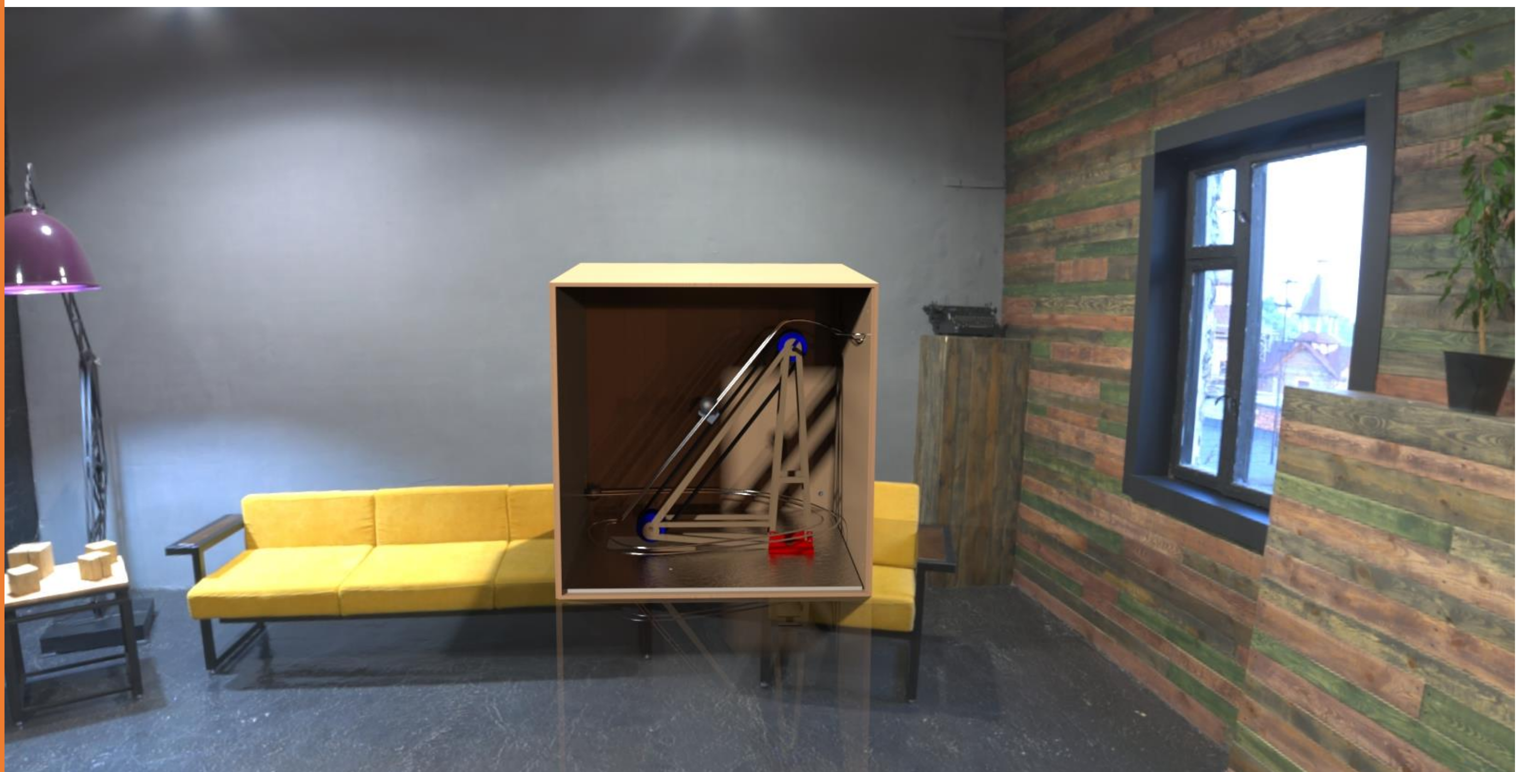
SEPTEMBER 15, 2023

THE MARBLE MACHINE



DESIGN DOCUMENT

2023 SPINE ENGINEERING PROJECT PRACTICE ENGG2000/3000

MACQUARIE UNIVERSITY

ENGG3000/20000

Team 3 – Motions 4

Table of Contents

List Of Figures

List of Tables

1. Revision History

Table 1 Revision History

Date	Changes Made	Committed By
01/09/23	Initial formatting and data fill	Oliver Gordon
10/09/23	Added CAD drawings	Tyler Johnson
12/09/23	Added Detailed Design Segment	Tyler Johnson
13/09/23	Added Alternative Designs and Comparisons Section	Tarun Gangolli
14/09/23	Added x5 Conceptual Drawings to Alternative Designs and Comparisons Section.	Tarun Gangolli
14/0/23	Added design traceability section with requirements and constraints.	Reece Deluca

2. Division of Labor and Workload Acknowledgement

Table 2 Division of Labor and Workload Acknowledgment

Section	Team Members	Sign Off	Workload %
Detailed Design, CAD, Detailed Analysis, Requirements	Tyler Johnson	Oliver Gordon - 13/09/23	~20%
Initial and Detailed Analysis	Oliver Gordon	Tyler Johnson - 11/09/23	~20%
Conceptual Design and Design Alternatives	Tarun Gangolli	Oliver Gordon – 14/09/23	~20%
Document Structure and Design Traceability	Reece Deluca	Tyler Johnson – 14/09/23	~20%
Problem Definition and Requirements	Blake Verdi	Tyler Johnson – 12/09/23	~20%

3. Introduction

ENGG2000/3000 students were tasked to create a marble machine to be presented at the main engineering building's entrance. The marble machine will consist of multiple 250 x 250 mm interchangeable marble machines created by different selected groups. These machines will consist of different internal subsystems which transport the marble throughout the machine while achieving the customer's requirements. Our group will design and construct the motion components of the marble machine. This document will provide further details and outline the design calculations while tracing the requirements achieved.

4. Scope

This document will outline and provide further detail into the established design. This includes the conceptual design, detailed design, and design traceability to reaffirm the feasibility. The conceptual design will establish the subsystems components and design. The detailed design will provide further details into the designs functionality and calculations required to successfully accomplish the desired applications. Finally, the design traceability will connect how each requirement is met.

5. Terms, Definitions, and Abbreviations

Table 3 Definitions and Abbreviations

Abbreviation	Definition
MQU	Macquarie University
TPM	Technical Performance Measures
FR##	Functional Requirement ID
PR##	Performance Requirement ID
IR##	Interface Requirement ID
AR##	Additional Requirement ID
CON##	Constraint ID
IN##	Inclusion ID
EX##	Exclusion ID
COMMS	Team 4 Communications 6
STRUCT	Team 4 Structures 1
MOTIONS	Team 4 Motions 3

6. Problem Definition

To test the teamwork, problem solving, and technical skills of the ENGG2000/3000 class, each of our teams are to construct part of a kinetic sculpture. The sculpture will comprise of 16 interconnected boxes, collectively measuring 2.4 meters in height and 2.4 meters in length. Each individual box will have dimensions of 250mm x 250mm and will accept, transport, and release marbles in specific ways. The primary objective of this project is to create a kinetic sculpture, wherein a steel marble passes through a number of these different boxes, each controlling the marble in specific ways.

The development of this sculpture will be executed by a collaborative team, organized into sub-teams, consisting of students specializing in structural, motion, and communication engineering. Each sub-team will be responsible for specific tasks that align with their respective disciplines. The ultimate goal is to demonstrate the innovative and cooperative prowess of the engineering faculty through this creative endeavor.

7. Subsystems

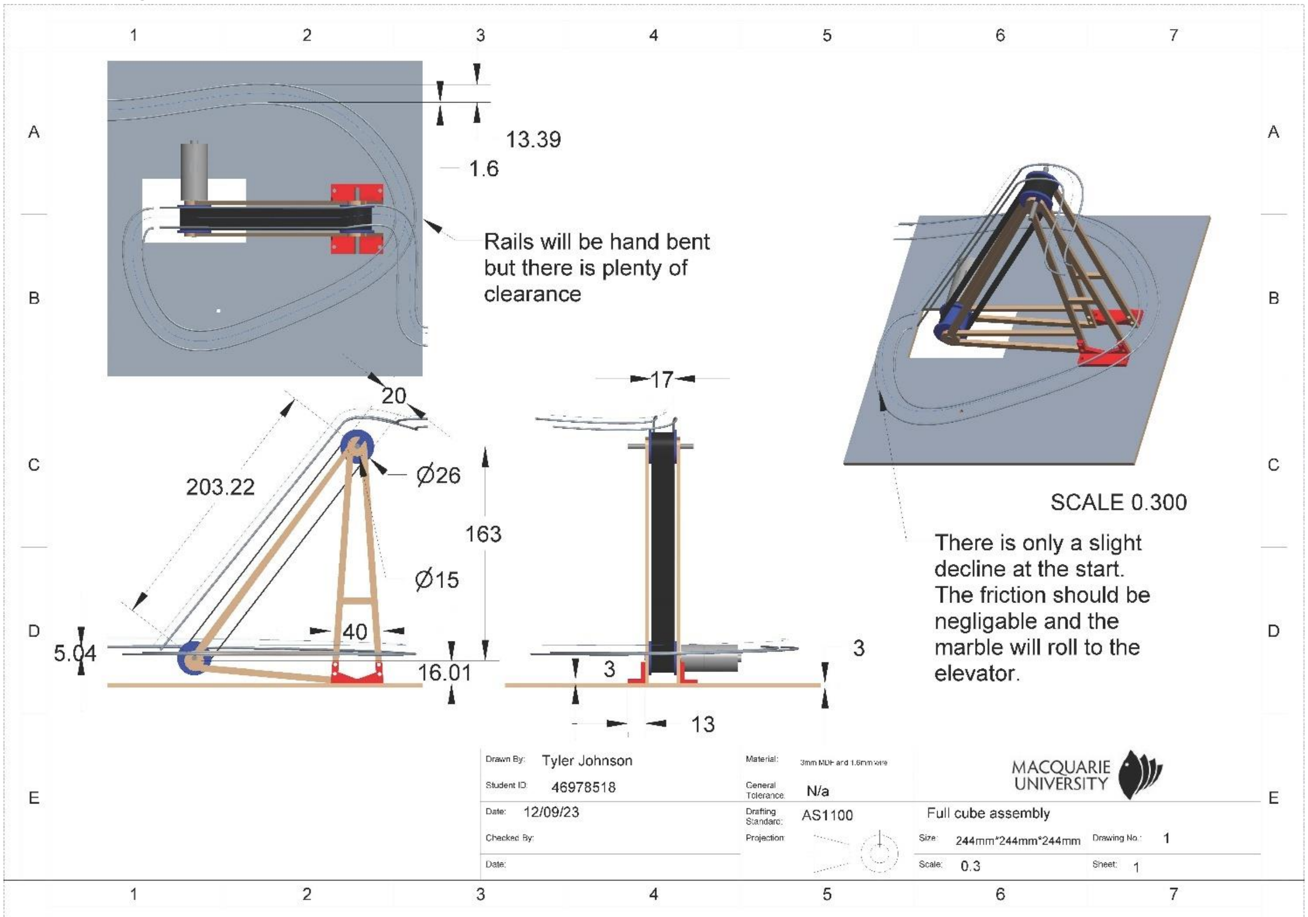


Figure 1 Detailed Design

The project will be divided into subsystems, each subsystem will be in place to complete a certain requirement. These will consist of the following:

Table 4 Subsystem

Subsystem Name	Description	Addressed Directly
Spiral Rails	A set of 3mm metal rails that run around the perimeter of the box. These rails guide rolling marbles.	FR1, FR5
Lift System	Lifts marbles using a series of receptacles attached to a drive belt, these receptacles collect marbles off the rails and lift them up to the Exit Rails	FR4, PR3, PR2, FR4
Exit Rails	Accept marbles from the Lift System and guide them to the exit.	FR4, FR5

To ensure quality and efficiency, the project will be divided into subsystems corresponding to each discipline. Each sub-team will be responsible for their designated section of the sculpture, allowing for specialized focus and effective completion. Regular collaboration among sub-teams will promote a cohesive workflow and showcase the engineering faculty's creativity and skill.

7.1. Structures

The structures team will be responsible for the design aspects concerning the housing, as well as the collection and retrieval process of the steel marble. The collection procedure for the steel marble will predominantly rely on gravity in order to minimize the inclusion of complex moving components. On the other hand, the return mechanism for the steel marble will be addressed jointly by the motions team and the structures team. The motions team will be responsible for devising the lift system, encompassing the motorized elements, while the structures team will be tasked with handling the mounting intricacies. The mounting intricacies will fulfil the requirement IR5 where the cube must be placed on one of four mounting positions.

The housing aspect will fulfil the requirements PR1, IR2, IR4, IR6 where the cube must accept a 16mm iron marble. The front surface must not be structural for maintenance purposes, and transparent with the sides and back of the cube being composed of 3mm MDF. The cube must also be placed at the center of a 265*265mm square on a backing board.

7.2. Motions

The primary focus of the motions team lies in addressing all moving components present within the marble machine. Additionally, the motions team will be responsible for designing and constructing the lift system required for the return of steel marbles. In this regard, the lift system's development will strictly adhere to structural engineering principles to ensure the elimination of any potential clearance issues. Motions will also handle the Arduino and the coding that follows. Handling the Arduino will fulfil the requirement IR1 where the system must be controlled by an Arduino Uno Microprocessor.

In addition to the above tasks, the motions team will undertake the management of the Arduino integration and the subsequent coding requirements involved in moving components.

7.3. Communications

Given the nature of this project, the communications subsystem will be relatively less involved compared to other subsystems. Its primary focus will be on enhancing the visual aspect of the marble machine. This will encompass the integration of lighting elements, sensors, and the associated coding required for their proper functioning. This is to fulfill the requirement FR2 where there must be visual indication approved by the customer.

To ensure seamless coordination, the communications team will collaborate with the structures team, particularly in matters pertaining to clearance concerns. The joint effort will guarantee the absence of any interference between different components. This will fulfil the requirement IR3, where the Telecommunications and power must be routed through the rear end port.

Specifically, the communications team will undertake the design of an LED strip, which will be strategically mounted at the top of the box. This LED strip will function as a progress bar, and its activation will be synchronized with the sensor for each steel marble. To achieve optimal performance, fine-tuning of this feature will be required in alignment with the final design of the marble machine.

8. Assumptions

Below are some generic assumptions for the project:

Table 5 Assumptions

Assumptions	Description
Gravity	Acceleration due to gravity is 9.80 m/s^2.
Marble's size and weight	The marble's intended diameter is 16 mm with a mass of at most 16g
Marble Rate	Marble throughput should be AT LEAST 1 marble/second in all cases.
Cube's structure and measurements	The cube's outer structure is made of MDF with a thickness of 3mm and has a density of approximately 680-720kg/m^s.
Power supply	Assume a 5V and 12V power supply, with ample wattage
Environment	Assume room temperature environment of 44 Waterloo Rd Building

9. Requirements and Sign Offs

Requirements listed below will form the basis of our TPM's during the testing phase. These have been divided into three groups. Functional requirements must be met for the design to be fit for purpose. Technical Performance requirements describe what conditions the system must be able to accommodate and operate predictably under. Interface requirements outline shared requirements between groups.

9.1. Functional Requirements

Table 6 Functional Requirements

Req ID	Requirement	How will this be Achieved?
FR1	The marble makes a full rotation around an imaginary line that MUST NOT intersect the marble, drawn through the cube. The marble's direction must change in at least two dimensions by the size of the marble.	Achieved with the spiral rail subsystem making a 360-degree rotation around the center of the box.
FR2	A cube MUST provide some visual indication using LEDs or other lighting system approved by the customer as to the function being performed.	Achieved using the mounting of an LED strip in a visible location.
FR3	The only forces provided to a cube are gravity and electrical power. A cube MUST NOT use any liquid in its operation and MUST NOT use compressed air or other gases.	The system only requires gravity and electricity.
FR4	Each cube MUST control the marble in such a fashion that the bottom of the exit opening is at least 100mm higher than the top of the input opening.	This is achieved by elevating the marbles through the lift system.
FR5	Each cube MUST accept a marble through an input opening on a surface other than the top surface of the cube. This location must be agreed to by the customer. It MUST expel marbles through a different surface to where they entered.	Location has been agreed upon with the customer and is demonstrated in schematics.
FR6	Each cube MUST accept marbles that are a solid steel sphere with a diameter of 16mm. The cube SHOULD also accept marbles that are made of lighter materials.	Rails, elevator, entry, and exit will be designed with a diameter of 16mm in mind.

9.2. Technical Performance Requirements

Table 7 Performance Requirement

Req ID	Requirement	Measure	Importance
PR1	Each cube MUST accept marbles that are spaced no closer than 1 second apart through the opening port.	Each subsystem must be able to transmit **at least 1 marble/s.**	HIGH
PR2	Cubes SHALL NOT deliberately expel marbles at a speed significantly higher than that attributable to gravity alone.	Marble speed **must not exceed 3m/s.**	LOW
PR3	The Cube is to run 24/7 with minimal downtime.	Lower than **6hrs unplanned downtime per week**.	MEDIUM
PR4	Code written for the Arduino must work predictably and consistently.	System should be able to run indefinitely with no overflow or crashes for at least a **week**.	MEDIUM

9.3. Interface Requirements and Signoffs

Table 8 Interface Requirements

Req ID	Requirement	Team	Signoff	Date
IR1	The system is to be controlled with an Arduino Uno Microprocessor. The system SHOULD implement as few external components as possible.	COMMS	Nicholas Simos - COMMS	20/8/23
IR2	The lighting system should try to minimize occupation of Arduino Uno ports. The way they are controlled must reflect the progress of a marble through the machine.	COMMS	Nicholas Simos – COMS – Lighting system will utilize at most 4 Ports	20/8/23
IR3	Devices selected must be compatible with the Arduino Uno or at least be made compatible.	COMMS	Nicholas Simos – COMMS – Only compatible devices are used.	20/8/23
IR4	Telecommunications and power must be routed through the dedicated rear port.	STRUCT	Sakibul Alam – STRUCT – Adequate routing through port.	20/8/23
IR5	Each cube location on the backing board SHALL be in the center of a 265mm square. There is a 15mm distance between cubes.	STRUCT	Lachlan Burgess – STRUCT – Mounting points positioned.	20/8/23
IR6	Each cube MUST mount to the sculpture using only the four mounting positions.	STRUCT	Lachlan Burgess – STRUCT – Mounting points positioned.	20/8/23
IR7	Cubes MUST be manufactured from 3mm MDF for the back and side pieces, the front surface MUST be transparent.	STRUCT	Sakibul Alam – Manufactured with laser cut 3mm MDF	20/8/23

9.4. Additional Requirements

There are also some additional requirements that we as a team have added, these include requirements we have agreed on as a team to ensure a final product of professional quality.

Table 9 Additional Requirements

Req ID	Requirement	How will this be achieved?
AR1	Wiring SHOULD be hidden and routed through a dedicated channel to each component. Wiring SHOULD be neat where visible.	The use of cable covers, and preplanned cable routes should mitigate this.
AR2	Components and advanced wiring that are external to the microcontroller MUST be mounted to a prototype board and soldered neatly. Must be mounted where easily accessible.	Soldered board mounted directly above the Arduino, means connections can be neater.
AR3	Cube MUST only be able to run on 5V and 12V as supplied. The cube SHOULD be as energy efficient as possible.	Arduino is a 5V device and can run devices of lower voltages. Motors can use 12V.
AR4	The Cube SHOULD be easily maintainable and run with minimal downtime.	Designing for longevity and minimizing points of failure should address this.

10. Constraints

Constraints are defined as other limitations placed on the project by both the customer and our own circumstances. These include physical, financial, and time-based limitations.

Table 10 Constraints

Req ID	Requirement
CON1	Each cube MUST have a bill of materials, and each bill of materials MUST total to less than AUD$100.00.
CON2	All components MUST be sourced from the allowed suppliers. Bunnings, RS Online, Core Electronics, Hobby King, and Jaycar
CON3	Each cube MUST have the external dimensions of 250mm by 250mm by 250mm.
CON4	We are limited to the 13 Week period defined by the GANTT chart available on iLearn.
CON5	We are limited to the hardware and tools available to us at 44 Waterloo Rd. And tools available to team members within reason.

11. Conceptual Design

11.1. Initial Analysis and Calculations

Each marble is approximately 18 grams. As the lift system is expected to lift more than 1 marble at a time, we decided 6 marbles to be the minimum number of marbles to be lifted. So, the motor's specifications can be narrowed down, the minimum torque has been calculated.

Minimum Torque Calculations:

Total marbles weight = 6 * 18g =108 g.

To consider the conveyor belts weight, we adjust the marble weight with a 40% error.

So, marble + conveyor belt weight =151.2g

As the paddles would roughly be 1.25g, and as there's 6 paddles in the design,

paddle weight = 6*1.25g = 7.5g

Total Weight=151.2+7.5=158.7g

Force needed to lift 6 marbles straight up=9.8*158.7=1555.26 mN=1.55526N.

Marble Radius=0.008m.

As the conveyor belt should lift marbles at an angle close to 60 degrees, assume the angle is 50 degrees.

Minimum Torque needed for 6 marbles= r*F*sin(50) =0.009531Nm = 97.1892 gcm

Now that the minimum Torque is calculated we must calculate the speed of the motor at the torque, this will tell us whether the torque needs to be increased.

Speed Calculations:

As we are given a 12V power rail with 1A current.

Input Electrical Power = V*I

=12V*1A=12W

The average efficiency of motors is 65%, where efficiency is Output/Input power.

Therefore, our output mechanical power would typically be 7.8W, where:

Output Mechanical Power = Torque*Speed

=0.009531 *Speed

Speed=output power/Torque = 7.8/0.009531 =818.37rpm for minimum torque

As this speed is too fast for safe transportation of the marbles and using the calculated minimum torque is not enough when using physical components, we adjust the speed of the motor to 100 rpm and calculate the torque.

Torque=7.8/100=0.078Nm=795.38gcm

12. Realistic Design Alternatives and Comparisons

Our current design may or may not have flaws that need to be addressed in the Testing phase of the project we have ensured to consider alternative designs.

12.1. Brainstormed Alternatives to Current Design:

Brainstormed Alternative #1: One of these designs involves the integration of the Ferris wheel that collects the ball after it has been picked up and dropped down on a ramp towards the Ferris wheel lift cups that lift the marble up to a ramp with a curvy U shape and go towards the exit. Proper review and consideration will exceed the budget and testing time.

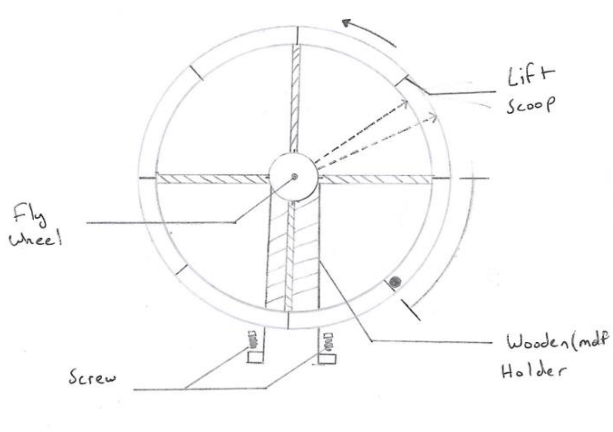


Figure 2 Brainstormed Alternative 1

Brainstormed Alternative #2: The exit hole at the top of the box can be shot with a push rod triggered by a sensor which can be readjusted/reloaded with a Micro-Servo or DC Motor. The marble goes through its course to reach the shooter mechanism when the sensor beam is broken that triggers the spring shooter mechanism that shoots the marble upwards to the next box. This design is merely hypothetical as the spring rod mechanism needs to be designed with various gears and a more technical approach to the spring release and lock feature.

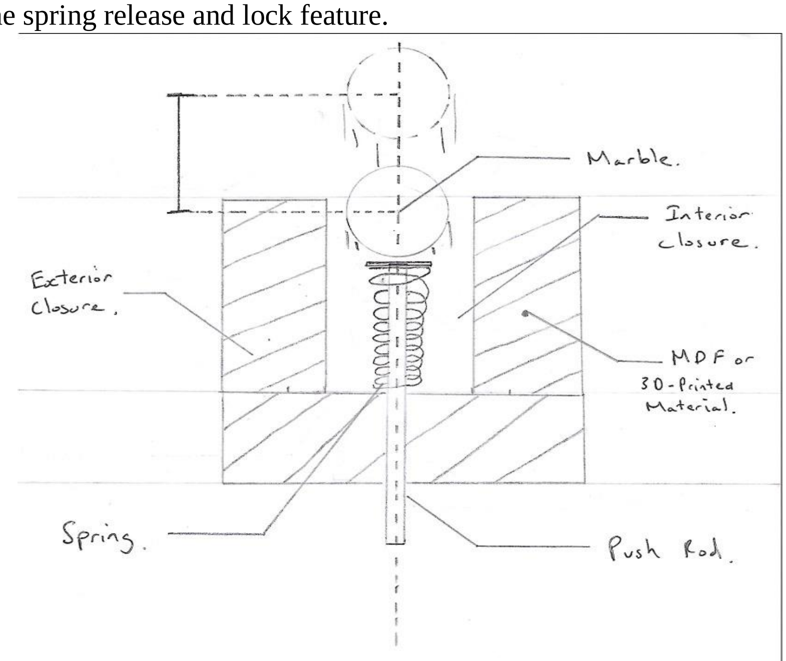


Figure 3 Brainstormed Alternative 2

12.2. Feasible Alternatives to Current Design:

Feasible Alternative #1: The alternative design involves the Ramp made with a simple CAD model constructed by a 3-D Printer; however, our design involves the steel rods parallel to each other with a distance from one another just enough to hold and guide the marble through the track. Otherwise, we could resort to using small PVC pipes that can be cut into a semi-circular shape to be part of the marble course in the box.

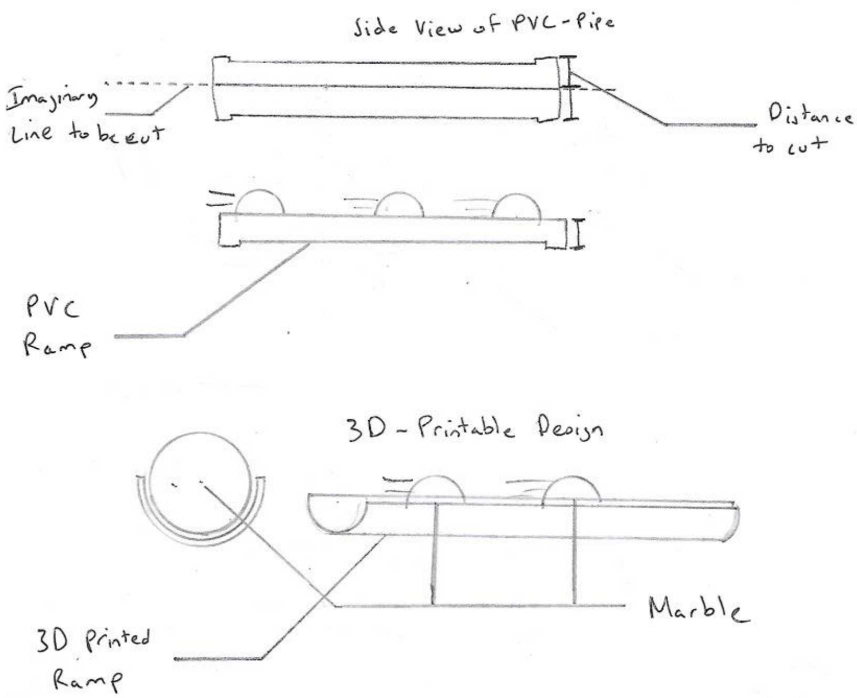


Figure 4 Feasible Alternative 1

Feasible Alternative #2: The IR beam break sensor which can be replaced with an IR distance sensor that can be placed before the conveyor belt, whose sole purpose is to measure the distance of the oncoming marble to counter-control the DC motor for the Lift receptacle in order capture the ball to progress through the track.

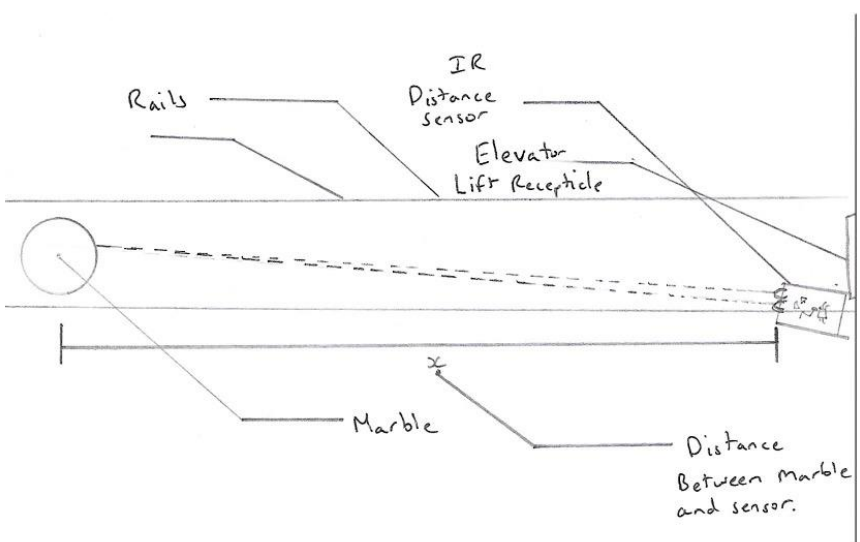


Figure 5 Feasible Alternative 2

Feasible Alternative #3: This design involves the integration of a Servomotor fitted with a mechanism designed to stop the ball. To visualize this, we must address that there are x number of balls entering the box which will result in stacking of the marbles at a certain point through the whole course which can only be determined in testing. To resolve this issue, we installed a Servo motor fitted with a valve hand that acts as a stopper to be placed right before the lift elevator of the current design, so when more than 2-3 marbles enter the box, they will most likely stack right after the spiral, the valve will stop and release of the marble in intervals to be collected in time by the elevator.

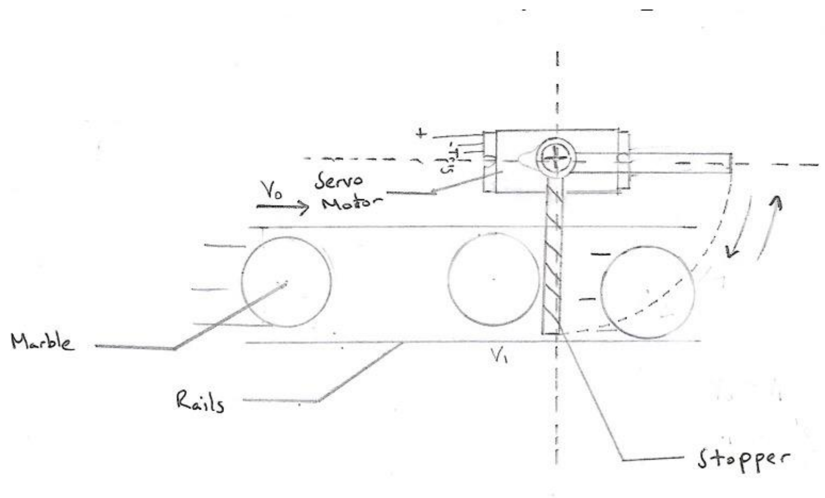


Figure 6 Feasible Alternative 3

Feasible Alternative #4: This design will involve the replacement of the MOSFET with a Darlington Transistor which involves are rearranged layout of the DC motor circuit. The DC motor power will be directly connected to 12V, and the Ground will be connected to the Darlington Transistor whose base will be connected to a current limiting resistor which in turn is connected to a normal Digital pin and PWM pin of the Arduino. The Component ID is TIP122Additionally, this will be part of the system as this design involves an LED and Photoresistor as part of the motor rotation sensor. The DC motor will have slotted wheel placed on the rotating shaft. The slotted wheel is a slot that can let light pass through to trigger the photo-resistive sensor which triggers the system to counter-control the DC motor. This Design model has the capability to be integrated into the current design, however, it will definitely exceed the limited budget.

13. Comparisons between Conceptual Designs Vs Current Design

We have addressed Brainstormed and Feasible Alternatives. Brainstormed ideas are feasible in terms of Engineering; however, they are capable of exceeding the budget of this project so we won't be comparing them with the current design but will only consider these as a form of last resort. The Feasible Designs are alternatives that are considered if and only if a specific component fails.

Comparison Of Feasible Alternative #1 to Current Design:

PVC pipes and 3D printable models of a ramp are amendable substitutes compared to the current ramp consisting of two steel rods. The horizontal cut of the PVC has the capability of passing during the testing phase in the event of a change to the design of the current ramp. Even the 3D-modeled ramp will have the advantage in testing. The concept of their designs is sound, however, the downside to these two models is additional changes of other areas of the box will have to be redesigned which will add more work hours and most likely exceed budget. With all that mentioned we must address the Advantages and Disadvantages:

Table 11 Advantages and Disadvantages of Alternative 1

Advantages	Disadvantages
PVC Pipe: • Smooth material. • Easier to Cut. • Corrosion Resistant. 3D Modeled Ramp: • Simple to Model and Create with CAD Software. • Various parts of the Ramp can be printed separately.	PVC Pipe: • None 3D Modeled Ramp: • Capable of Breaking due to plastic material. • Will exceed budget if a certain piece is broken.

Comparison of Feasible Alternative #2 to Current Design:

The IR distance sensor is capable of being a superior alternative as this sensor can measure the distance from the object to the apparatus itself, a feature that can provide more sequential feedback to the Arduino to counter-control the elevator. In terms of the failure of the current IR Beam Break Sensor, that is if it comes to that, the IR distance sensor will most likely flourish during testing as this sensor gives a real-time varying value of the distance between the elevator and the marble, which is more than enough information to counter control the elevator for the marble to smoothly transition from the track to the lift receptacle. With this design comes Advantages and Disadvantages:

Table 12 Advantages and Disadvantages of Alternative 1

Advantages	Disadvantages
• Senses objects at <10mm • Reliable • Faster Response time to the system • Physically smaller • Affordable • Able to detect ball from distance with enough time to counter control elevator. • Does not require direct contact to be triggered.	• Short range distance sensing abilities (but still sufficient for this project). • IR frequencies are affected by hard objects such as concrete, wood, dust, fog and sunlight. • Can control only one device at any one time. • Difficult to control it if nothing is in LOS (Line of Sight).

Comparison of Feasible Alternative #3 to Current Design:

The Micro-Servo Controlled stopper valve in theory will be a successful alternative if the current counter control with the IR beam break sensor fails. This design involved arbitrarily controlling more than 2 marbles when it enters the box. If implemented before or during testing most assuredly this design will take the spotlight. However, this concept will exceed budget if the current IR Beam break component fails, it won't if another component in the box fails. There are Advantages and Disadvantages to this design:

Table 13 Advantages and Disadvantages of Alternative 3

Advantages	Disadvantages
• More control of marble. • Can handle more than 3 marbles in box. • Efficient and Accurate. • High output power.	• Costly • Damaged if Overloaded • Control over DC motor is complicated.

Comparison of Feasible Alternative #4 to Current Design:

This design is to replace the current DC motor control circuit that has been designed with a MOSFET transistor, whereas this feasible alternative design is capable of sensing the speed of the motor with the slotted wheel which rotates with a slot on the outer edge of the flywheel which lets light through in order for the photo-resistive sensor to relay information to the Arduino. This model, if replaced by the current MOSFET design, will pass testing with minor adjustments to the program being made between tests in order to gain full control. We must address the Advantages and Disadvantages:

Table 14 Advantages and Disadvantages of Alternative 4

Advantages	Disadvantages
• Provides more Control over the Voltage and Current into the DC motor. • Darlington Transistor • Power Efficient. • Innovative. • Capable of Sensing Motor Speed	• Exceed Budget. • DC motor Susceptible to having lower life span.

14. Detailed Design

We learned a lot throughout the design process, and we were given some valuable feedback during the Design Review. Our current design aims to take the lessons learned from feedback and additional research and implement them into a more complete product. Each subsystem has had subtle but important changes implemented to ensure reliability and performance. **(See Appendix D).**

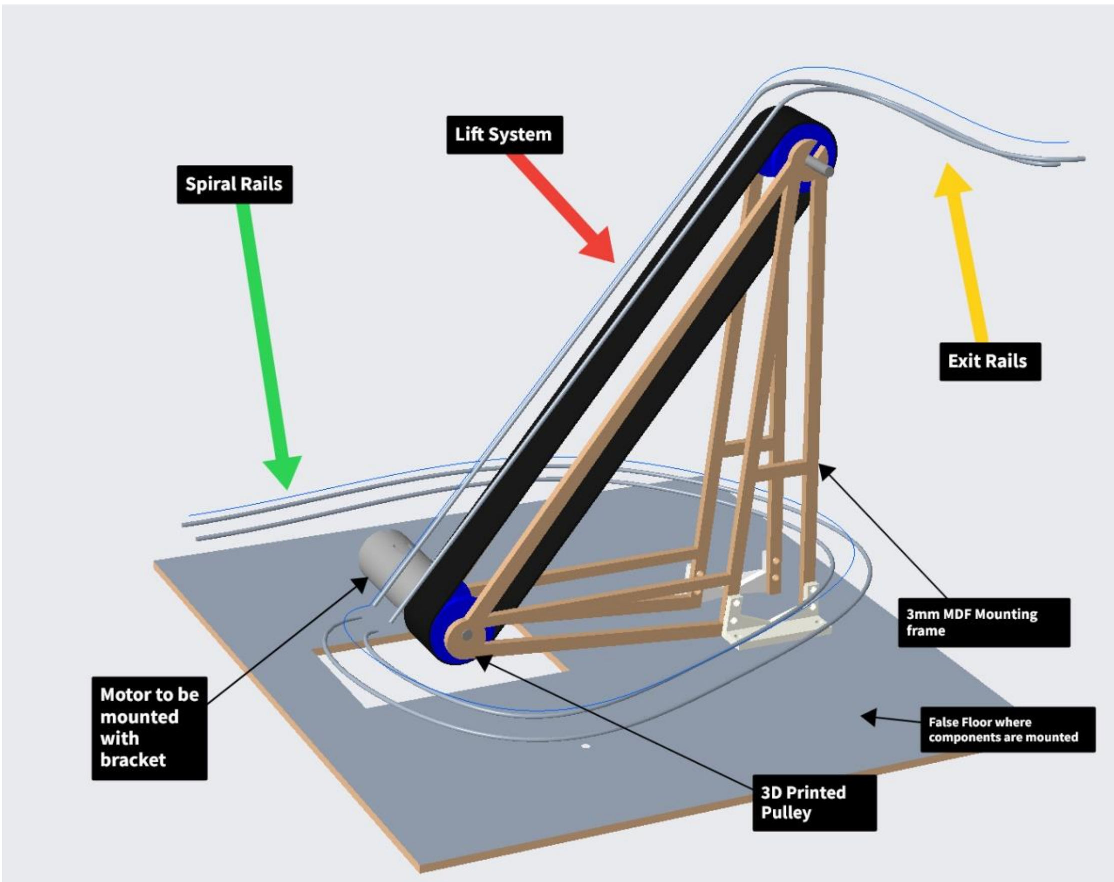


Figure 7 Full Assembly Labeled Diagram

14.1. False Floor

All components and mounting solutions will be installed on a false floor. This will make both construction and maintenance easy as components can be mounted to the plate before being installed in the cube. It will be manufactured out of 3mm MDF with slots cut out to compensate for the lost clearance.

Table 15 False Floor Requirements

Requirement Addressed	How Requirement is Met
PR3	The false floor design allows for easy maintenance and construction.
PR4	The false floor design allows us to mount things easily, but also to easily perform maintenance without the cube hindering access.

14.2. Spiral Rails

The Spiral Rails consist of two parallel runs of 1.60mm 304 Steel Tie Wire spaced at 14mm apart. The marble which enters through the hole in the back left of the cube, rolls along these rails making a 360-degree rotation about an imaginary axis. The rails have a very slight decline which ensures the marbles will maintain speed throughout the whole spiral. The rails from the spiral will continue into the lift system.

Table 16 Spiral Rail Requirements

Requirement Addressed	How Requirement is Met
FR1	Rails run around the perimeter of the box, making a full rotation about an axis positioned vertically in the middle of the box.
FR5	Marbles are accepted through an opening of 25mm centered 40mm from the bottom and rear face of the box.
FR6	Marbles are guided along rails spaced 14mm apart, allowing for marbles to roll effectively. This is true for all the rails.

14.2.1. Sensors

Sensors selected are 3mm IR Beam Break Sensors. And will be mounted by the Structures Team on either side of the rail. We chose these sensors for their reliability in past marble machine projects. There are to be four sensors positioned along the rails. One at the entrance opening, one at the base of the elevator, one at the top of the elevator, and one at the exit.

14.3. Lift System

The Lift System is a belt driven by a high torque motor, with a series of paddles riveted into it. The belt runs parallel to the rails, going up at a 50-degree incline for 200mm. As the marble approaches the belt the paddles riveted to it will push the marbles up the incline, without the marbles having to leave the rails. This differs from the previous design, as before we would be picking marbles up and having to support them on the elevator in custom receptacles. This will be more consistent than our old design as we aren’t reliant on timing marble drops and pickups. 3D printed belt pulleys will be mounted on laser cut 3mm MDF frames and held in place with a basic slot tensioning system. This enables fast repair as they are easy to manufacture in case of failure, and easy disengage of the belt.

Table 17 Lift System Requirements

Requirement Addressed	How Requirement is Met
FR4	The marble elevator will raise the marbles approximately 180mm. This number is approximate as the rails will be hand bent with the assistance of tooling.
FR3	The only service required for the operation of the box is electricity and data, both of which can be supplied through the rear port.
PR1	The motor that has been selected runs at 98 RPM at load, which will be more than enough to transmit that many marbles.
PR2	The motor will be controlled with PWM, with the assistance of sensors the motor speed will be adjusted so that it can keep up with marble throughput. Its speed will be capped so this isn’t a concern.
AR3	The motor selected runs off of 12V and all other devices such as the Arduino run off of 5V.

14.3.1. Lift Paddles

As the lift paddles were being 3D printed, it was important to model them in CAD beforehand. They are designed with the spacing of the rails in mind, and with consideration given to any surface the rail could catch or drag on. These are riveted through to the belt and are being 3D Printed by a member of the motions team to prevent wait times when using printers offered by MQ. Further testing will be done to refine the design. (**See Appendix A**)

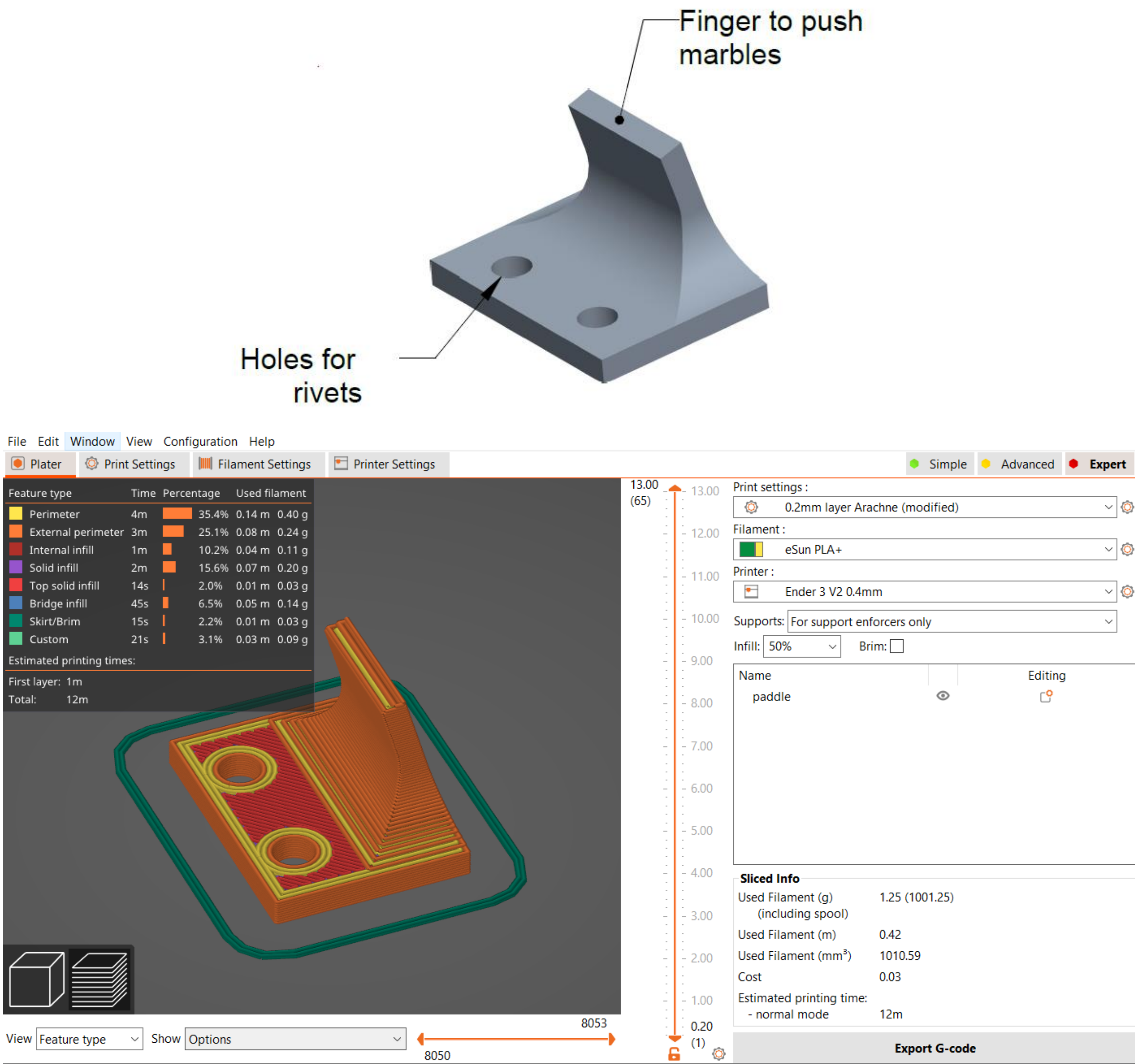


Figure 8 Conveyor Lift Paddles

14.3.2. Lift Pulley

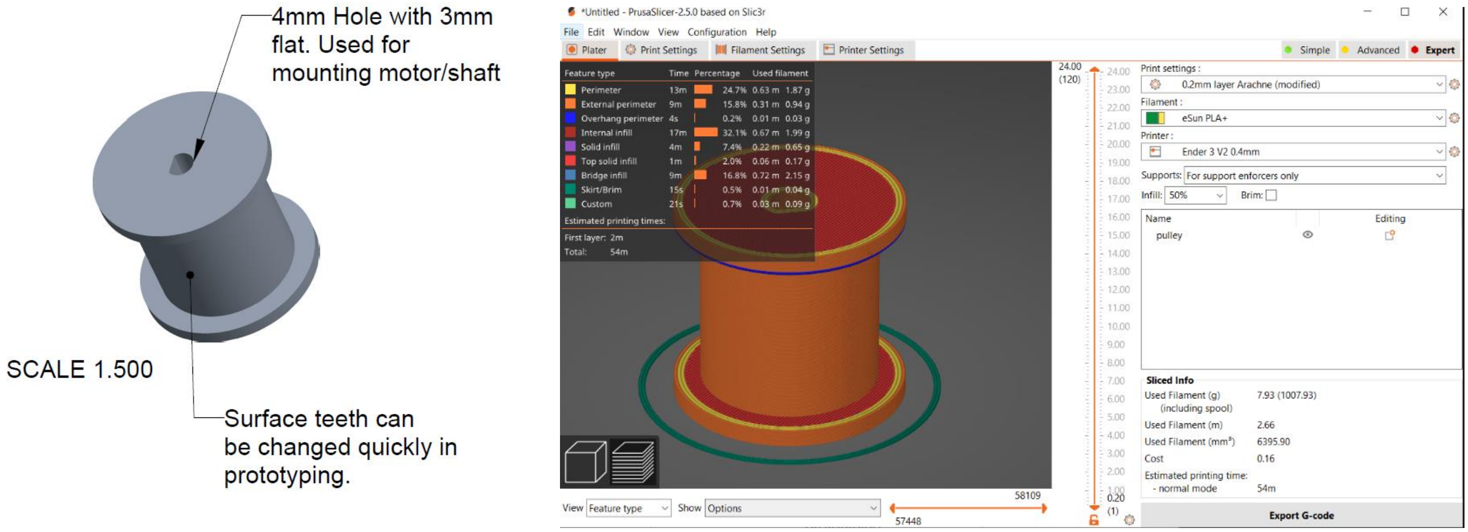


Figure 9 Conveyor Pulleys

The lift belt will be driven by two pulleys, one of which is connected to the 12V DC motor mounted on the bottom. The pulleys will have teeth in them, designed in the prototyping phase to maximize torque transition to the belt. This will be quick and easy as these will be 3D printed, and will take approximately 52 minutes to print, making prototyping fast and simple.

(**See Appendix B**).

14.4. Exit Rails

The exit rails continue from the lift system, the same 1.60mm wire spaced 14mm apart. These rails simply deliver the marble to the 20mm exit hole, centered at 40mm from the front and side space. There is a tight angle on the exit rail which assists in managing output speed.

Table 18 Exit Rail Requirements

Requirement Addressed	How Requirement is Met
FR4	Bottom of the exit opening is 145mm from the top of the entry opening.
FR5	Marbles exit through the opposite side of the box, centered 40mm from the top and front faces.
PR2	The tight turns at the end prevent speed ever exceeding that attributable to gravity.

14.5. Circuit Diagram

Below is a labelled diagram of our current circuit schematic. As we are provided with a 12V and 5V supply, our Arduino will be powered using Vin on the 5V rail. The circuit features a flyback diode to help improve longevity and efficiency, and an NMOS Transistor being controlled with PWM. This will control the motor's speed and ensure we are moving 1 Marble/s. (**Full Schematic see Appendix C**)

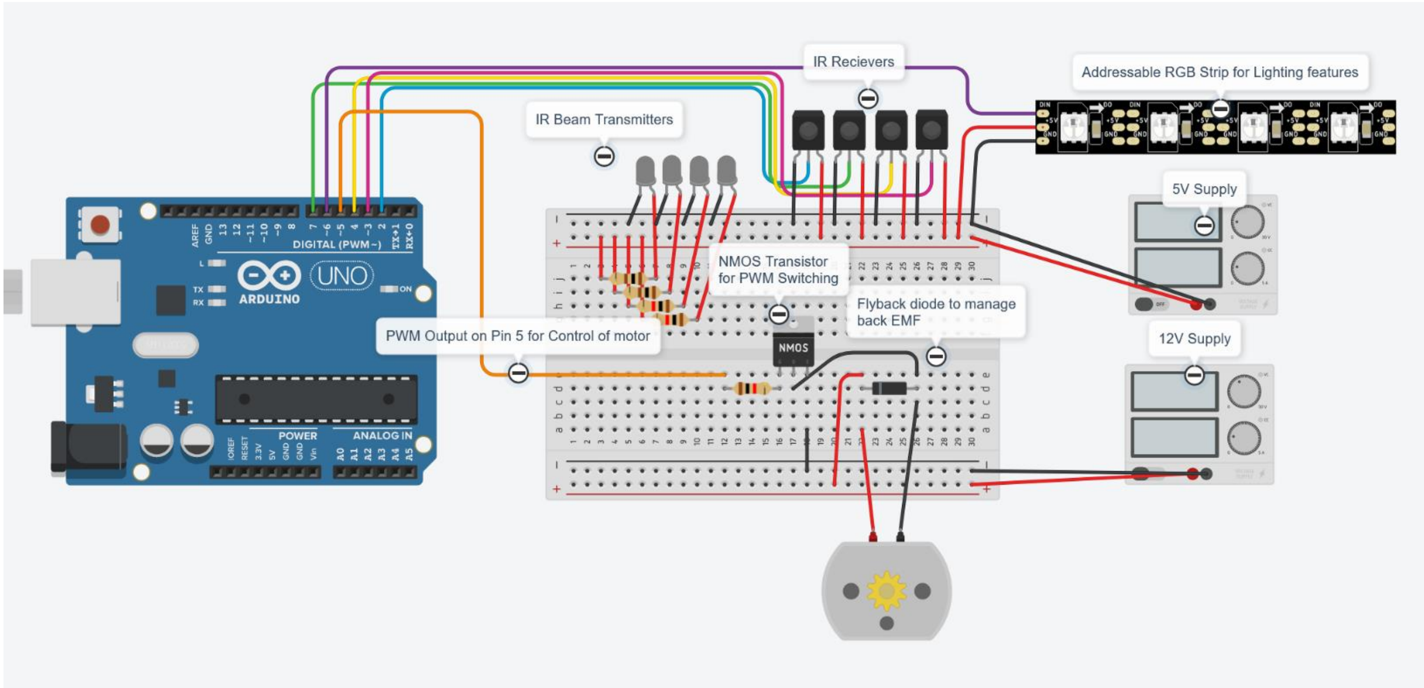


Figure 10 Tinkercad Diagram

14.6. Calculations and Analysis

The main concern about the system described is whether the motor is capable of transporting 1 marble/s up the belt, as stated in PR1. We can do this by working backwards from the task required to find the RPM the motor is needed to spin at.

Table 19 Detailed Design Assumptions

Assumptions and Context	Value
Marble Properties	16mm diameter, mass of 18g
Belt Capacity	Belt will be carrying up to 6 marbles at once.
Belt Paddles	Can be modeled as a 12mm*20mm*10mm (length*width*height) rectangular prism standing at a normal to the belt. **Spaced at 33mm apart.**
Max Load	We assume that every paddle will have a marble resting on it for purposes of load.
Pulley	Belt is run between two 20mm pulleys, with no gear reduction.

We can use these assumptions to calculate the required performance for the task.

$$2 \cdot \pi \cdot r = circumference$$

$$2 \cdot \pi \cdot (10mm) = 62.83mm$$

Given how the paddles are spaced, we can determine we need at least:

33mm/s Belt Speed

We can calculate RPM using this equation:

$$v = \frac{\pi}{2} \cdot D \cdot \frac{RPM}{60}$$

$$\frac{33mm}{s} = \frac{\pi}{2} \cdot (20) \cdot \frac{RPM}{60}$$

Pulley RPM = 63 RPM

Given the torque required for these same assumptions calculated in the conceptual phase (97.1882g/cm), we can compare these values to those of the motor selected and determine whether it will be sufficient.

Looking at the data sheet for the 12V Motor that has been selected and determined it had the following properties:

Table 20 DC Motor Values

Property	Value
Rated Voltage	12V
Output Speed at Rated Torque	93 RPM @ 12V
Rated Current	680mA
Rated Torque	343 mNm

We can determine from this, that the motor selected will be more than sufficient for the task. Careful PWM control is also incredibly important as we will need to run it at a much lower speed than it will regularly. This will impact the torque output, however the rated torque is also much more than is required.

15. Design Traceability

Table 21 Design Traceability

Requirement ID	Satisfied?	How it is satisfied
FR1	Yes	The marble makes a 360-rotation around the axis through the spiral rails (presented in the subsystem section).
FR2	Yes	LED strips will be mounted in a visible location within the machine.
FR3	Yes	The spiral rails use momentum and gravity to generate speed while the lifting system incorporates electrical power.
FR4	Yes	The lifting system will elevate the marble to a desired height. This ensures the marble is high enough to roll into the exit hole.
FR5	Yes	The marble will be accepted through the left side of the marble machine. The marble will pass through the lifting mechanism and the spiral rails to be finally expelled through the direct opposite.
FR6	Yes	The spiral rails and the lifting mechanism are designed to transport a marble with 16mm marble with a weight of around 18g. This can be substituted with lighter materials without affecting reliability.
PR1	Yes	The marbles will travel down the spiral and end up at the lifting system. The motor will spin at a high speed to withstand the one marble per second without collision.
PR2	Yes	The spiral uses gravity to expel the marble while the lifting system does not exceed gravity.
PR3	Yes	The downtime will be 6 hours or less during the week.
PR4	Yes	The code will run without any crashes or bugs in the system.
IR1	Yes	The Arduino microprocessor will control the LED strips and the lifting systems.
IR2	Yes	The lighting along the spiral will incorporate LED strips that flow the marbles down the track. The LED's will be controlled by the Arduino unit with minimal occupation.
IR3	Yes	All devices in the system are compatible with the Arduino.
IR4	Yes	The cube design has a service port with telecommunications and power routed through.
IR5	Yes	The 250 x 250 mm size ensures a gap of 15 mm gap between each cube.
IR6	Yes	The backing board incorporates 4 points for mounting the cube on the sculpture.
IR7	Yes	The MDF is supplied by the customer and all designs revolve around the assumption of 3 mm thickness.
AR1	Yes	The service port will ensure the wiring can be routed safely and neatly. The wiring for the LED strips and motor are separated for optimal vision.
AR2	Yes	All the wiring will be neatly routed through the service port for easy accessibility.
AR3	Yes	Arduino is a 5V device and can run devices of lower voltages. The motors will use 12V.
AR4	Yes	The cube will have a clear detachable screen for easy access and visibility.

Table 22 Constraint Traceability

Constraint ID	Satisfied?	How is it satisfied?
CON1	Yes	The bill of materials has been completed with a total less than AUD$100 (**Shown in Appendix E**).
CON2	Yes	All components are sourced from approved suppliers. Some components are supplied by the customer and are excluded from CON2.
CON3	Yes	The external dimension of the design is 250 mm^3.
CON4	Yes	The timeline and planning schedule stays within the dedication time frame.
CON5	Yes	The construction of the marble machine will be completed at 44 Waterloo Rd for 13 weeks.

16. References

[1] “DC Motor speed control and measurement,” *projecthub.arduino.cc*. https://projecthub.arduino.cc/ambhatt/dc-motor-speed-control-and-measurement-edb8ea (accessed Sep. 14, 2023).

[2] “IR Distance Sensor,” *projecthub.arduino.cc*. https://projecthub.arduino.cc/vicentezavala/ir-distance-sensor-00e39f (accessed Sep. 14, 2023).

[3] L. Cotton, “What Is The Best Electric Motor For A Conveyor System,” *Parvalux*, Mar. 17, 2022. https://www.parvalux.com/what-is-the-best-electric-motor-for-a-conveyor-system/#:~:text=If%20you%20need%20to%20vary (accessed Sep. 14, 2023).

[4] “DC Motor speed control and measurement,” *projecthub.arduino.cc*. https://projecthub.arduino.cc/ambhatt/dc-motor-speed-control-and-measurement-edb8ea (accessed Sep. 14, 2023).

[5] “5.7 Torque on a Current Loop: Motors and Meters | Texas Gateway,” *www.texasgateway.org*. https://www.texasgateway.org/resource/57-torque-current-loop-motors-and-meters#:~:text=Torque%20is%20defined%20as%20%CF%84 (accessed Sep. 14, 2023).

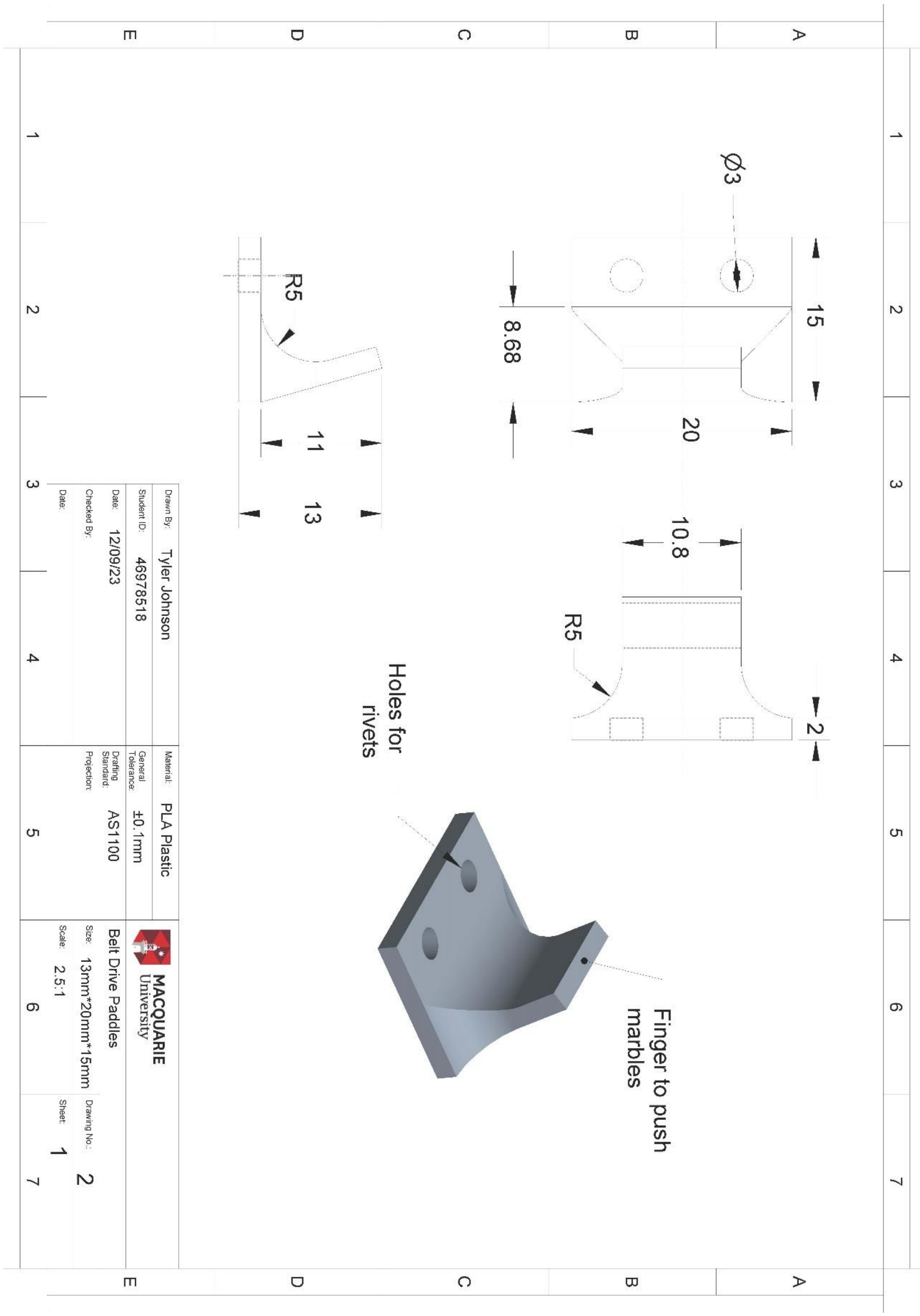
[6]

“Belt Speed Calculator,” *Calculator Academy*. https://calculator.academy/belt-speed-calculator/

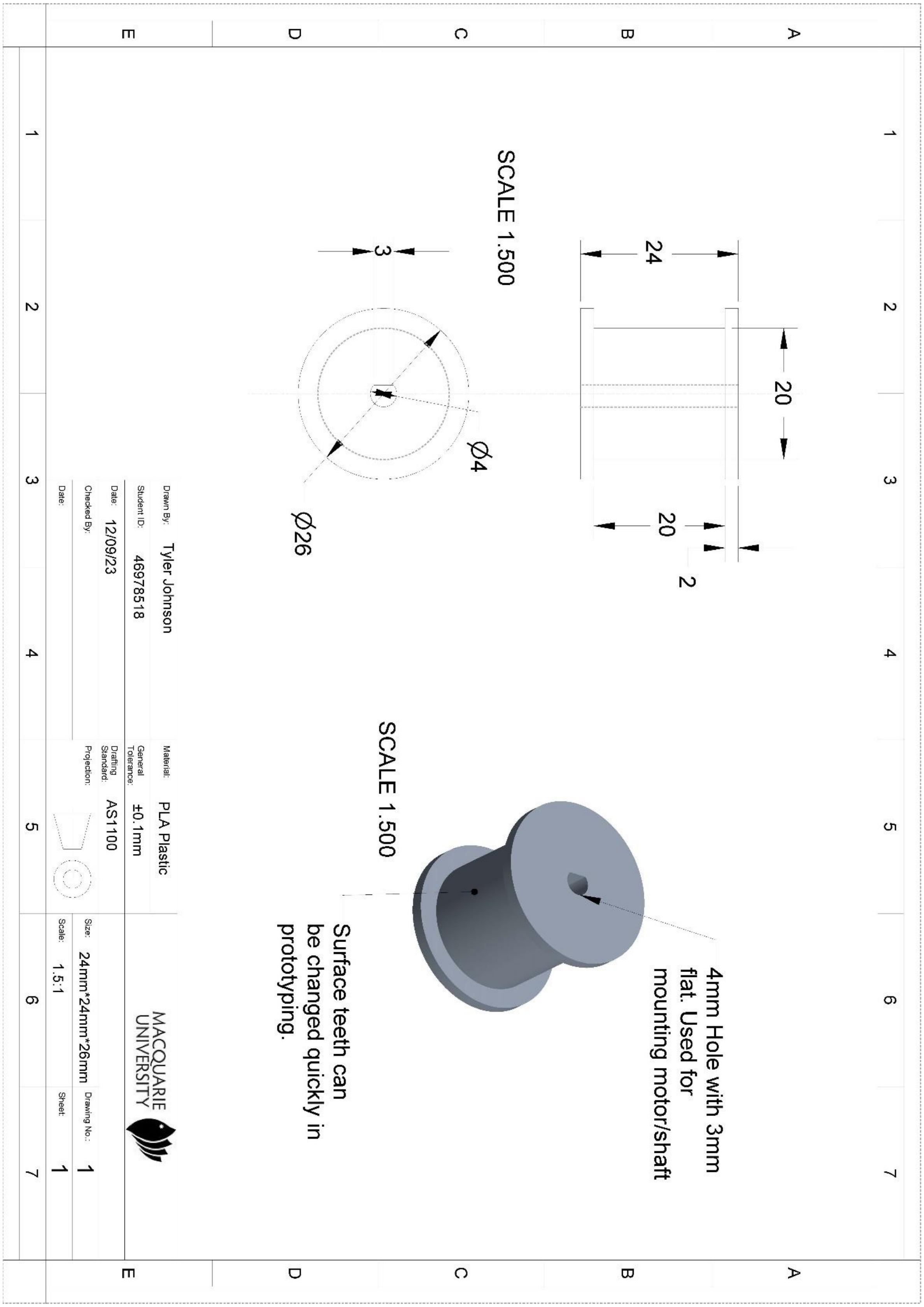
R. Di Bona, “2023 SPINE Engineering Project ENGG2000/ENGG3000,” Macquarie Engineering, iLearn, Jul. 20AD. Accessed: Jul. 23, 20AD. [Online]. Available: ilearn.mq.edu.au.

17. <u>Appendix</u>

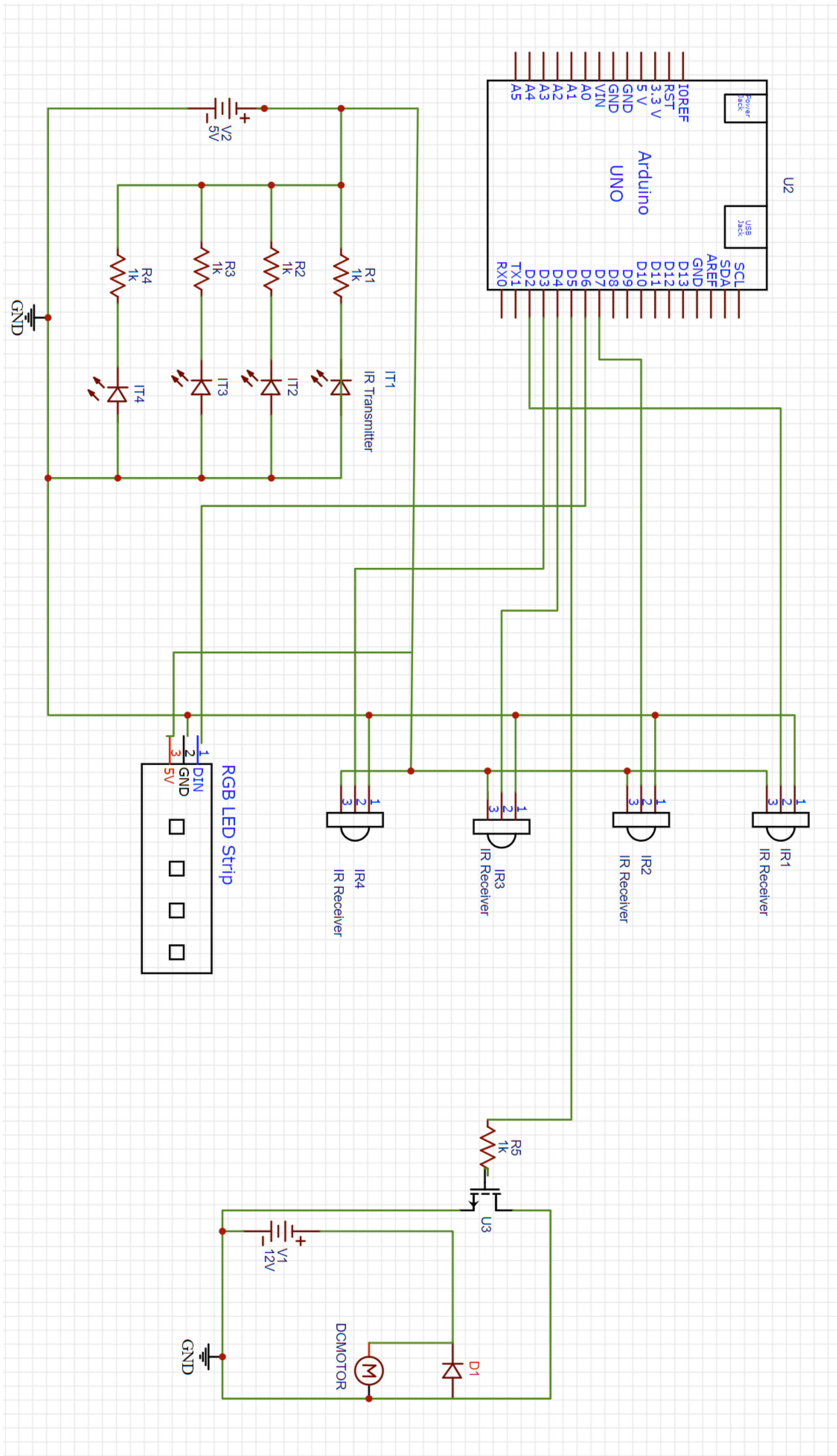
A. Lift Paddles



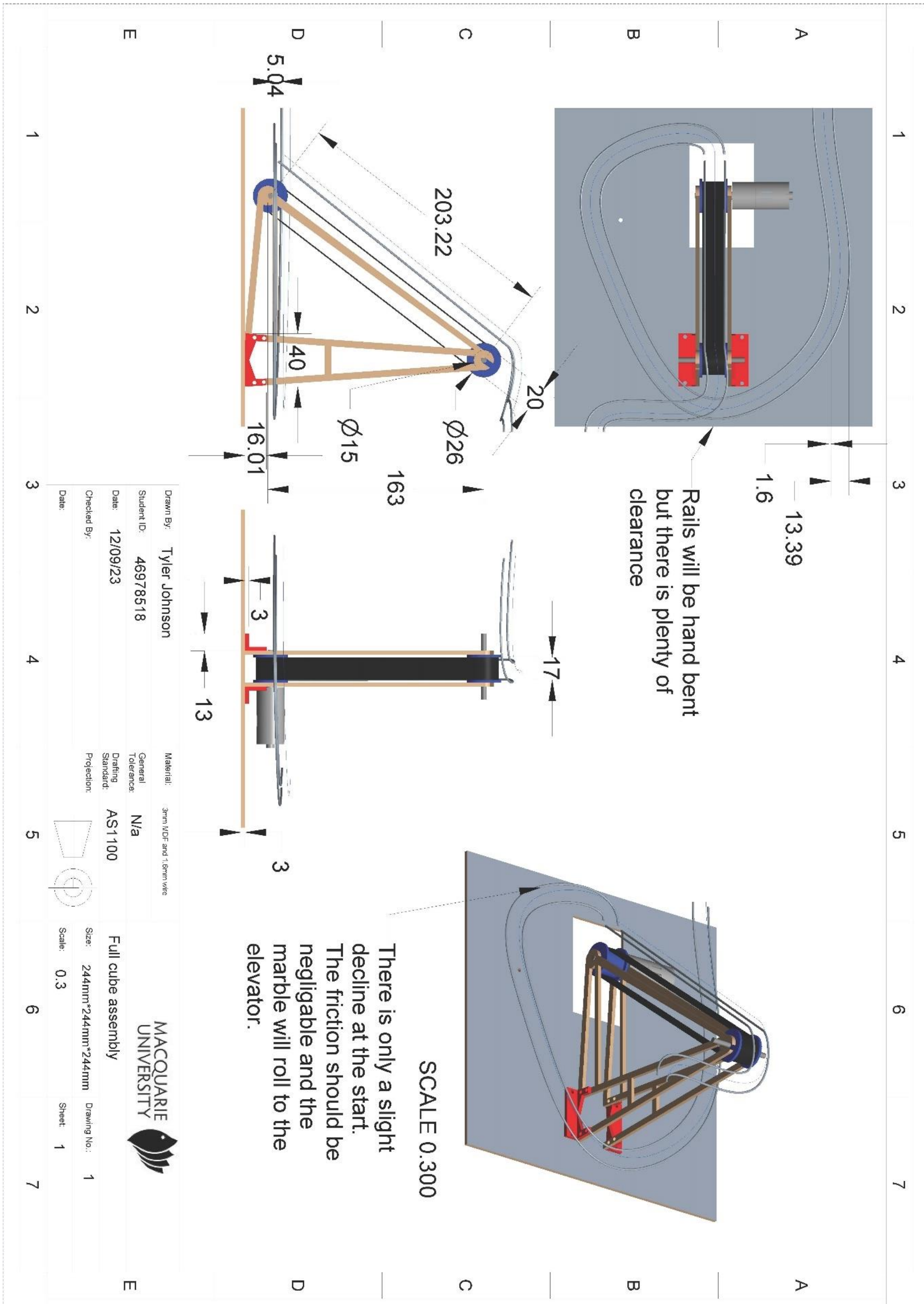
B. Lift Pulley



C. Circuit Diagram



D. Full Assembly Diagram



E. BOM: Bill of Materials

BILL OF MATERIALS - FOR TEAM TOTALS

Project: The Marble Machine

Teams: Structures 1, Comms 6, Motions 3

TEAM	Materials	Quantity Required	Description	Quantity (Supplier Units)	Unit Price (AUD)	Lead Time (Days)	Extended Price (AUD)	Alternative Acceptable?	Supplier	Store Link
Structures	MDF	1	600mm X 900mm	-	$0.00	1	$0.00	Y	Provided	N/A
	Acrylic	1	300mm X 300mm	-	$0.00	1	$0.00	Y	Provided	N/A
	Jack 1.60mm x 15m Stainless Steel 304 Grade Tie Wire	0.13	1.6mm X 2m	15m	$22.99	1	$3.07	Y	Bunnings	https://www.bunnings.com.au/jack-1-60mm-x-15m-stainless-steel-304-
	Jack 2.50mm x 24m 1kg Galvanised Tie Wire	1 m	1m	2.50mm x 24m	$15.99	1	$0.66	Y	Bunnings	https://www.bunnings.com.au/jack-2-50mm-x-24m-1kg-galvanised-tie-
	Z-bracket	2	50 x 100 x 50 x 50 x 4mm Galvanised Z		$4.58	1	$9.16	Y		https://www.bunnings.com.au/carinya-50-x-100-x-50-x-50-x-4mm-
	Screws	10	M3 x 6mm Long	1 X 100 pack	$10.75	1	$1.08	Y	RS Components	https://au.rs-online.com/web/p/self-tapping-screws/4827764?gb=b
	Crescent 200 x 4.6mm Outdoor Universal Cable Ties - 25 Pack	25	200 x 4.6 mm	1x25 Pack	$3.89	1	$3.89	Y	Bunnings	https://www.bunnings.com.au/crescent-200-x-4-6mm-outdoor-universal-cable-ties-25-pack_p0028887
	Soldering Flux	1	ROSIN Soldering Flux	-	$0.00	1	$0.00	Y	Provided	N/A
Motions	Brushed 12 V dc Motor, 34.3 mNm, 175 rpm	1	175RPM, 350gcm	1	$29.72	1	$29.72	N	RS Components	https://au.rs-online.com/web/p/dc-motors/0169409?gb=s
	eSun 3D Printer Filament (1kg)	0.1	1.75mm PLA Filament	1kg	$39.95	1	$4.00	Y	Jaycar	https://www.jaycar.com.au/esun-black-pla-filament-1kg-1-75mm/p/TL4454?pos=1&queryId=dbbb2796b32d9e08b908b38c03e338d9&sort
	Arduino Uno	1	Arduino Uno (ATmega328P)		$10.00	1	$0.00	Y	Provided	N/A
	IR LED (Side Looker)	4	950nm IR LED (Side Looker)	4	$0.79	1	$3.16	Y	RS Components	https://au.rs-online.com/web/p/ir-leds/0577538?gb=b
	IR Sensor	4	Vishay TSOP4838 950nm Reciever	4	$1.51	1	$6.06	Y	RS Components	https://au.rs-online.com/web/p/ir-receivers/7085115?gb=b
	Diode	1	Through hole diode 1N4004	1	$0.41	1	$0.41	Y	RS Components	https://au.rs-online.com/web/p/schottky-diodes-rectifiers/6289029?gb=s
	1kOhm Resistor	5	Through hole resistor	5	$0.395	1	$1.98	Y	Provided	N/A
	N-Channel MOSFET	1	500 mA, 60 V, 3-Pin TO-92 BS170	1000 (?)	$0.23	1	$0.23	Y	RS Components	https://au.rs-online.com/web/p/mosfets/1241745?gb=s
	Solderable Breadboard	1	46.99 x 24.76 x 1.5mm	1	$4.13	1	$4.13	Y	RS Components	https://au.rs-online.com/web/p/breadboards/8971641?gb=b
	Timing Belt	1	19.05 x 476 mm	1	$16.64	1	$16.64	N	RS Components	https://au.rs-online.com/web/p/timing-belts/4749800?gb=s
Comms	Digital RGB LED Strip 120 LED-Black	1	10mmx200mm	1	$21.20	1	$21.20	Y	Core Electronics	https://core-electronics.com.au/digital-rgb-led-strip-120-led-black.html?gclid=CjwKCAjwo9unBhBTEiwAipC116ytrApjWSDvUEEqMGC7wU
	Bluetooth	1	Arduino Bluetooth V4.0 BLE	1	$15.00	1	$0.00	Y	Provided	https://www.jaycar.com.au/arduino-compatible-bluetooth-v4-0-ble-
					TOTAL:		105.369			