landed within the valid zone, seven of those shuttles were FZ Forza shuttles (shuttles numbered 14, 15, 18, 19, 21, 22, and 23), while only two of the shuttles were RSL Classic shuttles (shuttles numbered 1 and 11).

The data can be used to answer the question posed in **1.1 Problem Description**:

Is there a large difference between shuttlecock brands?

From the data gathered by the consistency group in this experiment the average distance of shuttles was not large, however the spread of shuttles did vary between brands. The difference between the brands can however not be considered large enough to be considerable. From this data it can be assumed that the shuttlecock brand would not change the results of the experiment enough to be considered. It could however be interesting to test more different brands to see if there is any considerable difference between them.

4.3.2 Individual Shuttles

The table below shows the data for each shuttle tested by the consistency group. There were some shuttles that the consistency group ended up not testing, both by chance and by the shuttles getting lost before the members tested them. These shuttles are numbered seven and 24. It should be noted that due to loss of some shuttles others were used more often to try to keep the amount of shuttles each player tests close to the same amount, therefor it can be seen that most shuttles were tested the same amount of times (between three and five times each shuttle) while the shuttle numbered 17 was used more than the others since it was supplemented for lost shuttles.

Shuttle nr.	Brand	Average distance	Total Outs	Total Shuttles	Sample Size
1	FZ	7	4	5	1
2	FZ	2	1	3	2
3	FZ	4,67	0	3	3
4	FZ	3,5	1	3	2
5	FZ	2,33	0	3	3
6	FZ	4	1	3	2
7	FZ	0	0	0	0
8	FZ	4	0	3	3
9	FZ	4	0	1	1
10	FZ	3,25	0	4	4
11	FZ	5	1	4	3
12	FZ	6,25	0	4	4
13	RSL	3	1	3	2
14	RSL	5,33	0	3	3
15	RSL	5	0	3	3
16	RSL	2,5	1	3	2
17	RSL	2,83	1	7	6
18	RSL	4,5	0	4	4
19	RSL	6	0	3	3
20	RSL	3,5	2	4	2
21	RSL	5	0	3	3
22	RSL	4	0	3	3
23	RSL	5,25	0	4	4

Table 6: Shuttle data from consistency group

It should be noted from the data in the table that the column named "Sample Size" refers to the amount of shuttles that landed on the mat and were measured. The average distance in the table only considers distances recorded and excludes the shuttles that landed outside the mat.

The average distances of most of the shuttles on the table should therefor, for the most part, be ignored, as the sample size for most of them is too small.

The graph below compares the average distances and sample sizes of each individual shuttle between only data gathered from the consistency group against data gathered from all players.

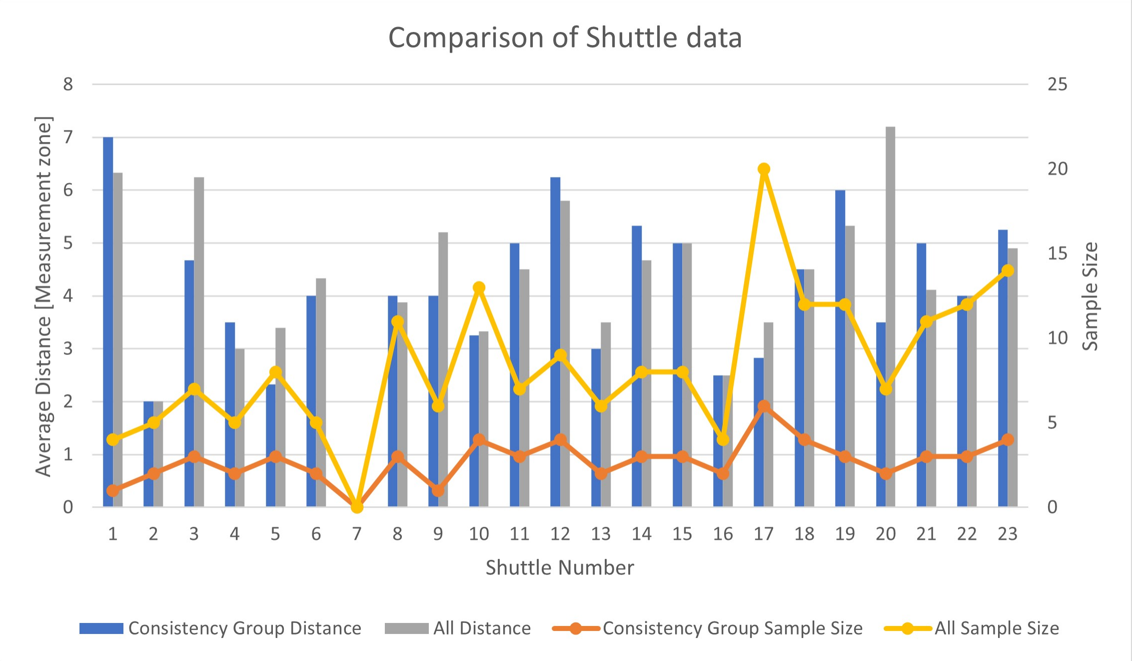


Figure 9: Comparison of data from the consistency group against data from all players.

The graph shows the differences in average distances and sample sizes for each shuttle when using only the data gathered by the consistency group and when using all the data gathered from the experiment. It can be seen that the biggest changes are for shuttle numbered 3, 9 and 20. The graph shows us that there are some changes when data from all players is taken into account, instead of only the data from the consistency group, as well as increasing the sample size of most shuttles to a size that could be used to analyse the average distance. A negative is that when using the data from all the players the data gets some what skewed as discussed in **4.3 Shuttles**.

The data can be used to answer the question posed in **1.1 Problem Description**:

Is the difference between each shuttle in a tube considerable?

The data collected from the consistency group gives a small sample size for each shuttle, and using data from all players introduces inaccuracies. A definite answer to the question can not be concluded, as using the data from the consistency group will likely only show that the different players served the shuttles different distances, and that the differences then in average distances between shuttles falls mostly on the players that served them.

4.3.3 Condition of Shuttles

The condition of each shuttle was noted after the experiment had concluded. The results are shown on the table below.

Shuttle Nr.	Effected feathers	Times tested
1	Broken	14
2	0	10
3	0	10
4	0	10
5	3	10
6	2	10
7	Lost	2
8	1	15
9	Lost	9
10	3	15
11	0	15
12	4	15
13	3	10
14	3	10
15	3	10
16	2	10
17	7	25
18	Broken	13
19	3	15
20	5	15
21	1	15
22	2	15
23	3	15

Table 7: Condition of all shuttles Post-Experiment

The table shows that after the experiment had concluded two shuttles had broken feathers. There were also some shuttles that had many feathers that were damaged or affected and might not be suitable for further use, some might not even be suitable for use during exercises or casual play. The shuttles numbered 7 and 9 were tested fewer times than the other shuttles due to getting stuck in the rafters attached to the ceiling in the gymnasium. Shuttles numbered 1 and 18 were also not tested as often due to being broken, however they might have been taken out of play later than they should. To try to have each player test approximately the same amount of shuttles other shuttles were supplemented for the damaged/lost ones, this is why shuttle numbered 17 was used significantly more often than any other shuttle.

As the condition of the shuttles was only documented after the experiment had concluded, it is difficult to make a clear correlation between times tested and the final condition of the shuttles. It would have been interesting to see, and is recommended for later experiments. It is also difficult to make a clear correlation between times tested and the condition of the shuttle as players hit the shuttle with a varying degree of force. The damage therefor to the shuttle will vary from player to player.

The conditions of the shuttles however can be used as data when developing a shuttlecock sorting device, as the degree of the shuttlecock condition can be used as a factor to decide whether the shuttle can be used for tournaments, for casual play, or for neither.

4.4 Landing Differences

All results above use the data for distance of where the shuttles ended up when they came to stop instead of where the shuttles initially impacted the ground after being served. This is how it is done currently, as a player will be able to see where the shuttle first impacts the ground, but when the player is serving the shuttle over 12 meters away he will not be able to recognize whether the shuttle landed within the valid zone, or whether it landed a few centimeters outside the valid zone. It is difficult to sort this in either under results for shuttles or for players as both will most likely have an effect on how the shuttle bounces.

By using the videos recorded on the Ipad, the initial impact to the ground was documented and compared to where the shuttle came to a complete stop. The table with all data is large and can therefor be found in **Appendix B**. From the data in the table it is calculated that on average each shuttle moved 1.26 measurement zones between where it first impacted the ground and where it came to a stop.

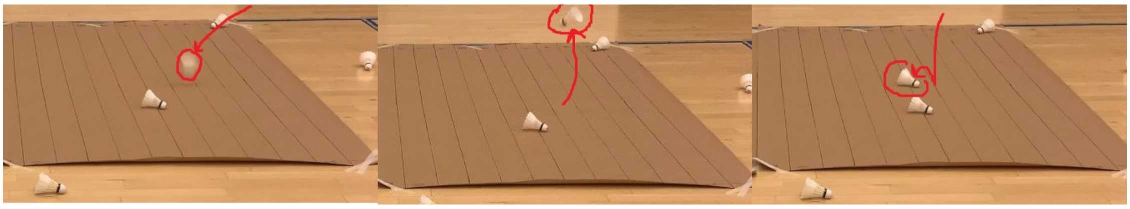


Figure 10: Progress of a shuttle bouncing on the ground

The camera that was used to record the mat, recording where the shuttles impact the ground, was not made to film slow motion video, therefor images taken from the video can be somewhat blurry, however it is possible by watching the videos to determine within which measurement zone the shuttle impacted first before bouncing.

It is somewhat more difficult to create graphs when it comes to this subject, and therefor easier to take into account players instead. It is therefor chosen to only focus on the consistency group.

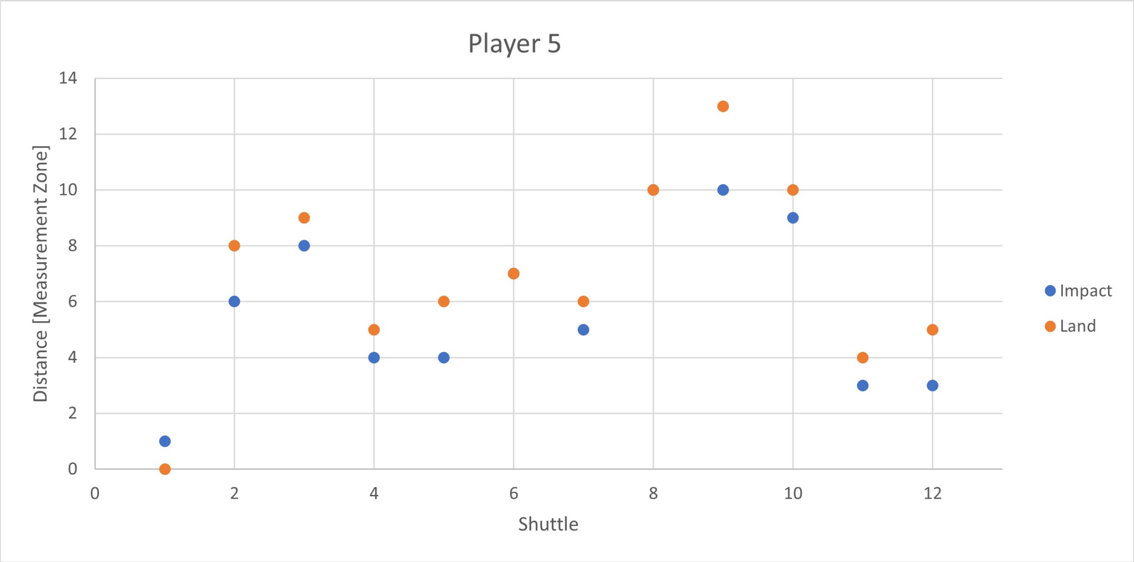


Figure 11: Impact and Landing Comparison for Player 5

The figure above shows how the shuttles that player numbered 5 tested. The blue dots called "Impact" represent in which measurement zone the shuttles first impacted the ground when it was tested, and the orange dots called "Land" represent where the same shuttles came to full stop and were recorded.

From the graph it can be seen that not all shuttles did move a full measurement zone after bouncing (shuttles numbered 3 and 8 on graph), but most shuttles did. It can also be seen that not all shuttles bounce further onto the mat, as shuttle numbered 1 on the graph does bounce off of the mat and ends up counting as a shuttle outside the mat in the final data for player 5.

Similar graphs for the other consistency group members can be found in **Appendix C**.

The data can be used to give an answer for the question posed in **1.1 Problem Description**:

Is the difference between where the shuttles first impact the ground and where they stop moving considerable?

From the data gathered it can be said that there is a difference between where the shuttle first impacts the ground and where it comes to a complete stop. The difference does vary and in some cases from the data gathered it can be seen that the shuttles sometimes impact and stop in the same measurements zone, however from all the data gathered it was calculated that on average distance between where the shuttle impacted the ground and where it came to a full stop was 1.26 measurement zones (between 10 - 20 centimeters). As the valid zone is only 46 centimeters long this distance can be seen as considerable. The differences in the distances can effect whether a shuttle is deemed within the valid zone or not.

5 Discussion

As results from the experiment have been presented and discussed in their separate chapter, this chapter will focus mostly on discussing separate factors from the experiment. Some of these factors are choices that were made before the experiment, when designing the experiment, and some during or after the experiment.

5.1 Shuttlecock Testing

There are some factors that were present during testing that should be discussed. As mentioned in **3.1 Experiment Description** the players that were not familiar with testing shuttles were told to perform a underhand serve directed towards the mat on the other side of the court. There were many players that were unfamiliar with the testing of shuttles, and discussions with players a few weeks after the experiment revealed that there were some players who were familiar with testing but did not understand that it was what they were supposed to do. This will have altered some of the data that was gathered during the experiment, as the players that might have been familiar with testing shuttlecocks, but did not understand that that was what they were to do would have performed a different serve then when they would when regularly testing shuttles.

Another factor was to discuss is that some players did not understand the concept of the experiment, and some believed it to be more of a game or a challenge. The concept of the experiment was introduced to all players before they were to test, and it was emphasised to the players that the goal was not necessarily for them to try to hit each shuttle onto the mat, but instead to test the shuttles as they would normally, and aim it in the direction of the mat as it would be easier that way to measure the distance afterwards. Discussions with some players after the experiment revealed that some of them believed it to be a game to get as many of the shuttles as possible onto the mat, with such comments as **"Did anyone get all of the shuttles on the mat?"** and **"Did anyone beat my score?"**. An idea to fix this was to obstruct the players view of the mat, for example with a object in the way the same size as the net, so that they might need to hit over it, and not be able to see whether the shuttle landed on the mat or not. This would however pose the problem that some players would test the shuttles lower, which would then hit the object, or that players should be able to adjust the power that they test the shuttles with, but they should not get discouraged if they did not hit any shuttles onto the mat.

Another factor was that the ceiling of the gymnasium used was lower than that of the stadium where badminton is usually played in Dragvoll. This along with the factor of not all players knowing how to test shuttles, ended in some shuttles hitting the ceiling, stopping and falling straight to the ground, effectively not letting them fly as far as they would have, along with a couple of shuttles getting stuck in the rafters attached to the ceiling and being lost. There were some players that ended with more shuttles outside the mat due to this factor, so it can be assumed that it effected their results.

5.2 Simplification of Data

The simplification of the measuring system during the experiment is used to make it easier to work with (simpler numbers) and to make it much faster to document the travel distance of each shuttle during the experiment, which was in some cases time restrained due to the experiment being held during a tournament, and players not wanting to waste their time with the experiment. It is also due to the cameras used not being ideal for doing accurate measuring, both for where the shuttles would initially impact the ground when tested, and of the players position when they serve the shuttle.

The simplification of the data does also introduce minor inaccuracies of the measurements. Instead of measuring how far the shuttles travel from where the player serves them it tells us in what distance range the shuttle landed in. That means there is a maximum of 10 centimeter, and then there is the question on what part of the shuttle is where you determine where it is. If the shuttles were to land between two distance zones, which one would it be documented in? For this experiment it was determined that the shuttle is documented in the distance zone that the entirety of the shuttles cork head is, or if the cork head is not entirely in the same zone, then the shuttle is documented where the majority of its body is located in.

This simplification also comes in effect when the data was adjusted according to if the shuttle was impacted by the racked beyond the marked line. The amount of length each player served over the line differed, and moving the final landing spot of the shuttle by an entire measurement zone (10 centimeters) might be suited for some, but might be somewhat extreme for others.

It can also be more difficult to interpret the data in some cases when it is simplified. The shuttles that did not reach the mat were marked as out or with ”U”s, which makes them more difficult to use. The question is do you use them when calculating averages or do you put them to the side and only use the shuttles that landed on the mat and were measured? If you only use the shuttles that were measured then you might get higher averages but with a smaller sample size, and then you would need to redo a sample analysis, to see if the sample size is large enough for a valid analysis. If you will use the shuttles that landed outside the mat, then what value do you give them? Since they are all marked as the same value, an out or ”U”, then you cannot differentiate between the shuttles that barely made it onto the mat, and those that landed a meter or more from it. A more accurate measurement system, such as just measuring to absolute distance of the shuttle, would have given better data in that case, but would have taken more time, as well as would required better a better camera to pin point where the shuttle first impacted the ground.

5.3 Condition of Shuttlecocks

The condition of the shuttlecocks might not have been the best, as when discussed with a player that did testing he found them to not be optimal, as well as after inspecting the shuttles after the testing it was inspected that some had broken. A way to have fixed this would be to document the condition of each shuttle after they were tested, both to see how they are affected by each player, seeing how long they last, and to avoid players using shuttles that are not in proper condition to be used in a tournament.

There is also an argument in that the tubes of shuttles were opened the day before use to be numbered and marked, placed back into their tubes, and left in a cold dry room until use. As the shuttles were not kept in a humid room, nor steamed before the experiment, they might have been drier than they ideally should be, and that might have affected the results from the experiment.

5.4 Collecting More Data

The data gathered was shuttle distance and how the player served the shuttle.

Additional information could be interesting to see in similar experiments to compare between players as for example: the players height, the players arm span, age, how long they had been playing badminton, and their skill-level. In this experiment, the names of the players was noted, and later their rankings from ”badmintonportalen.no”, however to keep player anonymity in the thesis, it was not published. It should also be noted that due to the COVID-19 virus shutting down or restricting some tournaments the data from the website might not be very accurate or very useful.

If further study is to be done on the differences in shuttles, then other factors could be collected, such as: The weight of each shuttle pre-experiment, the condition of each shuttle after a player has tested them, shuttles being tested more often to have a larger sample size, and more brands tested.

Other factors that might be interesting are the environmental factors. The gymnasium that was used had its temperature regulated to 18 degrees Celsius, however using a room or gymnasium that did not regulate its temperature, or just changing the temperature could yield different results. The experiment was also only done in one gymnasium, so it would also be interesting to attempt the experiment at another location, to see if to what degree altitude might have changed the results.

6 Conclusion

The experiment was done at Norways championship under 23 tournament in Dragvoll, Trondheim, where players were taken aside between their games and made to perform shuttlecock tests. The players serves and the landings of the shuttles were filmed and documented.

From the experiment data was collected on the shuttlecock distances and the players servings on video. From the data gathered it can be determine that the differences in shuttlecock testing between players varied considerably, and that from the players attending the tournament a majority could not be consider consistent enough to test shuttlecocks. For the two brands of shuttlecocks there was little difference in average travel distance, and little can be said about the individual shuttles, as the sample size of each shuttle was not large enough to make assumptions about. There were some factors that affected the final results, such as players not understanding their task in the experiment, players not being familiar with testing shuttlecocks, and shuttles not being in ideal condition. The data might have been further affected by the simplification of data and data adjustments. From the results gathered it can clearly be seen that the procedure of testing shuttlecocks should be altered. It is recommended that a device is developed to sort shuttlecocks into different speed classes, and can be used both in larger and smaller tournaments.

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Appendix

A Data Before Adjustments

Pers Nr.		1	2	3	4	5	6	7	8	9	10	11	12
1	Ball Nr.	1	4	6	16	17	18	2	15	14	13	3	5
	Distance	U	U	U	U	3	2	2	3	5	5	5	3
2	Ball Nr.	1	2	6	16	15	4	3	5	17	14	18	13
	Distance	U	U	U	U	U	U	U	U	U	1	3	3
3	Ball Nr.	13	2	16	14	5	4	15	17	18	6	3	1
	Distance	U	U	1	1	1	4	4	4	4	5	6	7
4	Ball Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
5	Ball Nr.	1	20	11	10	17	8	21	22	19	18	23	12
	Distance	1	5	5	6	7	7	7	9	10	10	11	13
6	Ball Nr.	1	19	11	10	17	8	21	22	18	23	12	20
	Distance	U	3	U	U	U	U	U	U	U	U	U	U
7	Ball Nr.	17	13	2	15	16	6	3	18	1	14	5	4
	Distance	U	U	U	U	U	U	U	2	3	3	4	U
8	Ball Nr.	3	1	18	5	16	13	6	17	2	4	14	15
	Distance	4	U	4	4	4	2	2	2	3	3	10	8
9	Ball Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
10	Ball Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
11	Ball Nr.	16	4	2	13	6	5	15	14	3	18	17	1
	Distance	U	U	2	6	6	8	10	10	12	12	11	10
12	Ball Nr.	5	2	13	18	1	16	3	6	14	15	4	17
	Distance	U	U	U	U	U	U	U	U	2	2	3	4
13	Ball Nr.	20	17	12	11	10	23	X	X	X	X	X	X
	Distance	U	1	5	7	6	5	X	X	X	X	X	X
14	Ball Nr.	21	8	9	7	22	19	X	X	X	X	X	X
	Distance	U	U	8	U	1	9	X	X	X	X	X	X
15	Ball Nr.	7	8	9	23	19	22	20	17	21	10	12	11
	Distance	U	U	U	U	U	U	U	U	U	U	U	U
16	Ball Nr.	12	11	17	21	22	19	23	20	9	10	8	X
	Distance	U	U	U	3	3	4	4	5	6	9	10	X
17	Ball Nr.	10	8	12	9	20	23	19	11	17	22	21	X
	Distance	U	U	U	U	U	U	U	U	4	7	8	X
18	Ball Nr.	20	10	11	12	22	17	21	23	8	9	19	X
	Distance	U	U	U	U	U	2	3	4	4	7	4	X
19	Ball Nr.	12	9	19	17	8	21	11	10	22	23	20	X
	Distance	U	U	U	1	1	2	3	4	4	8	16	X
20	Ball Nr.	20	17	10	23	22	8	12	11	9	21	19	X
	Distance	U	U	1	1	2	2	3	4	4	5	6	X
21	Ball Nr.	20	11	9	21	22	12	10	8	17	19	23	X
	Distance	U	U	U	1	2	1	2	2	3	4	5	X
22	Ball Nr.	11	8	10	21	23	17	12	9	22	20	19	X
	Distance	U	U	2	2	2	4	5	2	9	10	9	X
23	Ball Nr.	22	23	17	20	8	11	21	10	19	12	X	X
	Distance	U	U	U	U	U	U	U	U	U	U	X	X
24	Ball Nr.	23	22	17	20	8	11	21	10	19	12	X	X
	Distance	U	U	U	U	U	U	U	U	U	U	X	X
25	Ball Nr.	22	21	12	1	20	11	19	10	8	18	17	23
	Distance	U	U	U	1	U	U	U	2	3	3	6	7
26	Ball Nr.	1	11	10	17	22	19	21	8	23	12	20	X
	Distance	U	U	2	3	3	3	4	5	6	4	3	X

Table 8: Documented Data Before Adjustments

B Data of Shuttle Impacts

Pers Nr.		1	2	3	4	5	6	7	8	9	10	11	12
1	Ball Nr.	4	1	15	6	5	18	17	16	3	14	13	2
	Imp	U	U	2	U	U	1	U	U	2	4	2	U
	Land	U	U	2	U	2	1	2	U	4	4	4	1
2	Ball Nr.	1	2	6	16	15	4	3	5	17	14	18	13
	Imp	U	U	U	U	U	U	U	U	U	1	U	U
	Land	U	U	U	U	U	U	U	U	U	U	2	3
3	Ball Nr.	13	14	18	3	5	17	16	15	4	2	1	6
	Imp	U	U	3	4	U	4	1	3	1	1	5	3
	Land	U	1	3	5	1	4	1	4	4	U	7	5
4	Ball Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Imp	U	U	U	U	U	U	U	U	U	U	U	U
	Land	U	U	U	U	U	U	U	U	U	U	U	U
5	Ball Nr.	1	22	18	10	8	21	17	19	12	23	11	20
	Imp	1	6	8	4	4	7	5	10	10	9	3	3
	Land	U	8	9	5	6	7	6	10	13	10	4	5
6	Ball Nr.	1	19	11	10	17	8	21	22	18	23	12	20
	Imp	U	U	U	U	U	U	U	U	U	U	U	U
	Land	U	2	U	U	U	U	U	U	U	U	U	U
7	Ball Nr.	5	6	1	18	3	4	2	15	14	16	17	13
	Imp	U	U	U	U	U	U	U	U	U	U	U	U
	Land	3	U	3	2	U	U	U	U	2	U	U	U
8	Ball Nr.	16	18	14	5	1	6	3	15	2	13	4	17
	Imp	3	2	9	3	U	1	2	8	1	U	1	1
	Land	4	4	10	4	U	2	4	8	3	2	3	2
9	Ball Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Imp	U	U	U	U	U	U	U	U	U	U	U	U
	Land	U	U	U	U	U	U	U	U	U	U	U	U
10	Ball Nr.	1	2	3	4	5	6	13	14	15	16	17	18
	Imp	U	U	U	U	U	U	U	U	U	U	U	U
	Land	U	U	U	U	U	U	U	U	U	U	U	U
11	Ball Nr.	4	2	6	1	13	3	18	5	17	14	15	16
	Imp	U	U	3	6	3	7	9	3	10	9	9	U
	Land	U	2	5	9	5	11	11	7	11	9	9	U
12	Ball Nr.	16	1	17	18	3	14	5	15	4	2	13	6
	Imp	U	U	1	U	U	1	U	1	1	U	U	U
	Land	U	U	3	U	U	1	U	1	2	U	U	U
13	Ball Nr.	20	23	17	11	12	10	X	X	X	X	X	X
	Imp	U	3	U	5	4	5	X	X	X	X	X	X
	Land	U	5	1	7	5	6	X	X	X	X	X	X
14	Ball Nr.	21	8	9	7	22	19	X	X	X	X	X	X
	Imp	U	U	6	U	1	8	X	X	X	X	X	X
	Land	U	U	8	U	1	9	X	X	X	X	X	X
15	Ball Nr.	7	8	9	23	19	22	20	17	21	10	12	11
	Imp	U	U	U	U	U	U	U	U	U	U	U	U
	Land	U	U	U	U	U	U	U	U	U	U	U	U
16	Ball Nr.	12	11	10	8	9	19	23	21	17	20	22	X
	Imp	U	U	7	7	4	4	1	3	U	4	U	X
	Land	U	U	9	10	6	4	4	3	U	4	2	X
17	Ball Nr.	10	8	12	9	20	23	19	21	22	11	17	X
	Imp	U	U	U	U	U	U	U	9	7	U	2	X
	Land	U	U	U	U	U	U	U	8	7	U	4	X

Pers Nr.		1	2	3	4	5	6	7	8	9	10	11	12
18	Ball Nr.	20	8	12	9	10	23	19	11	17	22	21	X
	Imp	U	2	U	3	U	2	2	U	1	U	2	X
	Land	U	4	U	7	U	4	4	U	2	U	3	X
19	Ball Nr.	20	12	9	8	23	21	17	22	19	11	10	X
	Imp	13	U	U	U	6	1	1	2	U	3	2	X
	Land	16	U	U	1	8	2	1	4	U	3	4	X
20	Ball Nr.	20	23	22	10	11	21	8	17	19	9	12	X
	Imp	U	2	U	1	2	5	1	U	6	2	1	X
	Land	U	1	2	1	4	5	2	U	6	4	3	X
21	Ball Nr.	20	19	21	9	11	12	8	22	23	10	17	X
	Imp	U	1	1	U	U	U	U	U	1	U	U	X
	Land	U	3	U	U	U	U	1	1	4	1	2	X
22	Ball Nr.	23	8	9	21	12	11	20	22	10	17	19	X
	Imp	1	U	U	U	1	U	8	8	1	2	6	X
	Land	1	U	1	1	4	U	9	8	1	3	8	X
23	Ball Nr.	22	23	17	20	8	11	21	10	19	12	X	X
	Imp	U	U	U	U	U	U	U	U	U	U	X	X
	Land	U	U	U	U	U	U	U	U	U	U	X	X
24	Ball Nr.	22	23	17	20	8	11	21	10	19	12	X	X
	Imp	U	U	U	U	U	U	U	U	U	U	X	X
	Land	U	U	U	U	U	U	U	U	U	U	X	X
25	Ball Nr.	22	21	20	19	12	8	17	23	18	10	1	11
	Imp	U	U	U	U	U	1	5	6	2	1	U	U
	Land	U	U	U	U	U	3	5	7	3	2	U	U
26	Ball Nr.	20	17	23	8	11	10	19	22	21	1	12	X
	Imp	1	U	4	U	U	U	1	1	2	U	1	X
	Land	2	2	5	4	U	1	2	2	3	U	3	X

Table 9: Impact and Landing Data

C Impact and Landing Comparison Graphs of Consistency Group Members

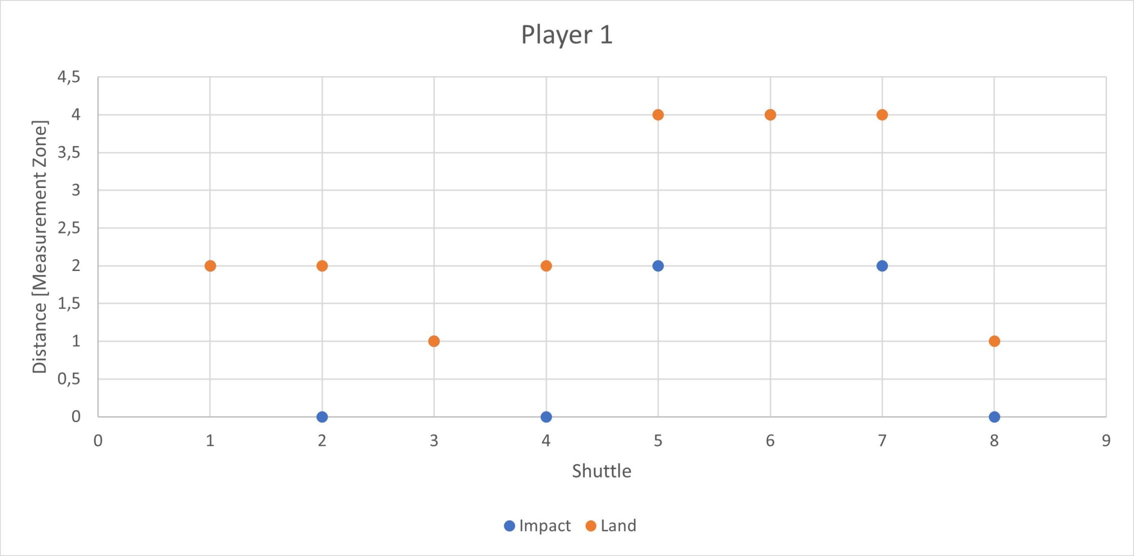

Figure 12: Impact and Landing Comparison for Player 1

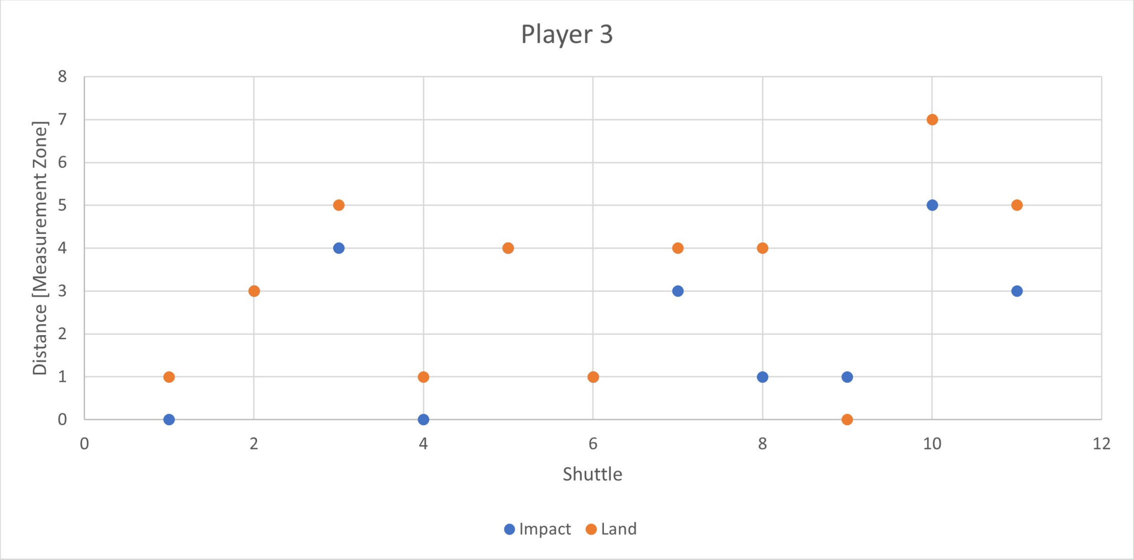

Figure 13: Impact and Landing Comparison for Player 3

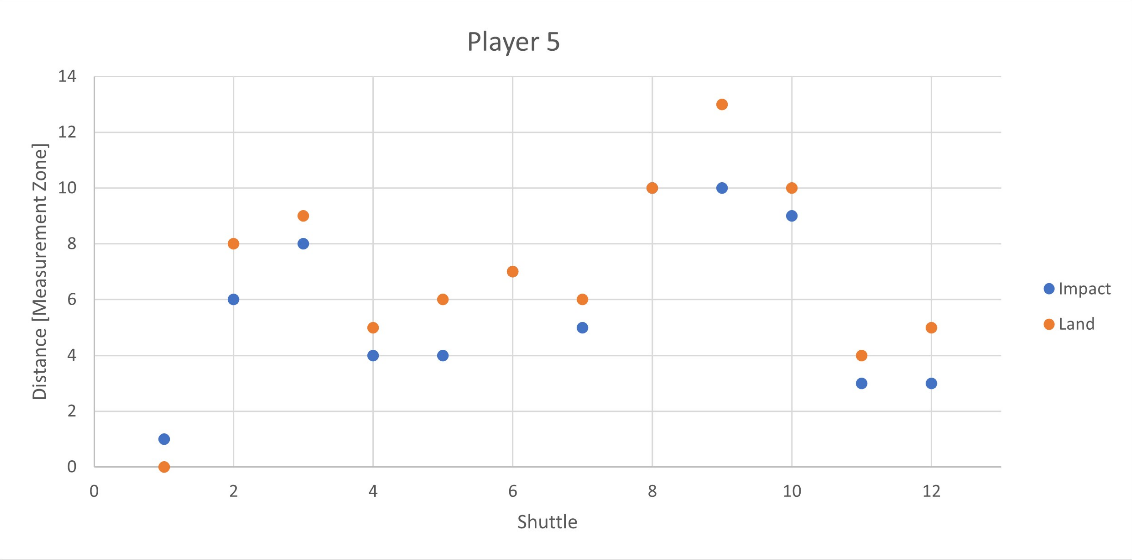

Figure 14: Impact and Landing Comparison for Player 5

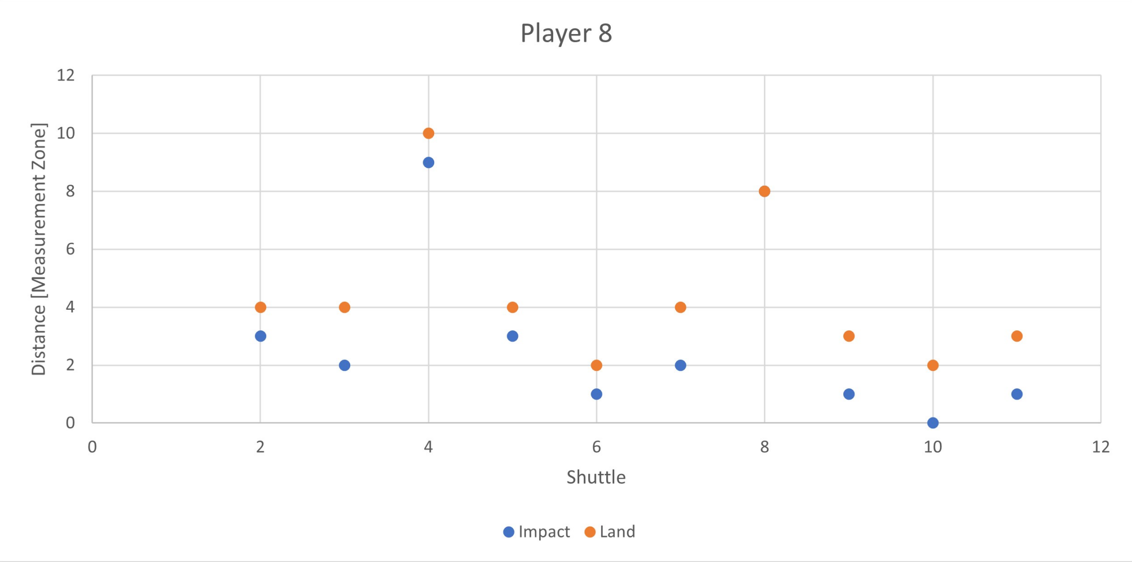

Figure 15: Impact and Landing Comparison for Player 8

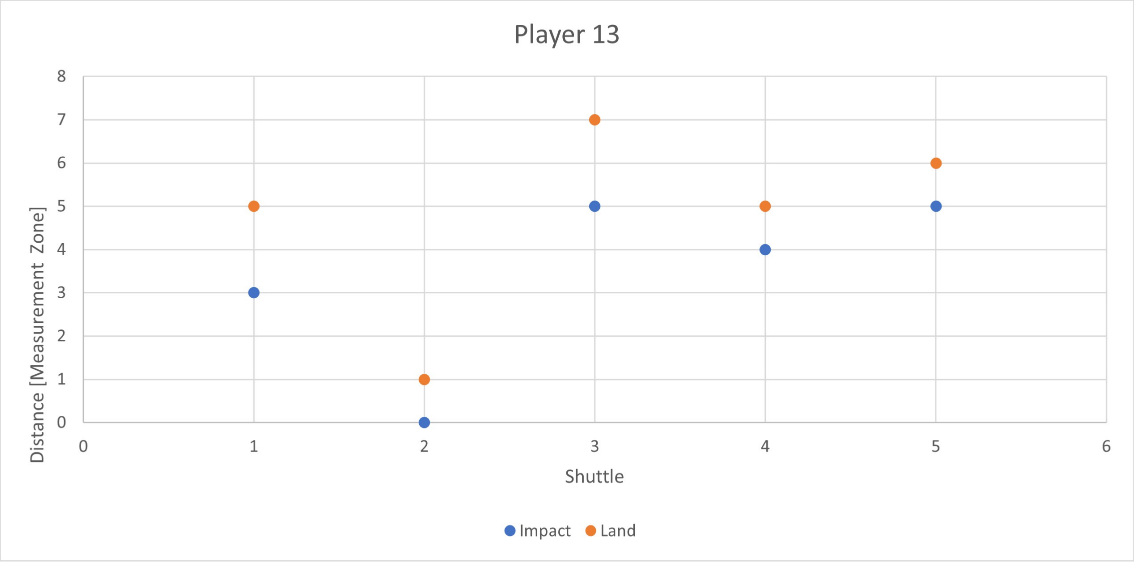

Figure 16: Impact and Landing Comparison for Player 13

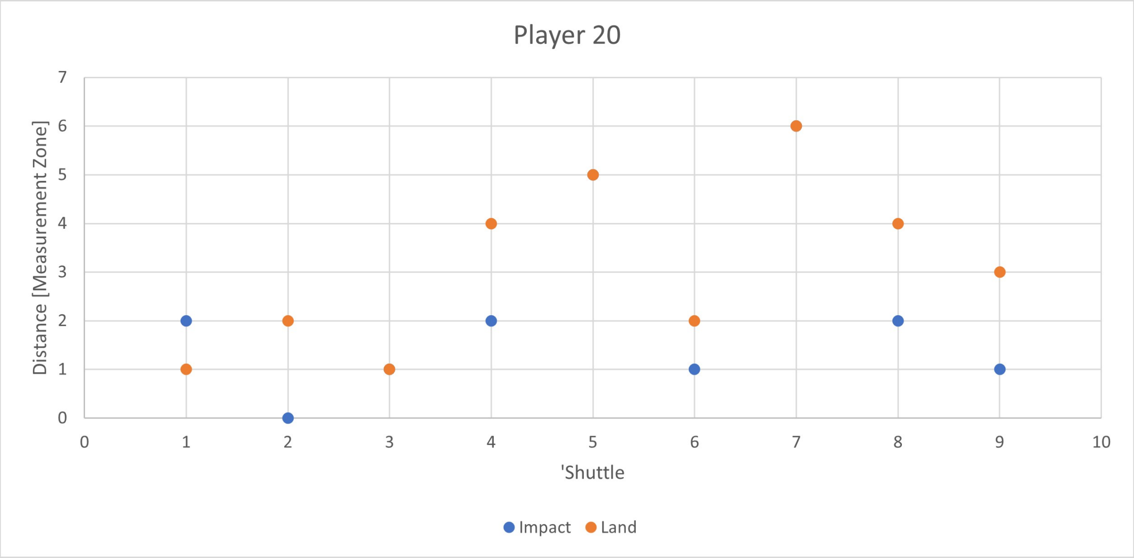

Figure 17: Impact and Landing Comparison for Player 20

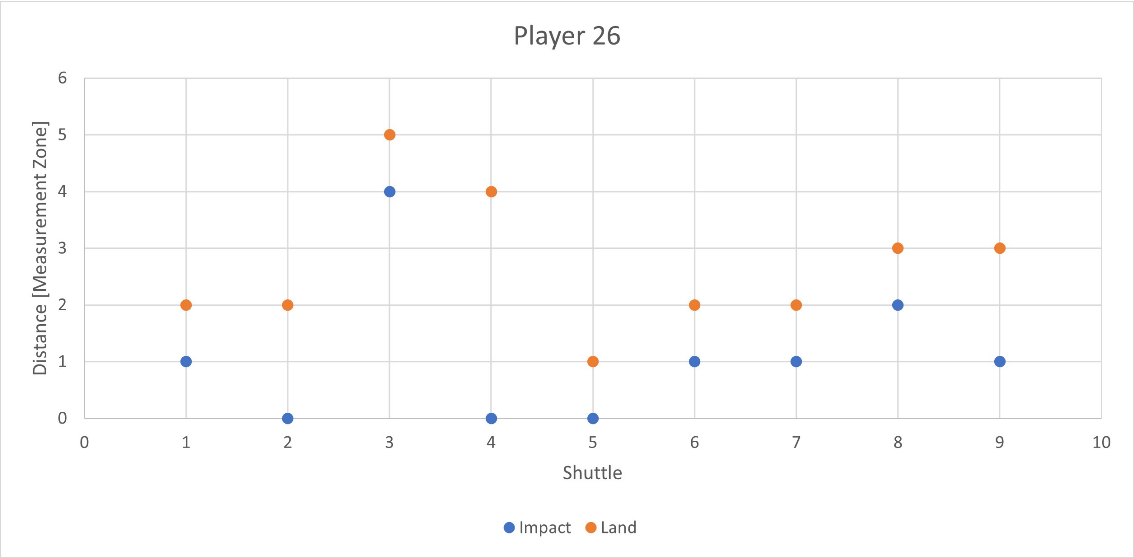

Figure 18: Impact and Landing Comparison for Player 26

D Final Shuttle Location Photos

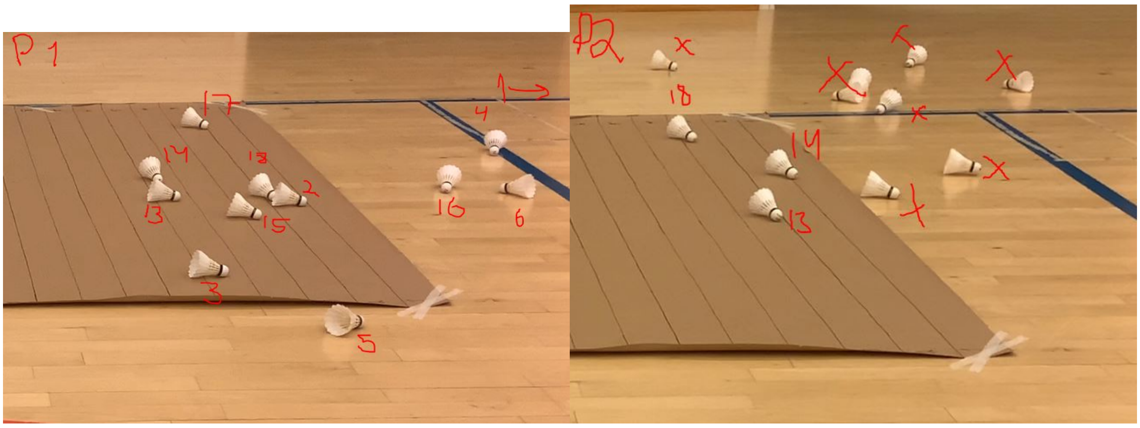

Figure 19: Final Shuttle Position: Player 1 and Player 2

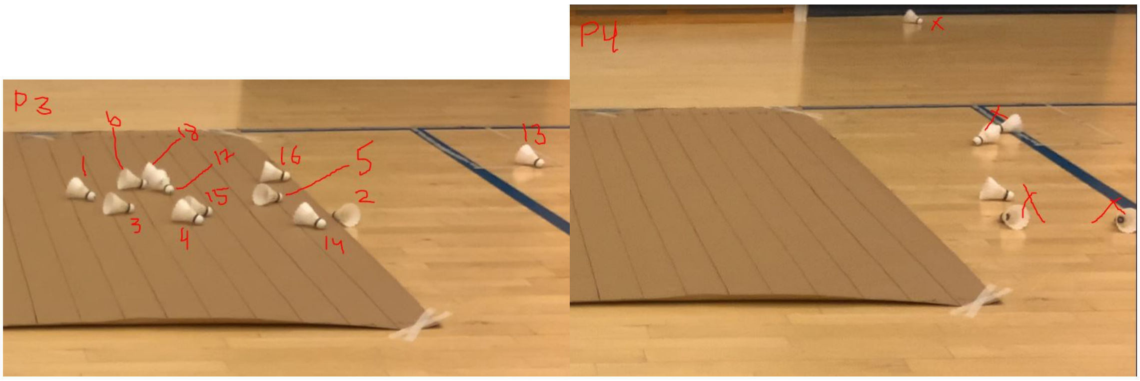

Figure 20: Final Shuttle Position: Player 3 and Player 4

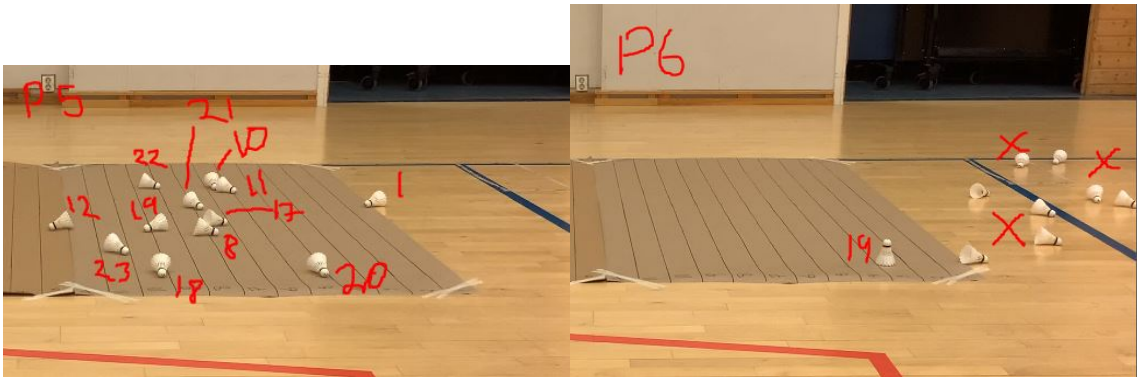

Figure 21: Final Shuttle Position: Player 5 and Player 6

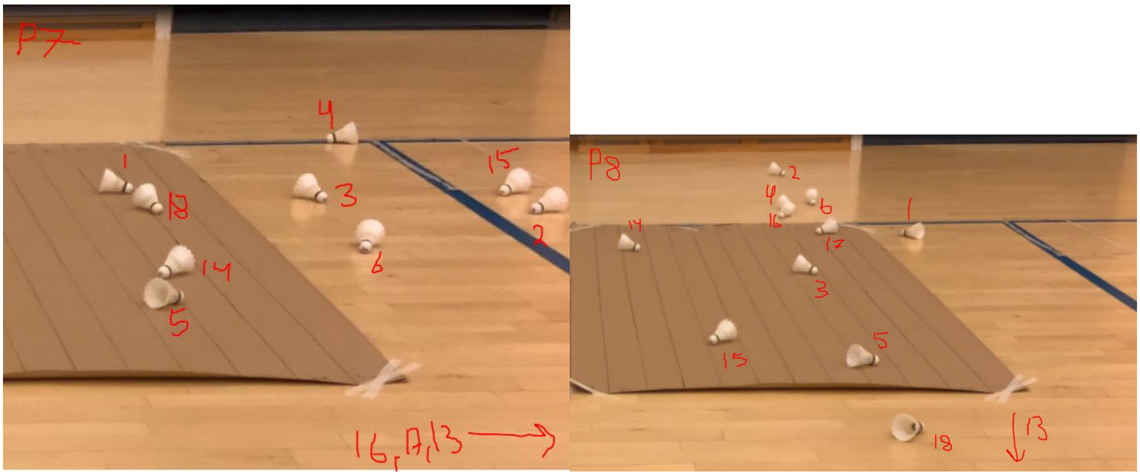

Figure 22: Final Shuttle Position: Player 7 and Player 8

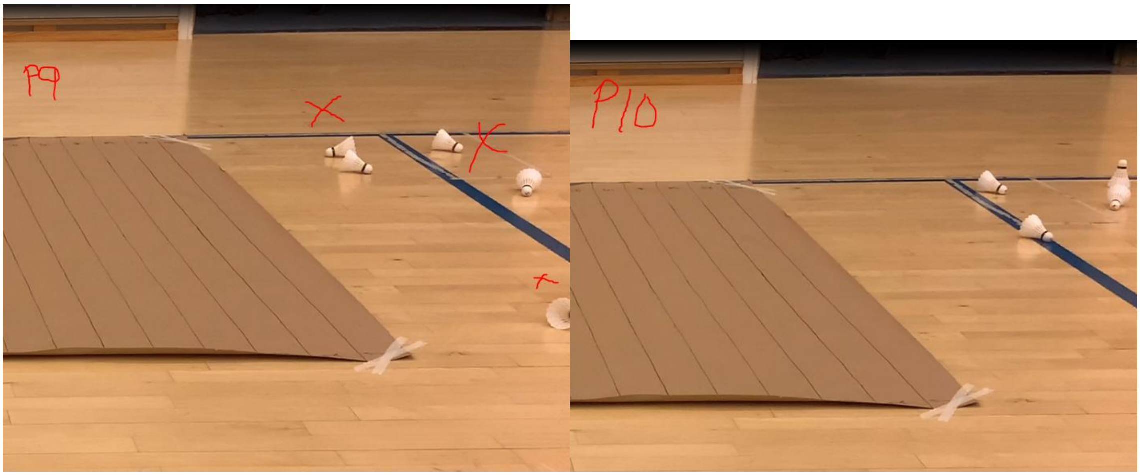

Figure 23: Final Shuttle Position: Player 9 and Player 10

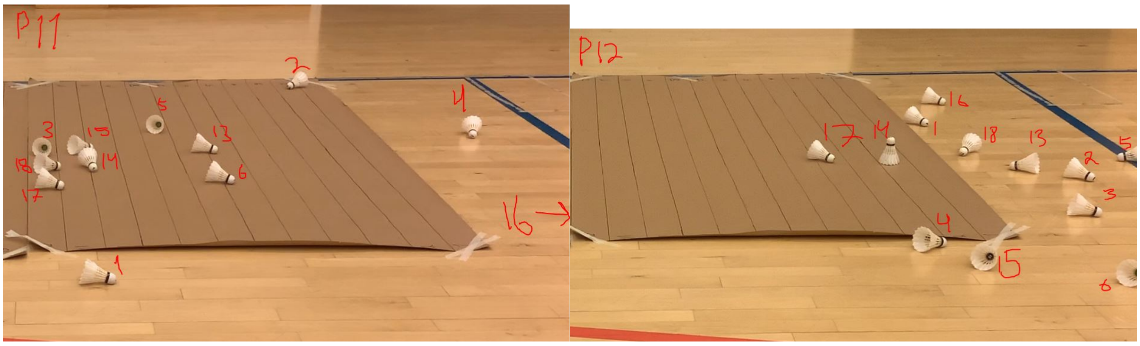

Figure 24: Final Shuttle Position: Player 11 and Player 12

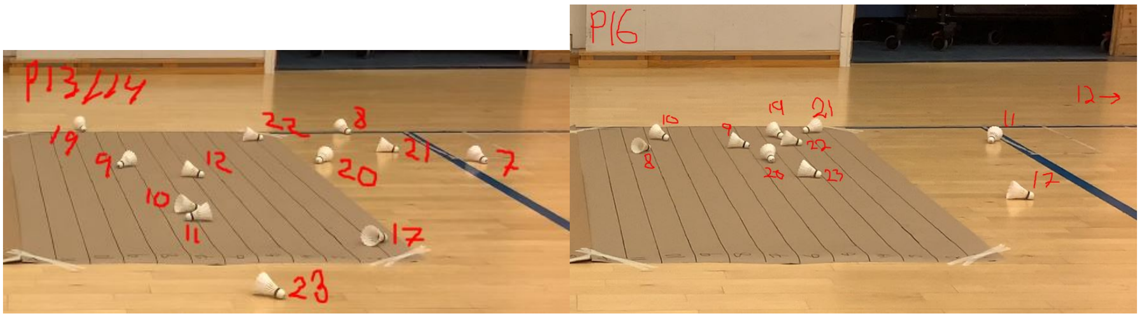

Figure 25: Final Shuttle Position: Player 13 and Player 14, and Player 16

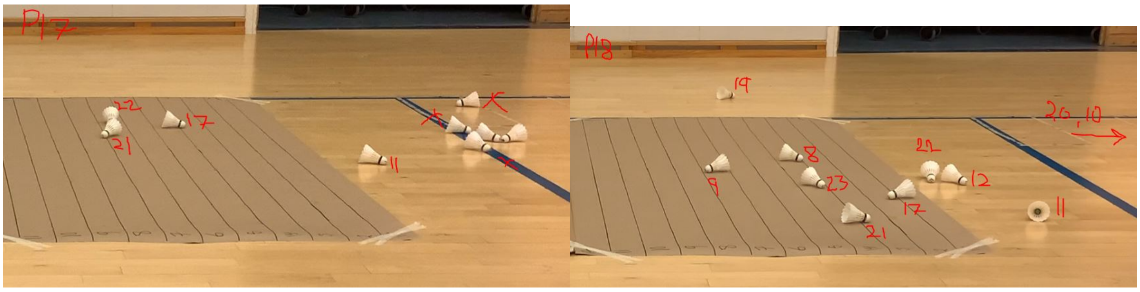

Figure 26: Final Shuttle Position: Player 17 and Player 18

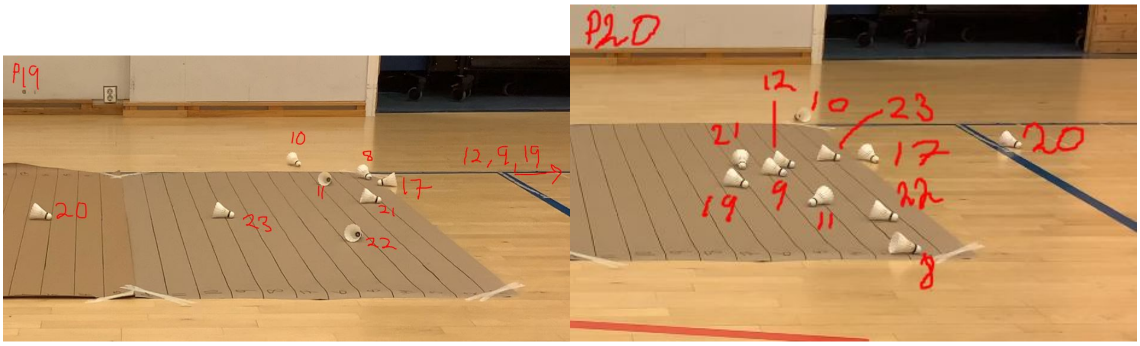

Figure 27: Final Shuttle Position: Player 19 and Player 20

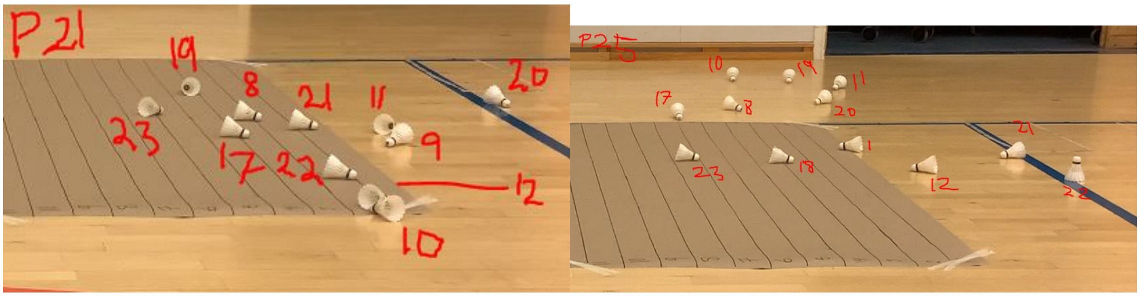

Figure 28: Final Shuttle Position: Player 21 and Player 25

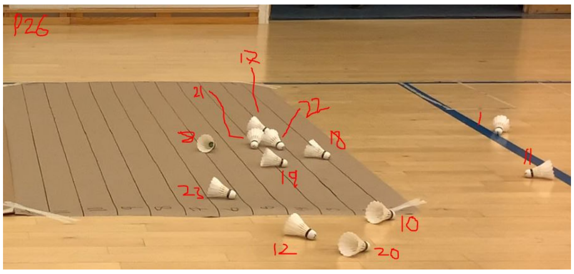

Figure 29: Final Shuttle Position: Player 26

Hafsteinn Einar Håkonarson

The Development of a Shuttlecock Sorter

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Science and Technology