2.007 Milestone #1 – Explore the Kit and Consider “What is Design?”

LEARNING OBJECTIVE: Begin the ideation process of design. Understand the design constraints and freedoms you have in your kit and the competition, and start thinking about how you can design around/with them.

INSTRUCTIONS:
During the first week of the semester, you will visit the Pappalardo lab and obtain your kit of materials and components. Included will be an at-home mini kit that will enable you to prototype, iterate, and practice driving your robot at home! Note that your total “kit” includes components and materials in the stock area in the middle of Pappalardo. Your machine will be built from whatever is in that kit (and additional items that are explicitly allowed), so understanding the kit is a good initial step in your design process. Your assignment for this week is to explore the kit and to document some aspects of that activity in your lab notebook. Please also take some time to think ahead about your design process.

A suggested approach to this week’s milestone is described below:

1. Design **constraints** and **freedoms** – Think about and document in your notebook what constraints the kit and the competition table impose. Are there limits to strength, friction, power, etc. of your components? Are there aspects of the competition around which you will have to conform your robot? Also think about and document in your notebook the design freedoms that the kit and competition table offer. Do certain kit components naturally lend themselves to performing certain functions on your robot? What useful functions might they serve in the competition? It is valuable for you to codify your design constraints and design freedoms, as they will help guide the design of your robot towards a tractable solution.
2. **Learning from the past** – Choose one of the robots on display that was made by a past student. Study the construction and design of the robot and sketch in your notebook roughly what tasks you think it was meant to perform. Note: for this sketching part, you could take a picture of the robot and put it in your notebook, and point out key features on the picture. Then you could make simple stick drawings of the functions/movements of what the robot did. Discuss any points of the robot’s design that you think are well executed, clever, or poorly executed. Finally, choose a subsystem on the robot and draw a free-body diagram of the forces acting on it during the robot’s operation.
3. **Thinking about process** – Review notes from Lecture #1 “Design Process” and Watch the video *What is Design?* (posted under “Resources” on the course website). Write a few sentences stating how you envision your design process will unfold through the milestones in the class. How will it be similar to or different from the design process and methodologies described in lecture and in the video?

FORMAT OF DELIVERABLE: Three to five pages in your lab notebook. Make sure you **explicitly address all of the points above, and label**. Your lab instructor will tell you whether they want you to submit your notebook physically or via a digital scan/pdf.

NOTE ON AT-HOME KIT: At the end of the semester, you will be required to hand back your power drill and remote control system, or purchase them.

OTHER ACTIVITY: Some additional goals of lab in week #1 are:

- Get a safety orientation
- Meet your lab instructor, your classmates, and the Pappalardo lab staff
- Do the sheet metal tutorial (shearing/bending)
- Learn how to use the tools of your at-home kit to do fabrication at home
- Organize a small group of peers (3 to 5) with whom to review your design work

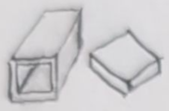
1) Design Constraints and Freedoms

Constraints:

Limited to only the parts we have in Pappalardo

Motors: Selection has limited power ranges, As a result I will likely up to have to include gearing to increase output torque, Can only use 4 gearhead motors plus 4 servo motors

Wheels: Two wheel tire option, so pretty much just two coefficients of friction to choose from. This will effect how my robot will be able to go up ramps, push, and pull.



Materials: Limited to mostly sheet, tube, and bar stock in 5052 aluminum.

3D Printing: can only use 6 in^3 of 3D printed parts

Fasteners, belts, etc are not limited

Electronics: Use Arduino, radio, and reciever that comes with default setup.

Can supplement Electronics with any additional parts or components I buy myself

Sensor selection is limited, might want to buy encoders to improve autonomous navigation

Freedoms:

Since the components, materials especially, are rather low-level, lots of freedom in the form of the robot. For example, the wheels could be used for driving with as few or as many axles as I want; 2 driven wheels, 4WD, 6WD, or something different. They could also be used as a manipulator to actuate the Centrifuge.

Even so, certain components lend themselves to certain tasks moreso than others. A servo is better for precise control of an actuater than a normal brushed DC motor.

There is a lot of freedom on the control side. We are originally given a 6-channel radio, but can use just about anything to control our robot. This could be a higher channel radio, a PS4 controller, a laser pointer, or something more.

Game Board:

Overall, even with all the freedoms, the robot must be able to complete objectives. To some extent, I can pick these objectives myself as the robot I build doesn't need to be able to do everything.

Simmons Bracelet:

Vibranium Return/Hiding: Move vibranium rocks across board

DNA Synthesis: Place rubber balls into spinning DNA structure, platforms are elevated

Beaver Mask Multiplier: Pull a ring out, but ring is heavy and must pull far

Lab Centrifuges: Spin Centrifuges to certain RPM, then disconnect

Benzene Ring Torque: Apply torque at a large height to raise flag

2) Learning from the Past

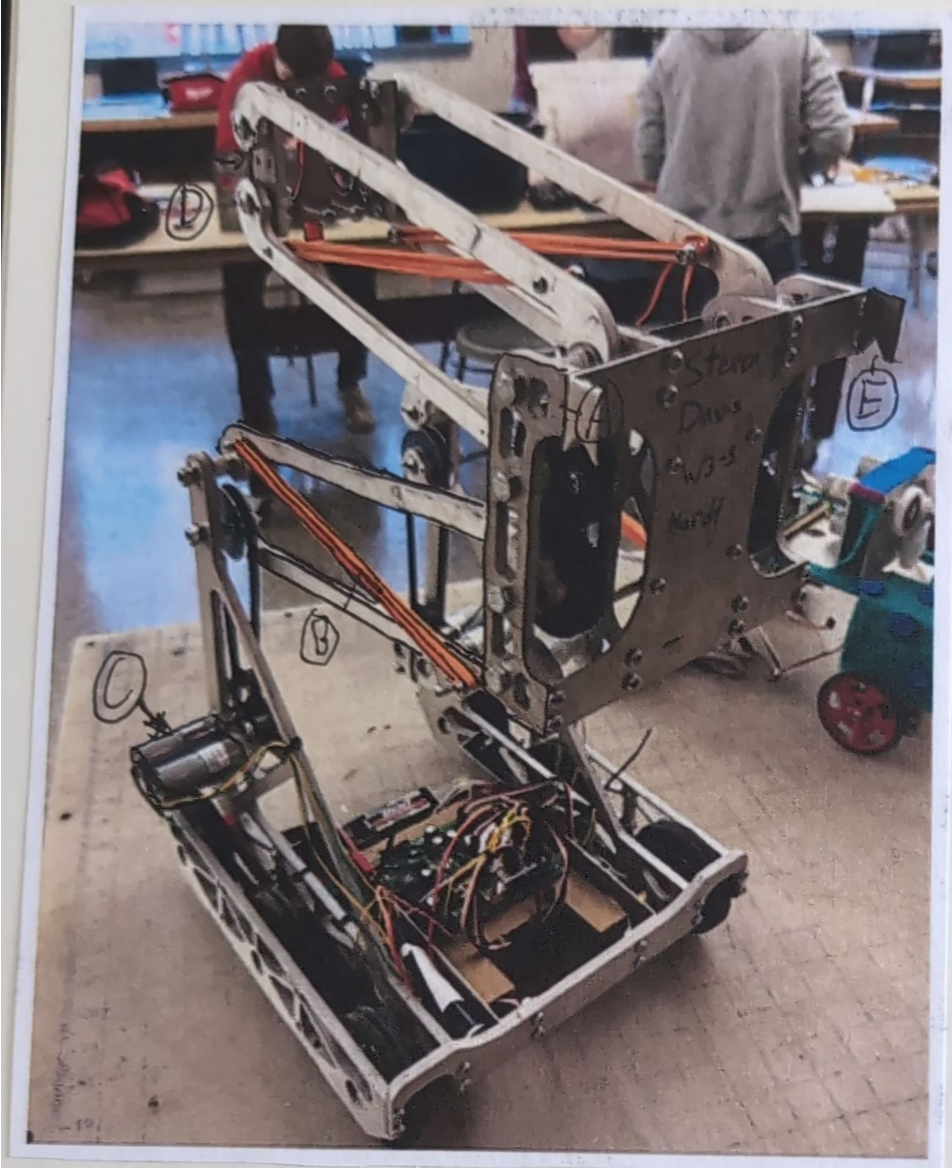


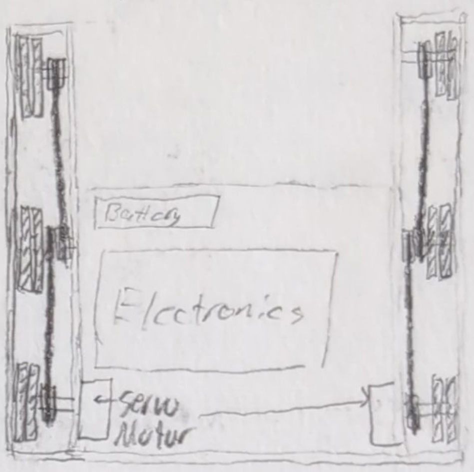
Photo taken by Evan Hutchinson

Sturdy and robust Double-reverse 4-bar link suggest robot needed to pick up something and transport it to a higher position. Manipulators at points E & D

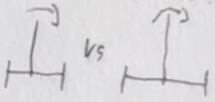
Drivetrain:

more traction with more contact area

6 axles,
12 wheels

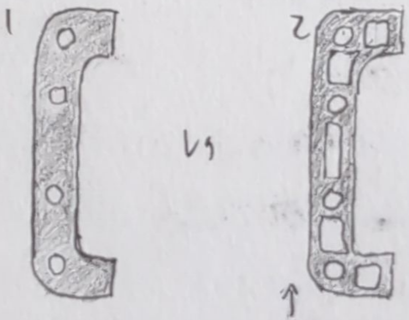


wheels on outside of axles to increase tipping stability



Swiss-cheese structural components to reduce load on motors by making forces lighter

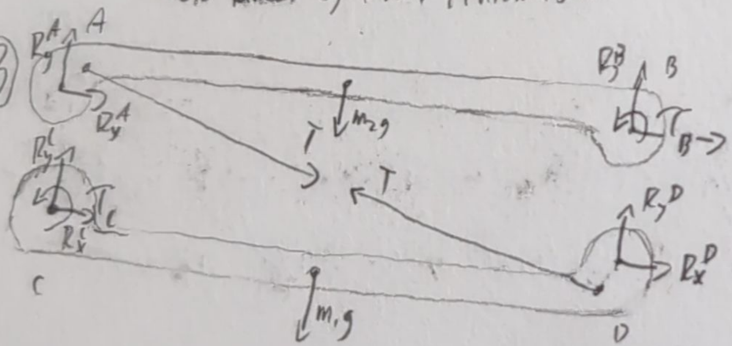
Ⓐ (in diagram):



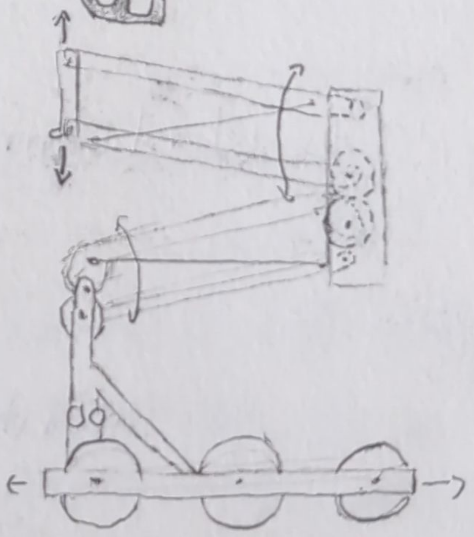
$m_1 > m_2$

$m_1 g > m_2 g$

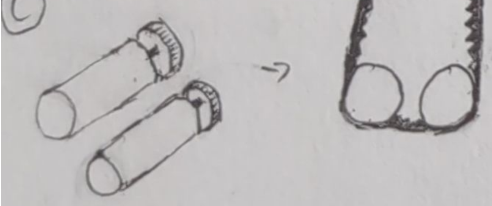
Ⓑ



Rubber bands reduce torque needed by motors



Ⓒ



double up motors for more power, } goes to large pulley for more torque

os: Overall very well constructed. Design might have partially been a demonstration of skill beyond what as required for strict function.

Good use of swiss-cheesing to reduce weight

Was conscious of force requirements and constraints imposed by design and worked to design with them in mind: more wheels, double motors, rubber bands, etc

s:

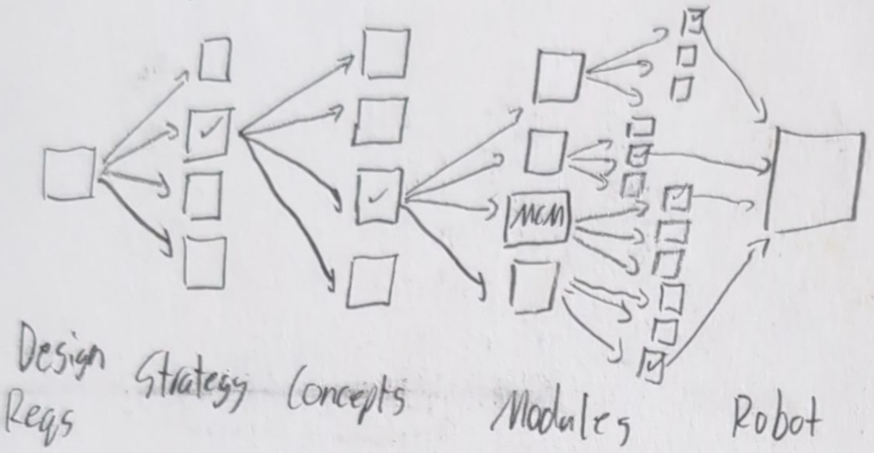
Used too many fasteners in, too many different sizes. For prototyping this increases tear-down and repair or modification time. Many different type of fasteners increases chance of confusion

Bot was likely still heavier than needed, could have incorporated more sheet metal over milled metal

3) Thinking about Process

Big Problems into small chunks
Fail early and often, not catastrophically
More ideas = better ideas, no pet concepts
Define Requirements, independent of solutions

★ Do research before building
Don't design too much before testing



Design will hopefully (if I stick to it) play out like as described in lecture.
In the "What is Design" video they had a couple steps they could have avoided if they chose to do more calculation earlier on, such as motor sizing. I hope to minimize excess steps by being thorough early on
Through the milestones, we will follow a similar design process as drawn above, but once the milestones end, we have freedom to fall off of a regimented design process, which could be far more inefficient.

A key step not discussed in the lecture or video is integration. This step, where you bring all your individual modules together and get them to work together can bring an otherwise smooth sailing project to an abrupt stop. By doing "micro-integrations" as I'm prototyping, I hope to avoid an Integration hell

2.007 Physical Homework #1 – Get to Know SolidWorks

LEARNING OBJECTIVE: Become proficient with the basic functions of SolidWorks and CAD design

Instructions:
Your first physical homework is to design your mini-me robot in SolidWorks or Fusion 360. The 2.007 instructors are best positioned to give you advice about SolidWorks, and the CAD lecture will use SolidWorks. However, we don't mind if students use Fusion 360, particularly if they have Macs or poor internet connection. Solidworks is available in all MechE computer labs.

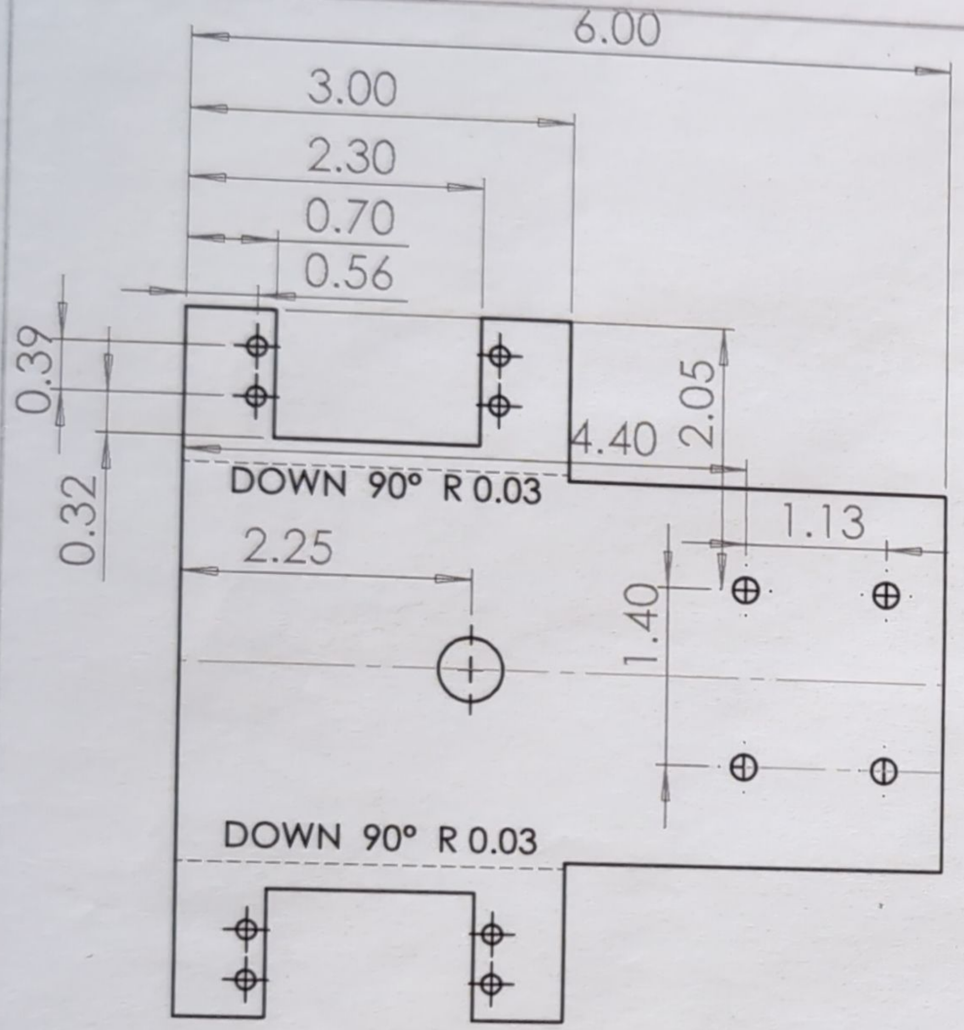
This Physical Homework will give you practice designing parts, creating assemblies, and making technical drawings. The following tasks are due as part of your Physical HW#1:

1. Complete the following SolidWorks tutorials: Lesson 1: Parts; Lesson 2: Assemblies; Lesson 3: Drawings. The tutorials can be found under the Help tab in SolidWorks. It is imperative that you complete these tutorials before you make your mini-me in SolidWorks. They will give you the skills you need to complete this assignment. For Fusion 360 users you may want to watch the tutorials (available on the CAD Resources link on Canvas). Additional CAD tutorials are posted in the CAD Resources page in the course information module.
2. Watch the YouTube tutorial on making sheet metal parts in SolidWorks (http://youtu.be/FkxJ3JchLuc). For Fusion 360, watch the video at (https://youtu.be/7hBZ6cFmWjQ).
3. Make a part of the base platform of your mini me. Make it a sheet metal part so you can fold the servo mount flanges down, just like you will bend them in real life. **Include a picture of this part in your lab notebook, with the sheet metal part in its flat and folded states.**
4. Make an assembly of your mini-me in SolidWorks or Fusion 360. **You can find CAD files (STEP) of the kit parts needed for your mini-me in the Course Information Module** (available on the CAD Resources link on Canvas). You are expected to assemble the sheet metal body with two ServoWheels, a Caster Wheel, and two servo motors (25-2 or 25-3). The assembly should include the base platform mated with the front caster and the servo motors, with the wheels connected to the servos. **Include a picture of this assembly in your lab notebook.**
5. Make an engineering drawing of your base platform in SolidWorks, **which includes all the necessary dimensions to fabricate the part. Include this drawing in your lab notebook.** Make sure your drawing shows where the bend lines are on the mini-me base platform, as well as the units of the dimensions. You will use this drawing to fabricate your mini me during Lab #2. We suggest bringing an additional printout(s) to lab to use while you fabricate your mini-me.

The pictures below are for your reference in making the mini-me. The drawing shows an example mini-me base platform. **Feel free to change these dimensions to customize your mini-me!** The dashed lines indicate the bend lines for the servo mounts. Note: the locations of the holes for the servos and casters are not shown. You should measure these locations off the servo and caster parts included in your kit. The picture shows a finished mini-me (with an RC receiver and a battery pack mounted on the top, which can be omitted in CAD).

2 1

B



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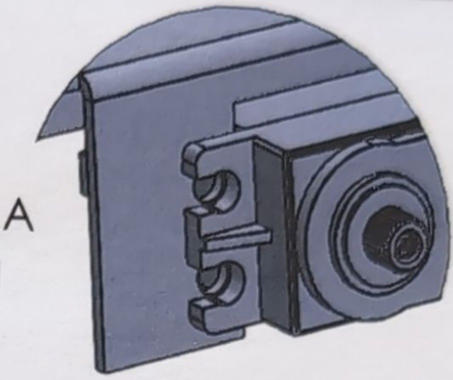

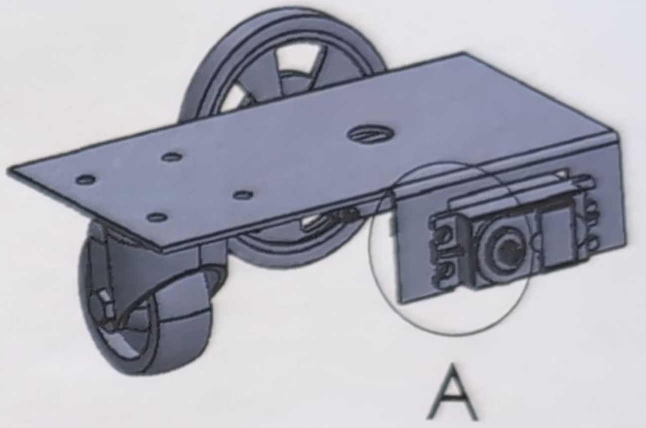

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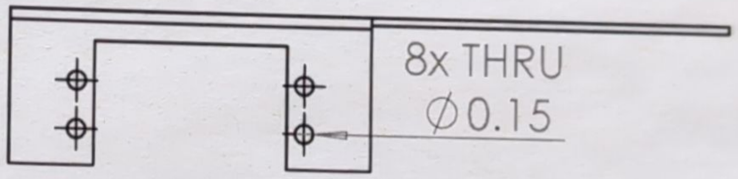

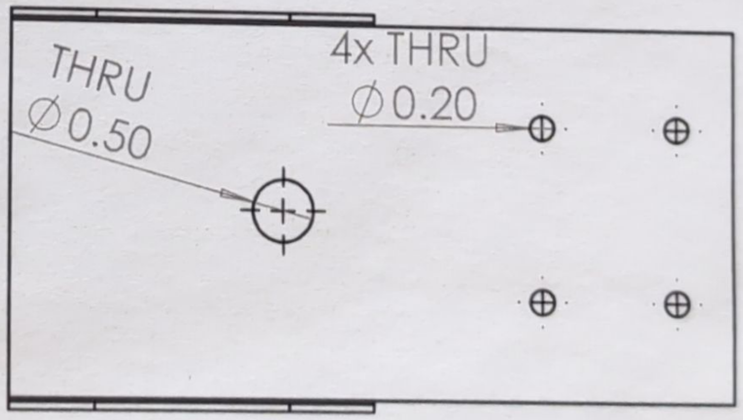

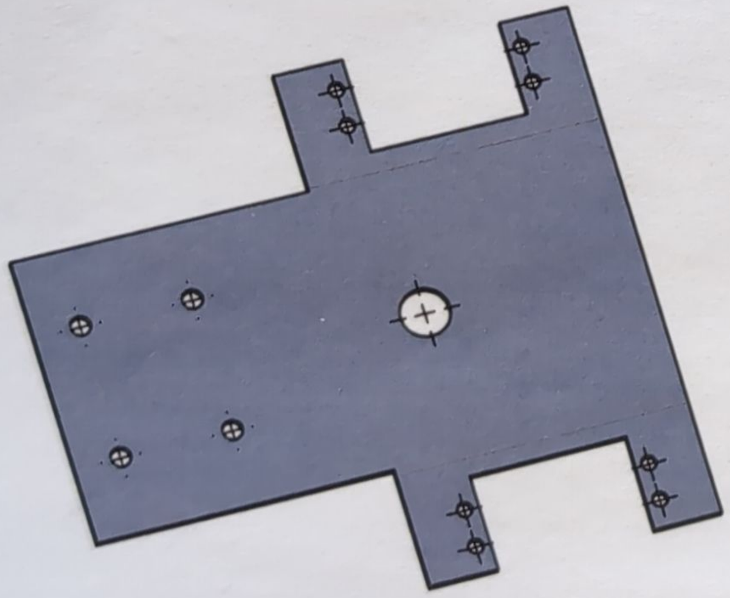

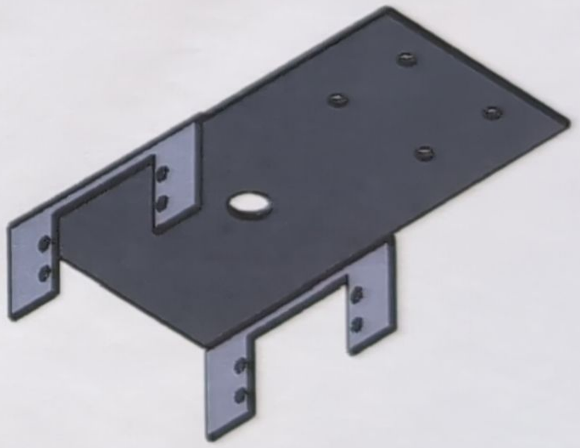

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

2.007 MIT

TITLE:

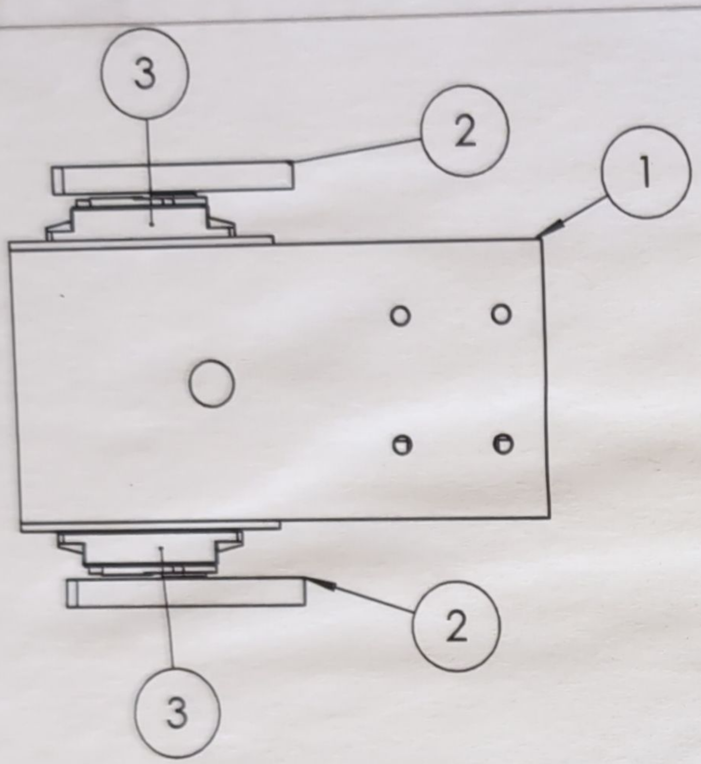
MINI-ME CHASSIS

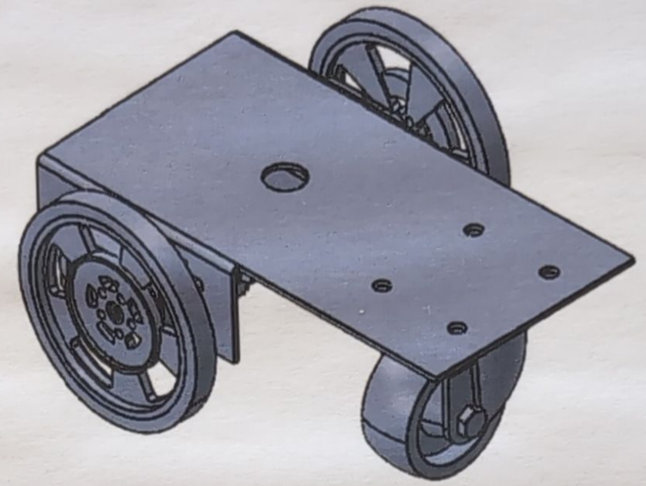
SIZE	DWG. NO.	REV
A	Chassis	

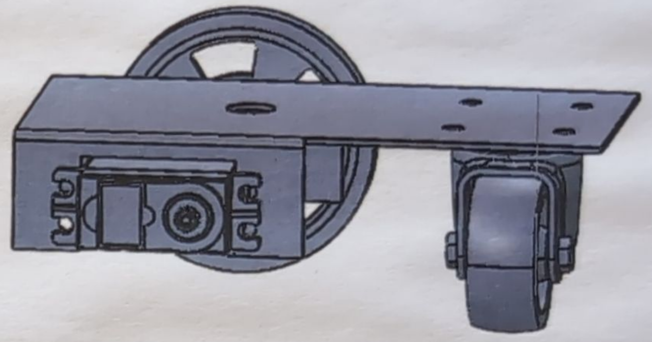
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

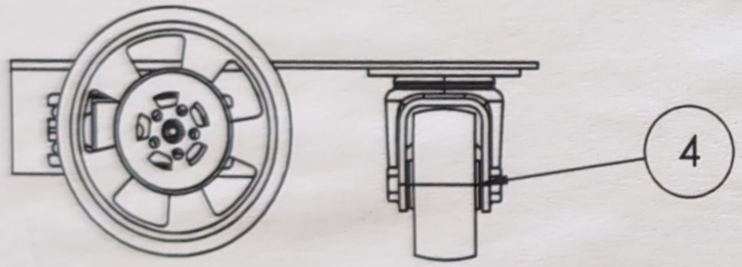
2 1

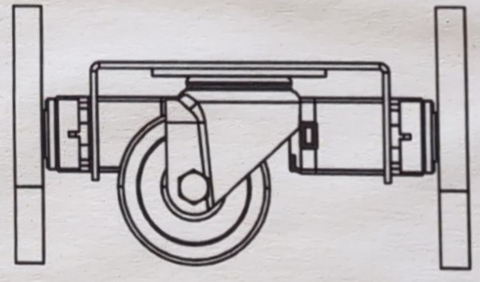
B B











ITEM NO.	PART NUMBER	QTY.
1	Chassis	1
2	Wheel	2
3	25-3 Servo	2
4	Caster Wheel	1

A A

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Elijah Bell	3/7/2023
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

2.007 MIT

TITLE:

MINI-ME ASSEMBLY

SIZE	DWG. NO.	REV
A	Mini-Me	1

SCALE: 1:2.5 WEIGHT: SHEET 1 OF 1

2.007 Milestone #2 – Preliminary Strategy and Simple Build

LEARNING OBJECTIVES: Become accustomed with the shop and some of its fabrication tools; get experience going from design to CAD to engineering drawing to fabrication; start interacting with the game board with your mini-me; practice generating multiple strategies; using design analysis/rational to pick your preliminary strategy.

INSTRUCTIONS:
This milestone has two parts. The first part is the fabrication of a simple vehicle (we call it the "mini-me"). It is a roving platform made from a cut and bent piece of ABS plastic or sheet metal, two servomotors, two wheels, and a swivel caster. Work from the drawing you made for Physical Homework #1 to construct your mini-me. Feel free to modify the design to suit your personal preferences, or to correct any errors in your drawings. The point of this exercise is to learn how to make a part from a technical drawing, get your hands dirty fabricating in the shop, and become accustomed to your kit components. You should be able to finish your Mini Me during Lab #2.

The second part of this week's Lab Activity centers on the definition and selection of your preliminary strategy for the contest. Since a *strategy* is plan of action designed to achieve a particular goal, independent of a physical embodiment, you don't need to describe your design concept (what your robot may look like) yet. The design concept is due in Milestone #3. Your preliminary strategy should be documented with about 3-4 pages in your lab notebook. These pages should generally include the items listed below. **Make sure you explore multiple strategies – i.e. different plans of action that your robot could accomplish.** You can mix and match elements of different strategies to find the best one. Do not just pick one strategy and answer the questions below. We want to see evidence of your exploration of multiple ideas, because more ideas lead to better ideas! Refer to Prof. Winter's example in Lecture #1 about exploring and evaluating multiple strategies.

1. Overall description – Explain, using words and graphics, what your strategy entails. An annotated sketch of the playing field is often helpful in communicating your ideas. This could include where your robot(s) will travel and what actions it will do.
2. Analysis – Decompose the strategy into various steps or sub-tasks. Include an estimate of how your strategy is expected to perform according to the scoring formula – i.e. work out the number of points you could score if you completed different tasks during the competition. Also estimate the time required to complete different tasks. Driving your mini-me around the game board is a great way to estimate the amount of time it takes to get from one place to another.
3. Physics-based estimates – Show that you can identify key problems and resolve them with physics-based reasoning. For example, a robot might need a minimum amount of power to lift an object quickly. You might make some calculations or simple experiments to create a rough, quantitative assessment of parameters related to your most critical tasks.
4. Choosing your best strategy – Show how you determined your best strategy. Your analysis and physics-based estimates may give you quantitative metrics by which to compare strategies. You may also use Pugh Charts (like what Prof. Winter showed in the example in Lecture 1) to choose between strategies. Fabricating simple physical mock-ups (such as EPS foam models) is also a great way to validate your design decisions.
5. List out the core design requirements associate with your strategy. These requirements must be met for your strategy to be successful. Try to make your design requirements as quantitative as possible (e.g. say robot must travel at 2 m/s rather than "fast"). In the next milestone, you will generate concepts for your robot that can satisfy the design requirements of your strategy.

NOTE: You are free to modify your strategy later in the term based on evidence accumulated during your design process. Experience has shown that *strategic thinking* is helpful to the design process at this stage. Even if the particular strategy is not so useful in hindsight, the process of working out a strategy places you in a better position to carry out your design. Design is iterative!

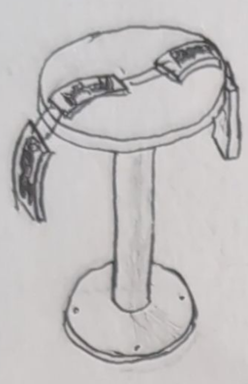
FORMAT OF DELIVERABLE:
3-5 pages in the notebook and a mini-me. Make sure to address all five points listed above and label them in your notebook.

Strategy:

Analysis of each game scoring objective:

Simmons Bracelet:

	Pts.
First player to collect bracelet	11 pts
Max	11 pts



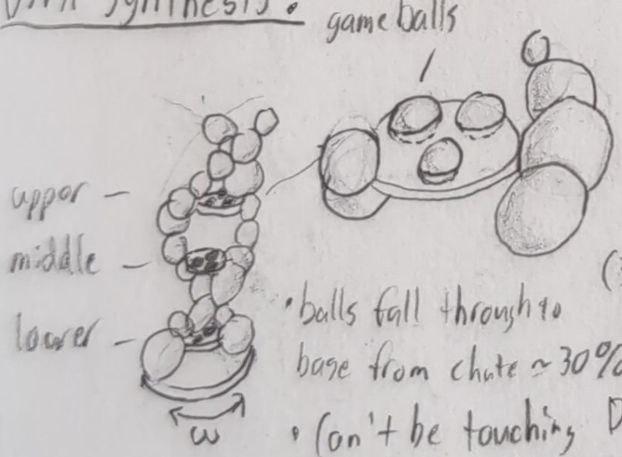
- Only element that has a time element to it, and
- Have to do it early on in the round - Autonomous? 22pts
- Too few points to be a serious priority

Vibranium:

	Vibranium in Hiding	Vibranium in Charles
Pts	0.5pts per	3pts per
Max	5·0.5 = 2.5pts	5·3 = 15pts

- Both robots can be along any part of the bridge area.
- Unless able to get the vibranium over the fence, points are almost meaningless.
- Vibranium comes in many shapes, sizes, and weights

DNA Synthesis:

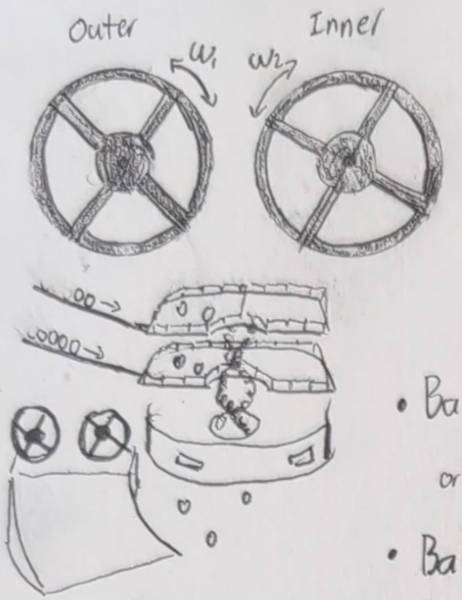


	Lower	Middle	Upper
Pts	21pts per	27 pts per	48pts per
Max (3 balls)	63pts	81pts	144pts
Max (3+0.3·10 = balls at n-1)	63 pts	144pts	225 pts

- balls fall through to base from chute ~30%
- Can't be touching DNA at end of round, but allowed to during the round.
- Could stop DNA from rotating to make placement easier
- Start with 3x balls loaded at beginning of round
- For extremely high scoring (628 pts technically possible) rely on luck for balls to fall down to floor to be retrievable
- Difficult objective, precision, height, manipulation, etc
- If facing other robot with DNA goal, will come down to who is faster, more precise, or stronger for who can put more balls on upper platforms

Strategy (cont.)

Lab Centrifuge:



	Speed (RPM)	Outer Pts	Inner Pts	
	25-50	5pts	3pts	
	51-100	10 pts	7pts	
	101-150	20 pts	15 pts	
	151-200	40 pts	21 pts	
Max	201-250	47pts	26 pts	73
	251+	0	0	

Ball Position	Pts
Base of Lab	0 pts per
Lower Shelf	2pts per
Upper Shelf	5pts per

Max based on chance

- Balls are released every 5 seconds within a particular speed zone.
  - Could spin at low speed to release balls and then spin up to 225rpm and detac
  - or? Could spin up to 225 and hold there to release balls and then detach.
- Ball releases also help DNA synthesis
- Reasonable to expect to be able to do during <u>autonomous period</u>, would result in 146pts + ball points

5sec · 5ball = <u>25sec</u>

- Spin wheels in opposite direction to counteract torque imbalance

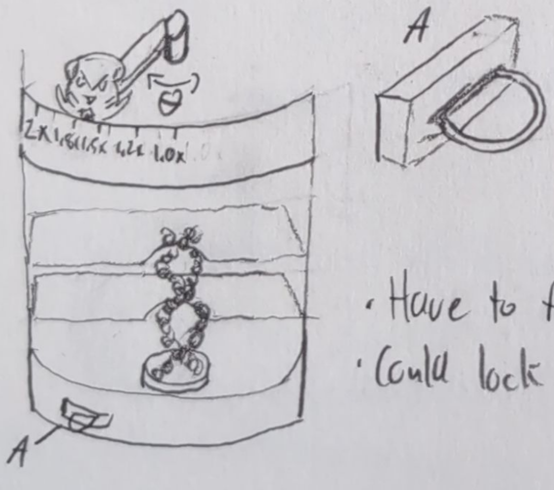
Benzene Ring Torque:

		Pts	Cumul. Pts
	First Zone	15	15
	Second Zone	11	26
	Third Zone	8	34
Max	Fourth Zone	5	39

- Placed close to centrifuge
- Torque at elevation could be hard to deal with without tipping

- Points are only awarded once

Beaver Mask Multiplier:



Multiplier
1.2x
1.5x
1.8x
2.0x

- Very big advantage to pull, especially if strong enough to block out other player
- Can be pulled at any time and applied to all points acquired during play

- Have to fight against other bot in torque if both ring pull at the same time
- Could lock ring in winch to prevent other bot from using at all

Point benchmarks

A well built robot will be able to score ≈200 points a game →

73pts from centrifuge
5 pts ramp
25pts balls
· 2x multiplier

206 points

A reasonably built robot will be able to score ≈120 points →

73 points from centri.
39 points from benzene
11 points from bracelet

123 points

Strategy (objectives)

Strategy #1: Autonomous Spinner + Bracelet grabber

Total = 218pts

3 manipulators

- Benzene ring = 39pts
- Centrifuge = 23pts - Autonomous
- Bracelet = 11pts - just try to snag with spinner
- Balls points = 22 pts

Autonomous Centrifuge = 146pts
Upper Rings x 3 balls = 144pts

Stategy #2 Lift expert

Upper ring x3 = 144 pts
Multiplier x2 = ·2x

Total = 288pts

No autonomy

Strategy #3 Tryhard:

Upper ring x3 = 144 pts
Autonomous Centrifuge = 146 pts
Multiplier x2
Ball points = 22pts

total = 602pts

Difficult but almost unbeatable

- Could spin both centrifuges with 1 motor, but might take too much time to get up to speed

Strategy #4 Picker-upper

Upper Ring x4 = 144 pts
Autonomous Outer Centri. = 94 pts
Ball points = [illegible] pts

90 seconds to pick and place 2 balls
starts with 3 loaded

Total = 404 pts

- Picks up ground balls

Strategy #5 Reasonable Bot

- Autonomous Centrifuge = 146pts
- Ring Pull multiplier = ·2

Total = 292 pts — about equal to Lift Expert

- Could definitely build this
- Lifts are cooler tho

Without multiplier, impossible to get past 150pts
Could lock off multiplier with a droppable module

Need to either be able to control multiplier or ignore it

- Get early - before pulled/locked by other robot
- X Do strategy #1 and ignore multiplier 3x
- Out pull other robot

Order of Importance:

- Key subassemblies
  - Strong (droppable?) ring puller 2
  - Lift + ball placer 3
  - Centrifuge spinner 1
  - Ball manipulator - pick-upper and placer 4

Strategy (Calculations):

Need to get Centrifuges up to speed within < 30 seconds for autonomous points.

Schedule #1

Autonomous start — 0s - 5s deploy and activate detachable mask ring puller
6s - 14s Get to Centrifuge and position spinner
14s - 30s Get centrifuge to 225 rpm
Autonomous end — 31s - 55s Maintain 225rpm on both spinners
~56 - 120s Grab bracelet if free or push Vibranium to my side

Schedule #2: (non-detachable)

Autonomous start 0s - 8s Get to Centrifuge from ramp start
8s - 23s Get Centrifuges up to 225 rpm
Autonomous ends ~24s - 48s Maintain 225 rpm
49s - 56s Move to Ring
56s - 70s Pull Ring really hard
71s - 120s Grab bracelet if free or push Vibranium to my side
Grab bracelet if free or push Vibranium to my side

In the last period for both, if have completed lift or ball manipulator, then put balls in DNA

ω ~~θ~~ vs t

$\tau = I\ddot{\theta} + \tau_f$ $\quad \omega = \frac{B}{A} + C_1 e^{-At}$

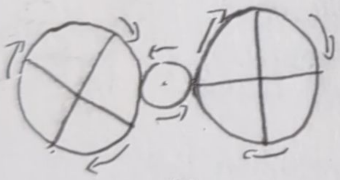
$I\dot{\omega}$

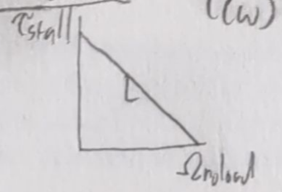
$\underline{\dot{\omega} + A\omega = B}$

Centrifuges Dual Spin Physics:

$\tau(\omega) = \frac{-\tau_{stall}}{\Omega_{noload}}\omega + \tau_{stall}$ $\quad \ddot{\theta}$

Target = 225 RPM = 23.562 rad/sec

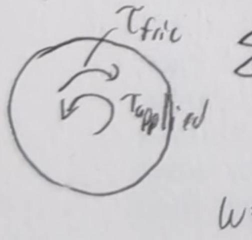




$$\boxed{\frac{-\tau_{stall}}{\Omega_{noload}}\omega + \tau_{stall} - T_{fric} = I\dot{\omega}}$$

$$\boxed{A = \frac{\tau_{stall}}{\Omega_{noload} I} \quad B = \frac{\tau_{stall} - T_{fric}}{I}}$$

$$\frac{\tau_{stall} - T_{fric}}{I} = \frac{\tau_{stall}}{\Omega_{noload} I}\omega + \dot{\omega}$$



$\sum T = I\alpha$ $\quad \omega = \dot{\theta}$ $\quad \alpha = \ddot{\theta}$

$T_{applied} - \tau_{fric} = I\alpha$

$\omega = \omega_0 + \alpha t \quad \frac{\omega}{t} = \alpha$

$$\boxed{\omega(t) = \frac{B}{A} - \frac{B}{A} e^{-At}}$$

rad/s or rpm? — ω(RPM)

$\tau^I_{fric} = 0.028$ kgm $\quad I^I = 0.05741$

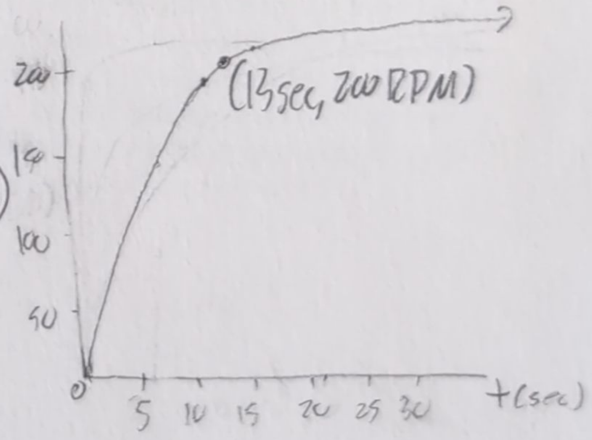
$\tau^O_{fric} = 0.007$ kgm $\quad I^O = 0.0133$

$I = I^I + I^O$

$\tau_{fric} = \tau^O_{fric} + \tau^I_{fric}$

Using 26:1 LDO $\tau_{stall} = 0.2$ nm
$\Omega_{noload} = 230$ rpm

2x 26:1 motor

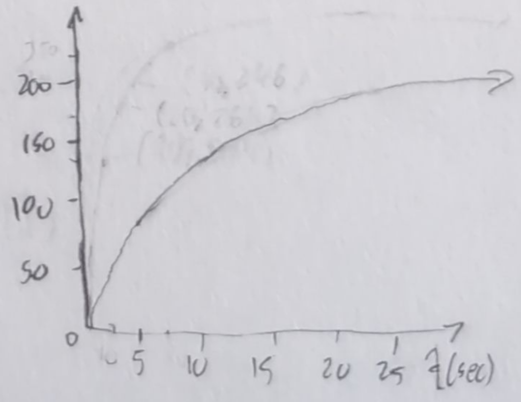


Need 2 motors

Need at least 2 motors

1x 26:1 motor

ω(RPM)



Math attempt #2:

$$\frac{-\tau_{stall}}{\Omega_{noload}}\dot{\theta} + \tau_{stall} - \tau_{fric} = I\ddot{\theta}$$

wrong t ew ↙

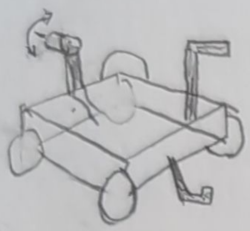
$$\xcancel{\theta(t) = \frac{\Omega_{n/c}\, t(\tau_s - \tau_f)}{\tau_s} + \frac{\Omega_{n/c} I k_1 e^{-\left(\frac{\tau_s t}{\Omega_{n/c} I}\right)}}{\tau_s} + k_2}$$

$\theta(0) = 0 \quad \dot{\theta}(0) = 0$

$$\xcancel{\theta(t) = \frac{\Omega_{n/c}(\tau_s - \tau_f) e^{-\left(\frac{\tau_s t}{\Omega_{n/c} I}\right)}\left(\tau_s t e^{\left(\frac{\tau_s t}{\Omega_{n/c} I}\right)} - \Omega_{n/c} I \left(e^{\left(\frac{\tau_s t}{\Omega_{n/c} I}\right)} - 1\right)\right)}{{}^2}}$$

Strategy Overview:

Reasonable Bot (with Expansion)



Total = 334 pts

- Objectives:
  - Autonomous Centrifuge (outer & inner) (23pts)
  - Mask Multiplier (2x)
  - Ball points (20pts)
  - Simmons Bracelet (22pts)

Schedule #2

- Expansion Objectives: (if time/need)
  1) Make lift and ball placer
  2) Make ball placer able to pick up balls too
  3) Detachable Ring Puller

Quantitative Requirements!

- Spin up both Centrifuges up to 225 rpm within 15 seconds
- Pull the max ring with more than most bot's torque, ≈60N
- Sense centrifuges and place spinner autonomously

Open to modifications if during design I realize clever ways to do previously prohibitively difficult tasks.

2.007 Physical Homework #2 – Design a Module for Your Mini-Me

LEARNING OBJECTIVES: This physical homework will give you practice ideating, making a bench-level prototype of a design, and then fabricating a finished design based on the results of your prototype; and you will gain practice driving on the game board and scoring points.

INSTRUCTIONS:
At this point you have a mini-me that you can drive around the competition table. Now it's time to see what you can do with it! The goal of the exercise is to design a simple piece that can be attached on the mini-me to effectively push vibranium from the Mass Ave. Bridge into the hiding area on the game board.

1. **Brainstorming and quick-and-dirty prototype**
   In your notebook, **sketch at least five concepts** for the added component on your mini-me to push the vibranium. Choose the most promising concept (using one of the selection processes taught in lecture) and make a bench-level prototype of the vibranium pushing device. You can make this out of cardboard using hot glue or double-sided tape. The point of this prototype is to validate your idea via experiments in a few minutes! – **quick** and **dirty** but functional is perfect! **Take a picture of this prototype and put it in your design notebook.**

2. **CAD model**
   Once you are confident your design will work based on your bench-level-prototype testing, design a final version using materials found in your kit. Draw the final version of your device in CAD and add it to the model of your mini-me. We do not want you to go overboard with this design; for example, simple implements composed of a single piece of bent sheet metal, a riveted box extrusion, or a revised mini-me platform are perfectly good solution. **Include a picture of your mini-me + the device CAD model in your design notebook.**

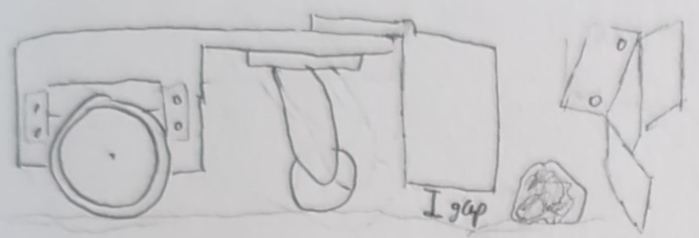
3. **Fabrication**
   Fabricate your final vibranium pushing device out of more reliable materials (plastic or aluminum) and attach it to your mini-me using screws (or some other reliable methods). Make sure you come to lab sometime during the week before the assignment is due and the shop staff will be happy to help you fabricate your creation. **Include a picture of your fabricated mini-me +vibranium pushing device in your design notebook.**

4. **Demonstration**
   You will physically demonstrate your design by having your mini-me to push one piece of vibranium from the Mass Ave. Bridge into the vibranium hiding area next to ramps. You must demonstrate this either by **emailing a video** to your lab instructor before Lab #3 or **physically demonstrating** your device during the Lab #3. **The physical demonstration is worth 50% of your grade on this assignment.** Accountability, and ensuring your design will work by testing it before the due date, is an important skill to develop as a design engineer. You will likely find many unexpected failure modes even in this simple practice. Welcome to the real world!!

Ideation:

1

2



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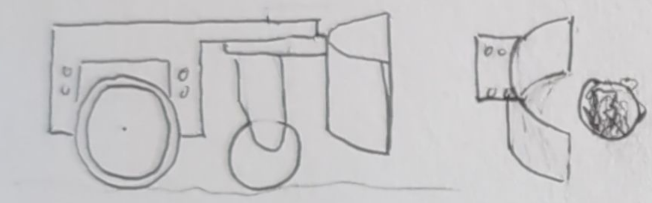
4



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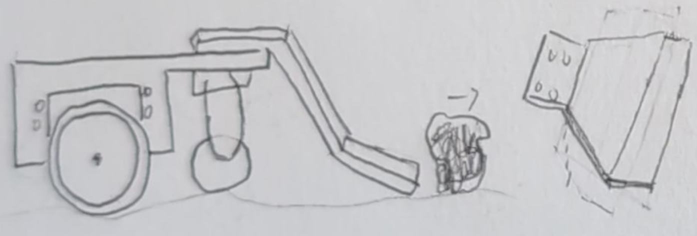
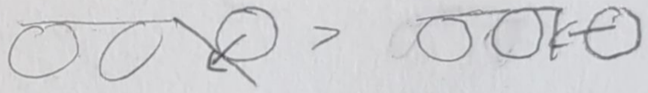
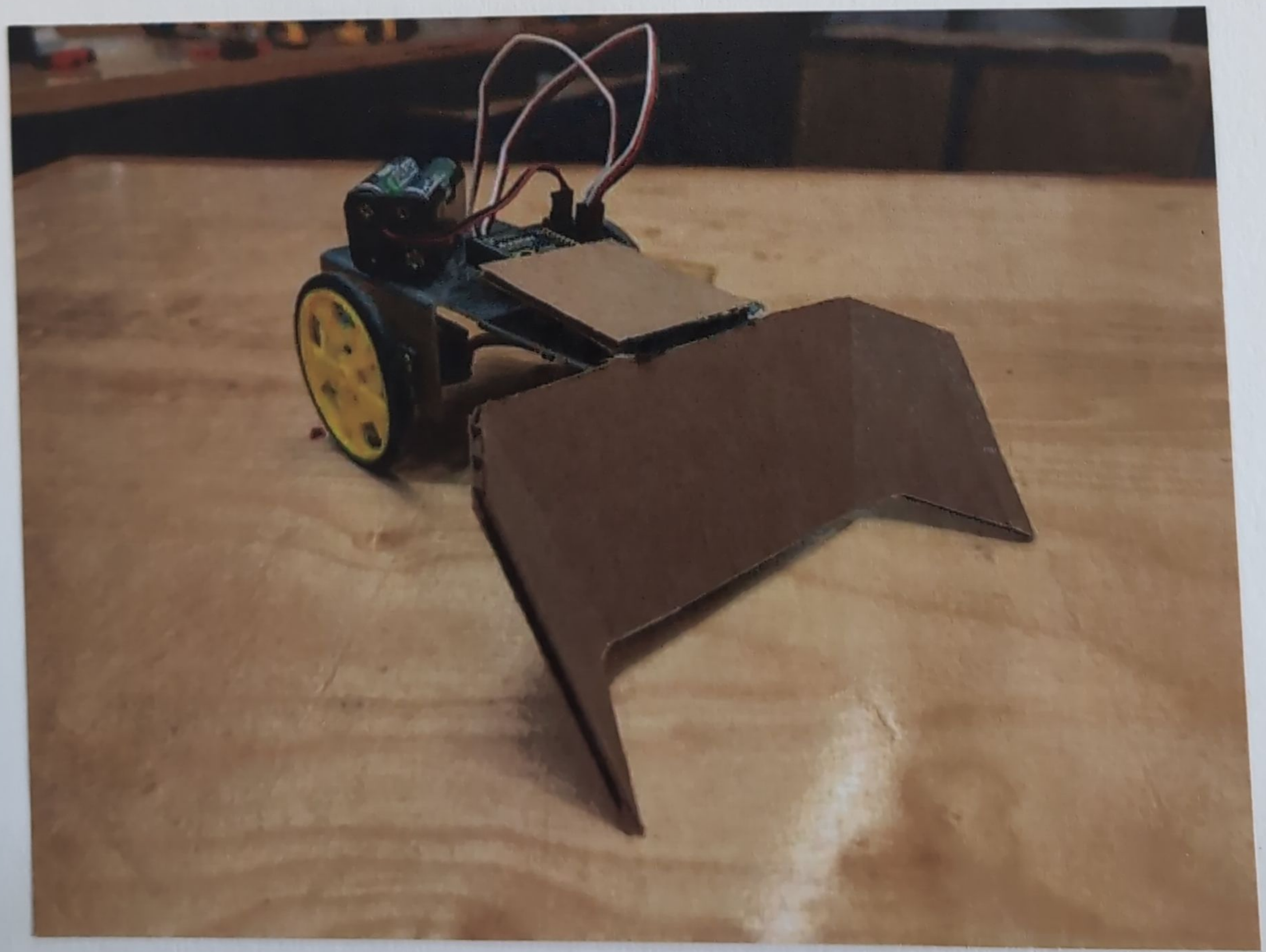


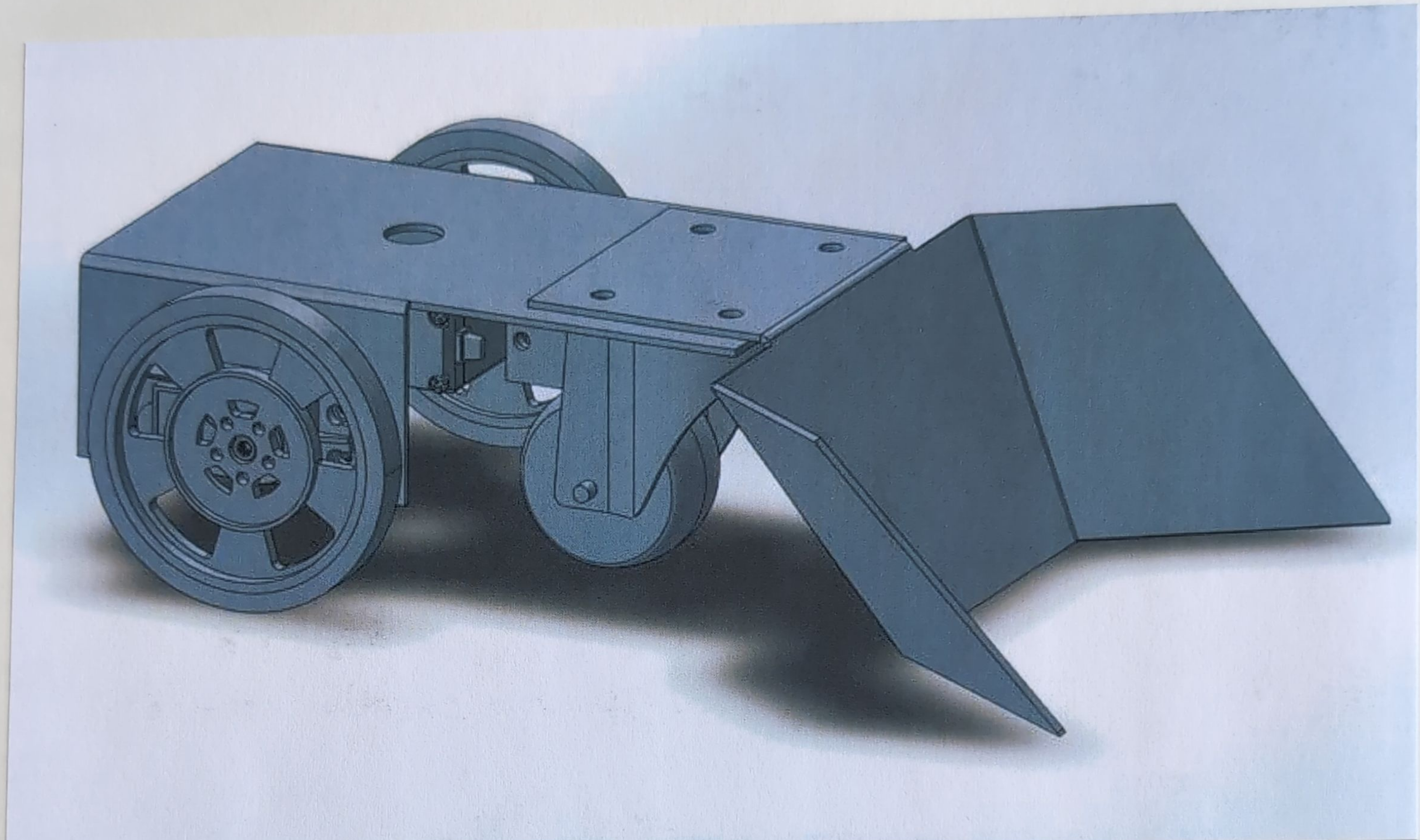
	Function 0-10	Manufacturing 0-10	Weight 0-5	Strength 0-5	total
1	8	6	3	3	20 ☆
2	7	7	3	3	20
3	6	4	4	2	16
4	8	3	3	4	18
5	5	6	3	3	17

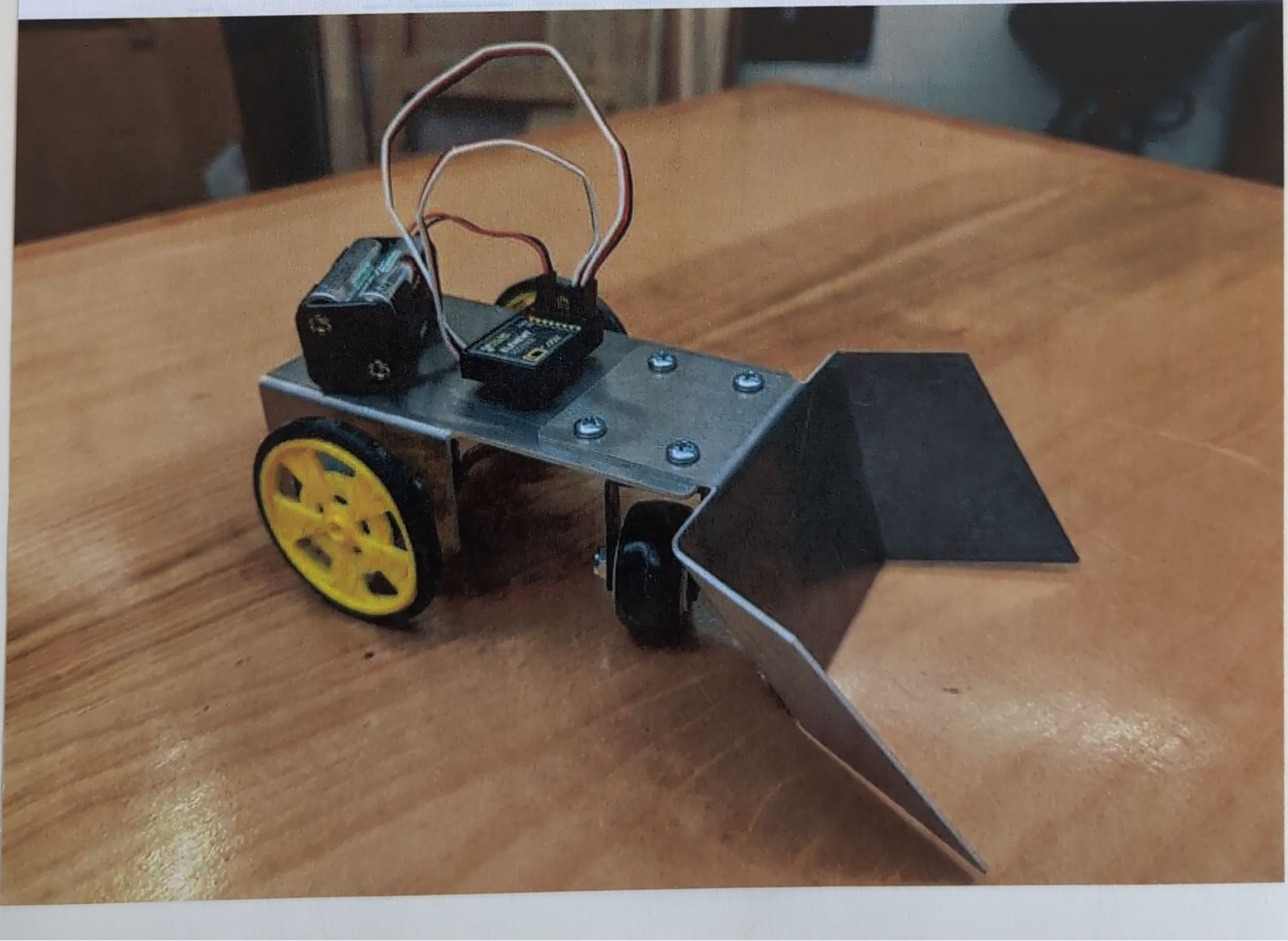
Going with option #1 because I like it more and it ties first place

Angled slope also might help push better by increasing Normal force and thus increasing traction









2.007 Milestone #3 – Design Concept

LEARNING OBJECTIVES: Learn how to generate and evaluate concepts, determine if they satisfy your strategy.

INSTRUCTIONS:
This milestone centers on the definition and selection of your design concept. A design *concept* articulates the physical embodiment of a design that can accomplish a strategy. Use the best strategy you devised last week and generate multiple concepts that can achieve it. Your concepts can leave out design *details* **that you'll develop later in the term.** Don't worry **about becoming locked in** -- this is a preliminary design that can be altered later as circumstances dictate. Your work should be documented with about 4-5 pages in your lab notebook. Please explicitly address each point below.

1. **Articulate the problem** – Update your list of design requirements from your strategy exercise. Write down all of your design requirements (at least five) that your concept(s) must achieve to successfully accomplish your strategy.
2. **Concept generation** – Sketch ***at least*** 5 concepts (pictures of what your machine would look like) that could achieve your strategy. More ideas = better ideas! You are welcome (and encouraged) to mix and match features of different concepts, or come up with totally new ideas for each. Ideally you will do both. Force yourself to think of different solutions – **don't just draw the same robot five times** with slightly different wheels, or **painted different colors. Don't be afraid to** generate crazy, somewhat intractable ideas; there may be features of those ideas that are usable. Push yourself to make each concept distinctly different. **Avoid black box syndrome!** Every concept needs to show enough detail so the reader can understand the core functions and elements of the robot, and it makes logical sense that such a robot could accomplish the intended task.
3. **Selection rationale** – Choose a best concept and explain why it seems preferable. As part of this, list a few criteria you have used in your selection process. A Pugh chart/matrix is one good way to summarize the information. Physics/analysis is also a good way to justify a design. **Describe any major risks you've** identified for your chosen concept and generate countermeasures you might employ to overcome them. You can often find good countermeasures in the other concepts you generated.
4. **First order models** – Generate some coarse models of your chosen design concept **(by "coarse" I mean** leaving out details, not necessarily implying sloppiness). We LOVE to see bench-level prototypes, similar to those that Prof. Winter showed in the second lecture. This week in lab would be a great time to test a bunch of models on the game board to see how well they may or may not work. You may also find it helpful to create very simple models of some of your ideas in SolidWorks, such as a linkage geometry or a layout for a mobile driving platform. Document all of your sketches/bench-level models/CAD in your notebook with pictures and printouts.
5. **Planning ahead** – Identify the Most Critical Module (MCM)[1] of your concept. You will develop your MCM in Milestone #4. Describe how you plan to address the development of your MCM using design and CAD work, and include a tentative plan for fabrication of the MCM.
6. We will do a quick tutorial workshop during next lab session. To prepare for that, you should install two programs on your computer beforehand. One is interface software and the other one is the FTDI driver for the communication between your computer and Arduino board. You should follow all the steps in the page below and exercise 'BLINK LED' then you are all set!!
   https://sites.google.com/site/2007arduino/installation

DELIVERABLE:
About 4~5 pages of text, drawings, screen captures of Solidworks models, calculations and plan in your design notebook.

OTHER ACTIVITY:

---

[1] Development of the MCM is an essential part of the design process. You have to strategically identify the **most uncertain but critical** function of your ideas and build a prototype to test the function quickly. The result of the prototype should be able to determine either the idea is going to work or not. The purpose of building MCM is test the feasibility of your idea. The upcoming milestones will focus on your MCM.

Subassemblies:

- Drivetrain (tank, mecanum, swerve, 2WD, 4WD, Holonomic) } geartrain?
- Spinner (double claw, spinner wheel)
- Ring Puller (winch, harmonic gear, Pneumatics, Screw Jack, use lift)
- Control (radio, ps4 controller)
- Ball Manipulator (Gripper, Vacuum, Conveyor)
- Lift (Elevator, Scissor, Reverse 4 bar, Telescoping Tube, Folding Arm

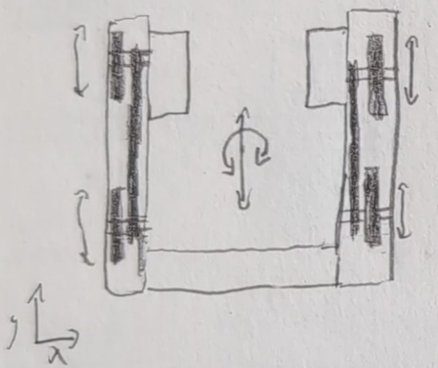
Drivetrain:

Requirements: Sturdy, immune to tipping & slipping, manuverable, and uses as few motors as is needed

Tank drive:

Decisions:
- Motor position
- 4 or 6 wheels
- Gearing?

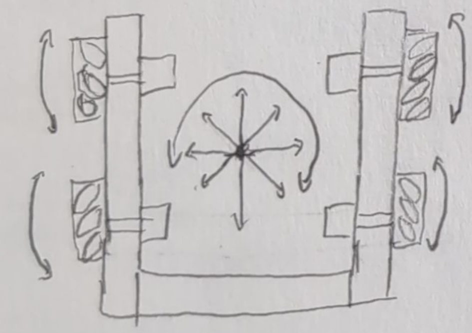
- Simple design, only slightly more complex than 2WD
- Difficulty with $\hat{x}$ positioning
- 2 motors



Mecanum Drive:

Decisions:
- Gearing?
- Wheel size
-

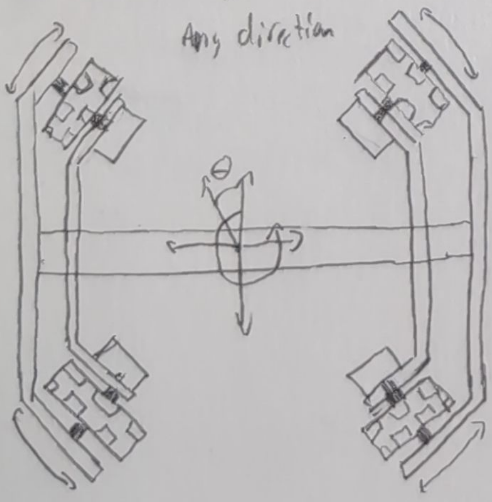
- Simple design, more complex to program perhaps
- Great maneuverability
- 4 motors
- Need Mecanum wheels



Holonomic Drive:

Decisions:
- Gearing?
- wheel size
- Frame attachment

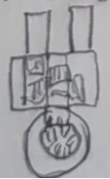
- More complex design, mid difficulty programming
- Great maneuverability
- 4 motors



Overall Choice for Drive train:

Tank Drive

Swerve:

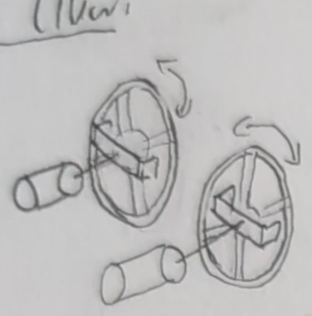


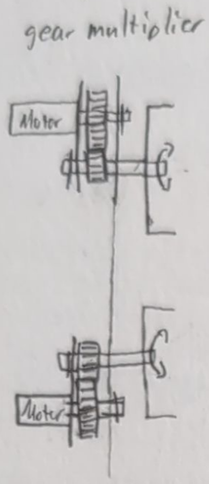
Great maneuverability but for too complex to be worth it

Spinner for centrifuges:

Requirements: Spin both centrifuges at $200<x<250$ within 15 seconds
- Calcs show need at least 2 gearhead motors

Double Claw:

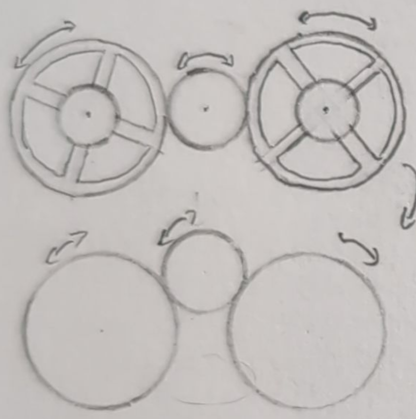




- 2 motors
- One motor working harder than other, centrifuges will accelerate at different rates
  - would need to calibrate each motor or gear differently or use encoders
- Might be hard to center autonomously

Maybe could work for benzen tau?
- Tested → doesn't

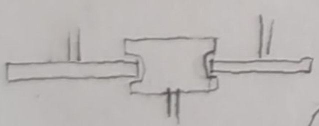
Wheel Spinner: ☆



wheel doesn't have to be centered

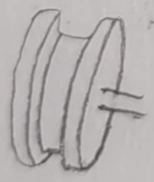
- Gearbox to link two motors to one output shaft
  - Might need differential? ← Ask for advice

- Fewer parts



- Come from below instead

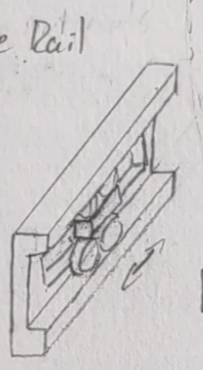
- Self centers

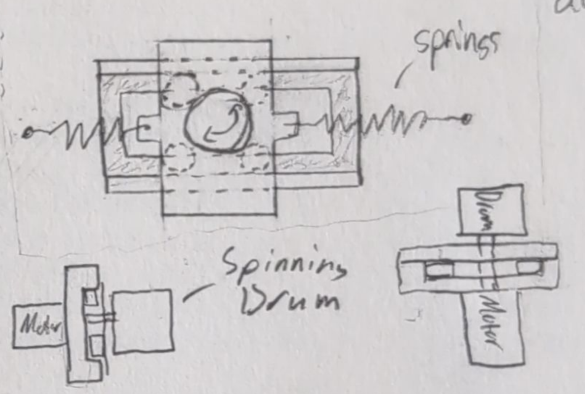


Push up w/ lift to increase friction

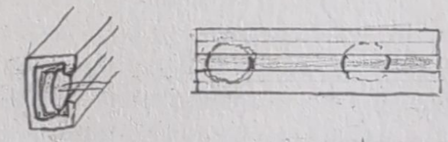
Centering Mechanism: (drawn for wheel spinner, but would work w/ double claw

Double Rail

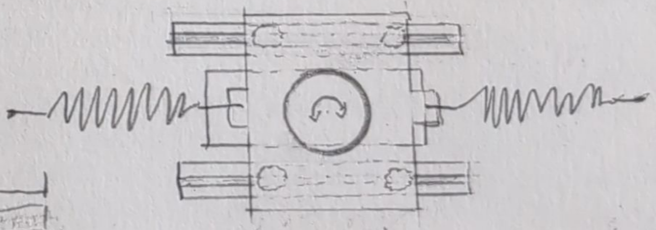


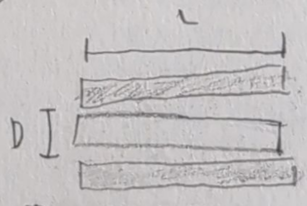


Two Single Rails

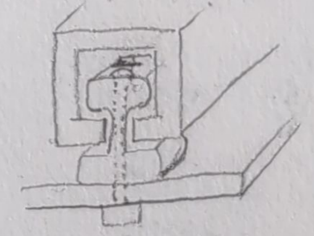


Mass motor ≈ Mass Drum
prevent imbalance

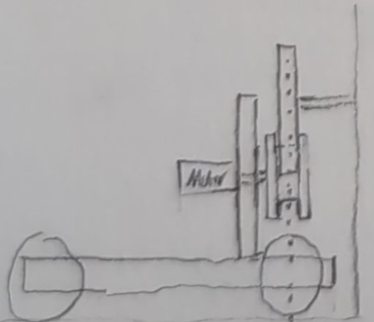




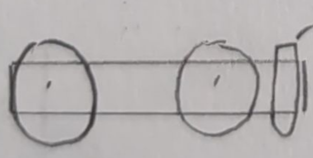
To prevent Jam
L/D > 2, 3-5 even better



Good idea to use LDOs and conserve space and conserve servos for higher torque needs

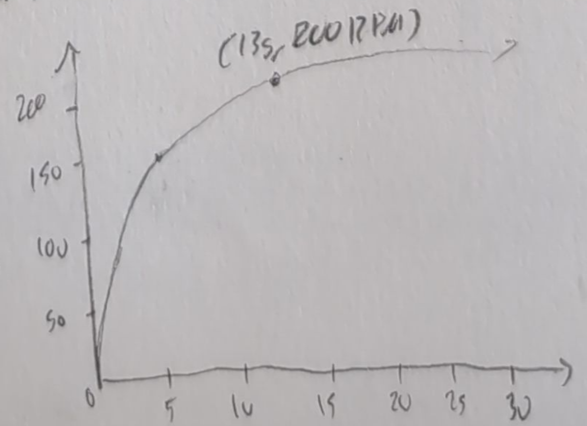


in line or behind front wheel



roller pin at front point

2x
20:1 LDO

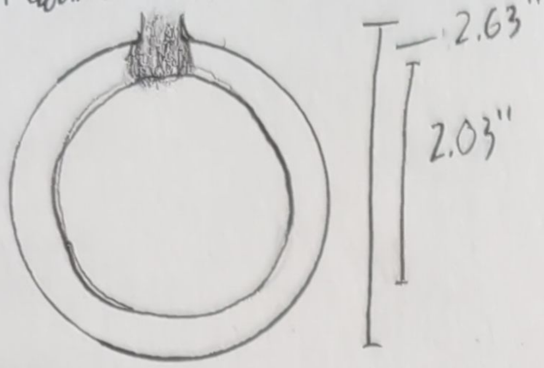


Better than Double Claw b/c:

- Self centers
- fewer parts
- Easier mounting to Lift

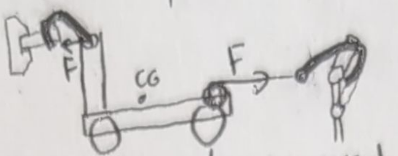
Ring Puller:

Requirements: Pull Mask Ring with 60N



- Need to be able to do with confidence, high priority task
- Might lift robot up winching

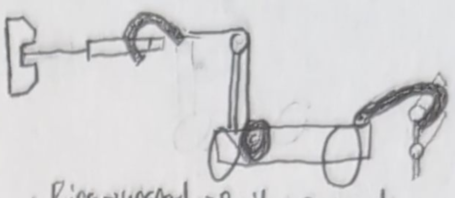
Option #1



- Rail → unspool → ring - respool

or

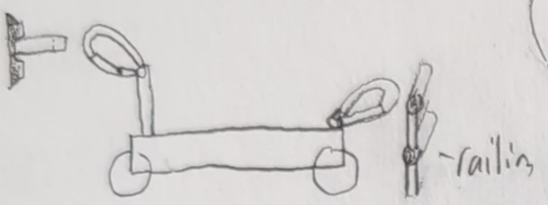
option #2 - need extra pulley



- Ring → unspool → Rail → respool

Double Carabiner:

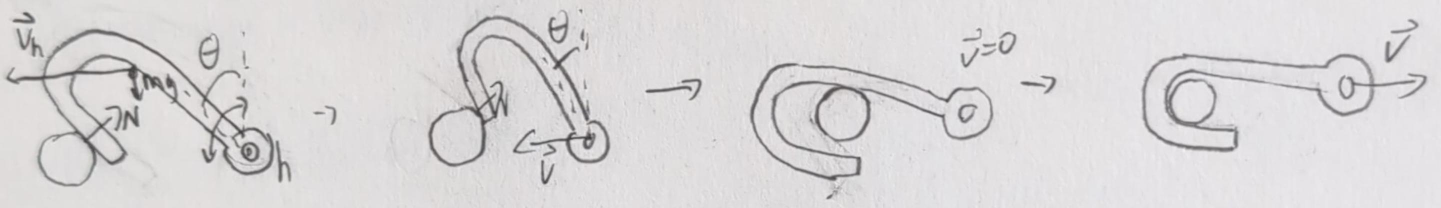
- Carabiners can't be outside starting volume



- Time consuming to construct
- Probably hard to get spring force just right
- Unneccessary to be locked onto anything

Pivoting Simple Hook: ☆

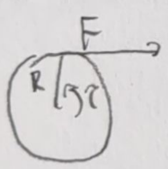
- Can't unhook, must be done at end of game



Winch:

260N worth of force needed, Try to mount directly to chassis

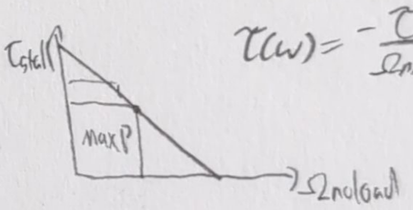
$FR = \tau$



$\Sigma\tau = m\alpha = -FR + \tau$

$\tau = FR$

$v = r\omega$



$\tau(\omega) = -\frac{\tau_{stall}}{\Omega_{noload}}\omega + \tau_{stall}$

$\tau(\omega) = p\,\tau_{stall}$

217:1 LDO Motor:

@6V 1.9Nm stall
28 RPM no load = 2.93 rad/s

Max Power at
0.95Nm
1.465 $\frac{rad}{s}$

$0.95 = 60 \cdot R \quad R = \frac{0.95}{60} = 0.0158\bar{3} \approx$ 1.58cm winch

$1.465 \cdot 0.0158\bar{3} = 0.0232$ m/s = 2.32cm/s

25-2 Torque Servo Motor

@6V 2.12Nm stall
50 RPM no load = 5.24 rad/s

Max Power
1.06 Nm
2.62 $\frac{rad}{s}$

$\frac{1.06}{60} = R = 0.017\bar{6}$m ≈ 1.7$\bar{6}$cm winch

$2.62 \cdot 0.017\bar{6} = 0.0463$ m/s = 4.63 cm/s

Need to use Servo Motor

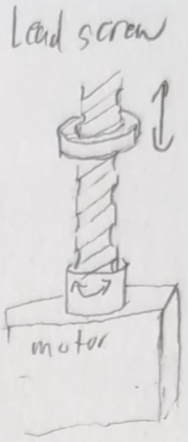
@7.4V 2.47 Nm
60 RPM = 6.28 rad/s

1.24 Nm
3.14 $\frac{rad}{s}$

" " = 2.07cm winch
" = 6.48cm/s

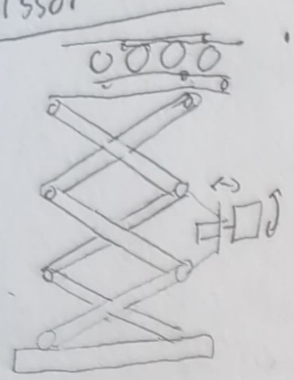
Lift:

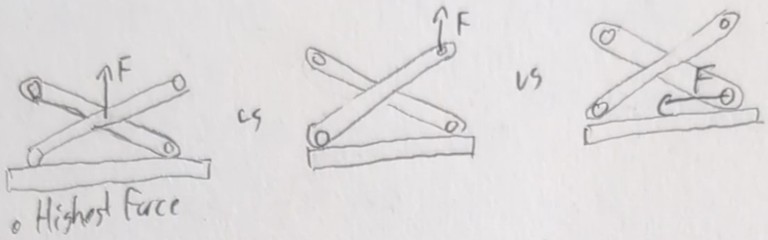
Requirements: Be able to reach a manipulater up to 42 inches and position a spinner wheel up to the centrifuges



Scissor Lift:

- Likely Aims at elevation I'm looking for
- weird placement for centrifuse spinner

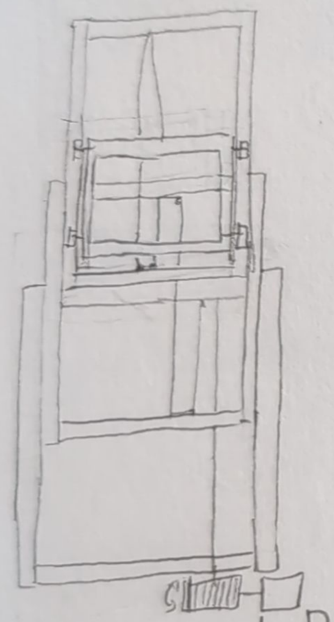


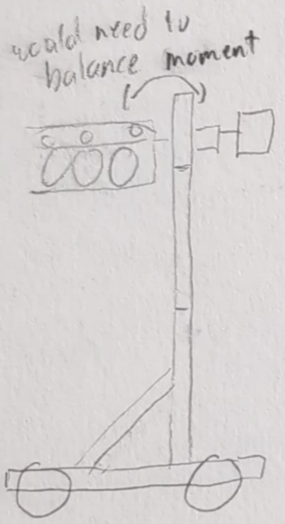


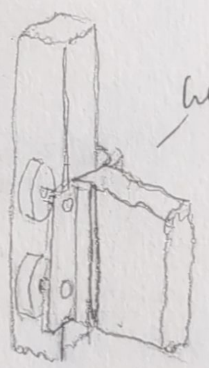
Elevator Lift:

Continuous vs Cascade Rigging

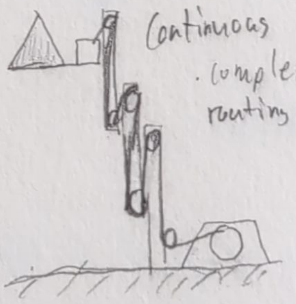
Need 3 stages 16·3 = 48"



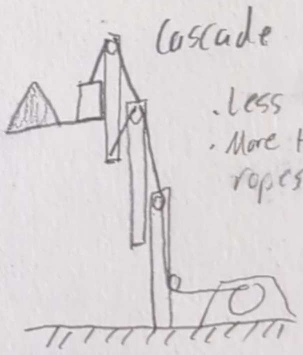




would be a pain to make 3·2 = 6 of these

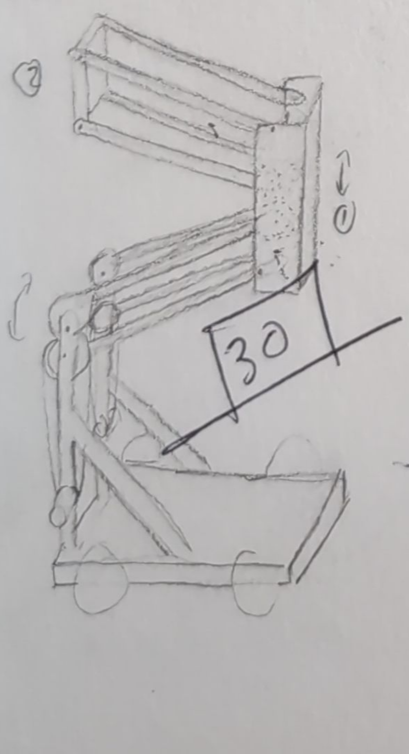


- complex routing of ropes



- Less likely to jam
- More tension on lower ropes

Double Reverse 4 Bar! ☆



2 Mounting points
① has 2x Force over ②

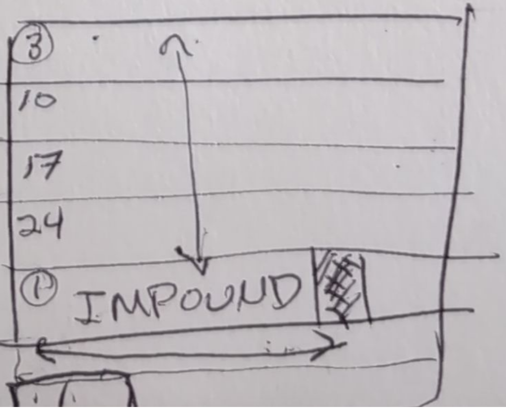
Might have issue reaching full height
16" + 10" + 10" + 4" + 4" = 44"
base arm arm ① ②

Needs 2 motors,
Complex design but stable

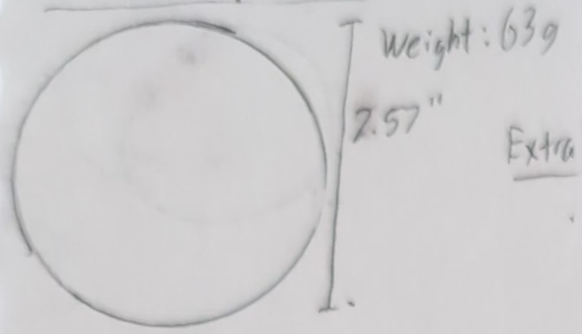
use LDO motors with pulley ratio
Need strong belt tensioners

Use LDOs with high gear ratio

→ Do this before any spinners



Ball Manipulator:



Reqs:

Hold three balls on start

Deposit three balls reliably into a given level

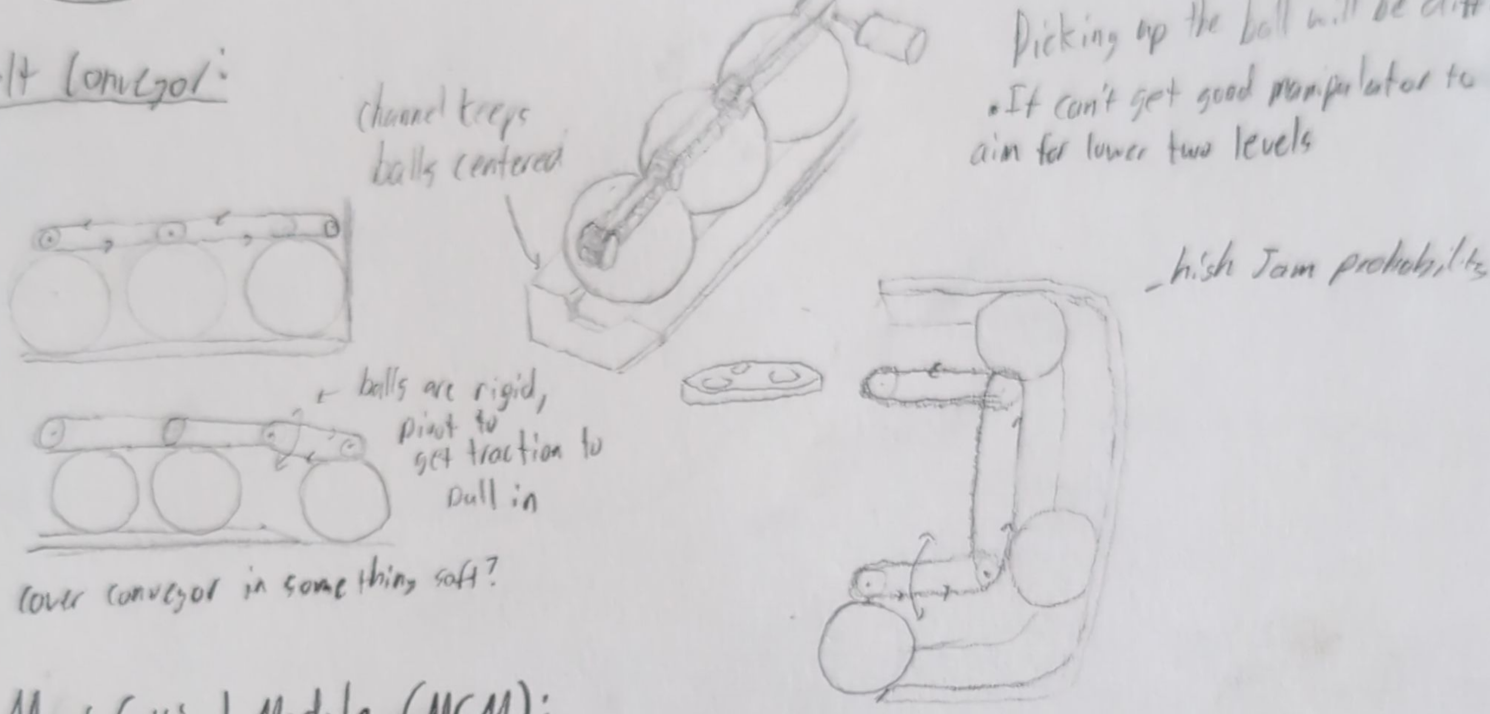
Extra:

- Pick up extra balls on the ground (avg 2.2 per round)
  - Top rack presumably full, 27 pts per ball on middle rack

Picking up the ball will be difficult

- If can't get good manipulator to top level, aim for lower two levels

Belt Conveyor:

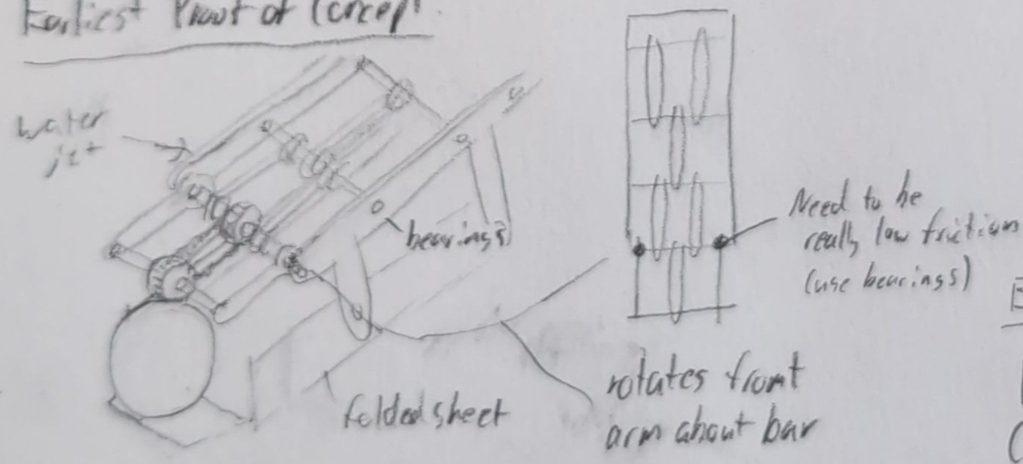


cover conveyor in something soft?

Most Critical Module (MCM):

- Design will impact lift design so it needs to be resolved early so that I can move forward with other parts of the design

Earliest Proof of Concept:



- Will fabricate early PoC and test for effectiveness
- Will iterate until successful prototype, or deemed unachievable
- Integration with rest of robot will be tested at multiple
- points to prevent divergence and integration hell

Early Robot Design:

Drive train: Tank Drive
Centrifuge: Wheel Spinner
Ring Puller: Pivoting Simple Hook
Lift: Double Reverse Four Bar
Ball Manipulator: Conveyor

Motor use:

Drive train: 2 servos
Lift : 2 LDOs
Spinner : 2 LDOs
Winch : 1 servo
Ball manip: 1 servo

2.007 Physical Homework #3 – Hill Climber

LEARNING OBJECTIVES: This physical homework will teach you how to apply the theory you learned about center of mass calculation, friction, and measurement to your robot designs. This knowledge will be critical in creating a robot capable of maneuvering effectively on the competition table as your robot design evolves through the semester.

INSTRUCTIONS:
Now it's time to make your mini-me climb a hill (the slope from the Mass Ave)! In this physical homework, you will modify your mini-me to be able to climb the slope up! This physical homework will give you practice positioning your center of gravity for optimal traction and stability. Feel free to remove the add-on part from the previous Physical Homework.

The following tasks are due as part of your PHW#3. Make sure you document and label each in your notebook.

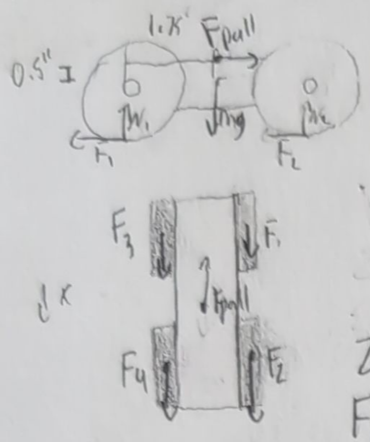
1. **Measurement of Coefficient of Friction**
   Measure the coefficient of friction between your drive wheels and the contest table. **Report the value in your design notebook and include a picture/sketch of how you obtained this value.**

2. **Calculation of CM location for no-slipping and no-tipping**
   Using physics/analysis/calculations, determine a suitable location (or range of locations) for the center of mass (CM) of your mini-me to be able to climb the slope, given the coefficient of friction between your wheels and the contest table. **Start by drawing a free-body diagram of your robot on a slope of generic angle θ.** Use the equilibrium equations to derive mathematical expressions for where the CM must be to prevent tipping and slipping. Then use these equations with the real gameboard slope angle and dimensions of your robots to determine an acceptable position of the CM to prevent slipping and tipping. You may do your analysis as a *static* problem for simplicity. However, **keep in mind** that mini-me can accelerate from stall and fall backward, while most of the time the mini-me has very little acceleration.

3. **Modification of mini-me**
   Measure the CM of your current mini-me and check if you have a suitable CM location that matches with your experiment results. If your CM must change to ensure your robot doesn't slip or tip, you can add weights or move components. This may entail fabricating new parts in the lab, so don't wait until the last minute to start this PHW. **Include a picture of your upgraded mini-me in your design notebook.** You may remove the caster wheel or the pushing device from PHW#2 if necessary. On the picture of your robot, **mark the location of the CM. Provide supporting pictures of experiments or CAD for how you determined this location. Also report the mass of the robot and how much weight is supported on the front and rear wheels.**

4. **Demonstration of climbing**
   You will physically demonstrate your design by having your mini-me climb the slope. This demonstration will take place at the beginning of your Lab #4, or you can email/put in Dropbox a video for your lab instructor beforehand. You will not be given time to finish your PHW#3 during Lab #4. The physical demonstration is worth 50% of your grade on this assignment.

Measurement of Coefficient of Friction:



By sym $N_3 = N_1$ & $F_3 = F_1$ & $N_2 = N_4$ & $F_2 = F_4$

$\Sigma F_x = F_{pull} - F_1 - F_2 - F_3 - F_4 = 0 \Rightarrow F_{pull} = 2F_1 + 2F_2$

$\Sigma F_y = 0 = mg - N_1 - N_2 - N_3 - N_4 \Rightarrow 0 = mg - 2N_1 - 2N_2$

$\Sigma M_c = 0 = -1.75(2N_1) - 0.5F_{pull} + 1.75(2N_2)$

$2N_1 = mg - 2N_2 \quad N_1 = \frac{mg}{2} - N_2$

$F_1 = N_1\mu \quad F_2 = N_2\mu$

$F_{pull} = 2N_1\mu + 2N_2\mu$

$0 = -3.5N_1 - 0.5F_{pull} + 3.5N_2$

$-\frac{7mg}{4} + \frac{7}{2}N_2 - \frac{1}{2}F_{pull} + \frac{7}{2}N_2$

$7N_2 = \frac{7mg}{4} + \frac{1}{2}F_{pull}$

$N_2 = \frac{mg}{4} + \frac{1}{14}F_{pull} \quad N_1 = \frac{mg}{4} - \frac{1}{14}F_{pull}$

$m = 118g = 0.114\,kg$

$g = 9.4\,m/s^2$

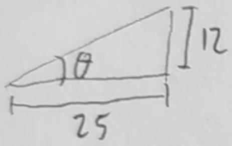
$F_{pull_{static}} = 55g = 0.54N \quad F_{pull} = mg\mu$

$F_{pull_{kinetic}} = 50g = 0.49N \quad \mu = \frac{F_{pull}}{mg}$

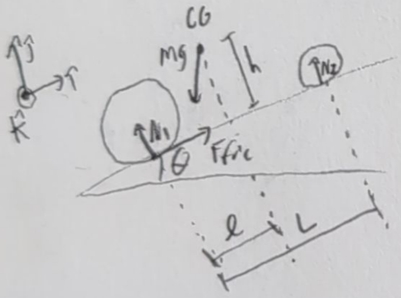
$\mu_{kinetic} = 0.42$ – low due to high dust levels

$\mu_{static} = 0.47$

Calculation of CM location for no-slip and no-tip:



$\tan^{-1}\left(\frac{12}{25}\right) = \theta = 25.64° = 0.448$ rad



~~No~~ Slip:

$\Sigma F_x = 0 = F_{fric} - mg\sin\theta \quad F_{fric} \overset{☆}{\geq} mg\sin\theta = \mu N_1$

$\Sigma F_y = 0 = N_1 + N_2 - mg\cos\theta \Rightarrow N_1 + N_2 = mg\cos\theta \quad N_1 = mg\cos\theta - N_2$

$\Sigma M_0 = 0 = -l\,mg\cos\theta + hmg\sin\theta + LN_2$

$\Rightarrow N_2 = \frac{l\,mg\cos\theta - hmg\sin\theta}{L} \quad N_1 = mg\cos\theta - \left(\frac{l\,mg\cos\theta - hmg\cos\theta}{L}\right)$

$☆: \; mg\sin\theta = \mu\left(mg\cos\theta - \frac{l\,mg\cos\theta - hmg\cos\theta}{L}\right)$

$\frac{\sin\theta}{\mu} = \cos\theta + \frac{h\sin\theta - l\cos\theta}{L}$

$\frac{L\sin\theta}{\mu} = L\cos\theta + h\sin\theta - l\cos\theta$

$\frac{L}{\mu}\tan\theta = L + h\tan\theta - l$

$\underline{l \leq h\tan\theta + L - \frac{L}{\mu}\tan\theta}$

In Mini-Me

$L = 2.11\,in = 0.0536\,m$

$l = 1.14\,in = 0.0290\,m$

$h = 1.88\,in = 0.0478\,m$

$\mu = 0.47$

No tip: $N_2 = 0$

$\Sigma F_x = 0 = F_{fric} - mg\sin\theta \quad F_{fric} = mg\sin\theta$

$\Sigma F_y = 0 = N_1 - mg\cos\theta \quad N_1 = mg\cos\theta$

$\Sigma M_2 = 0 = -LN_1 + (L-l)mg\cos\theta + hmg\sin\theta$

sub in:

$0 = -Lmg\cos\theta + hmg\sin\theta + (L-l)mg\cos\theta$

$L\cos\theta - h\sin\theta = L\cos\theta - l\cos\theta$

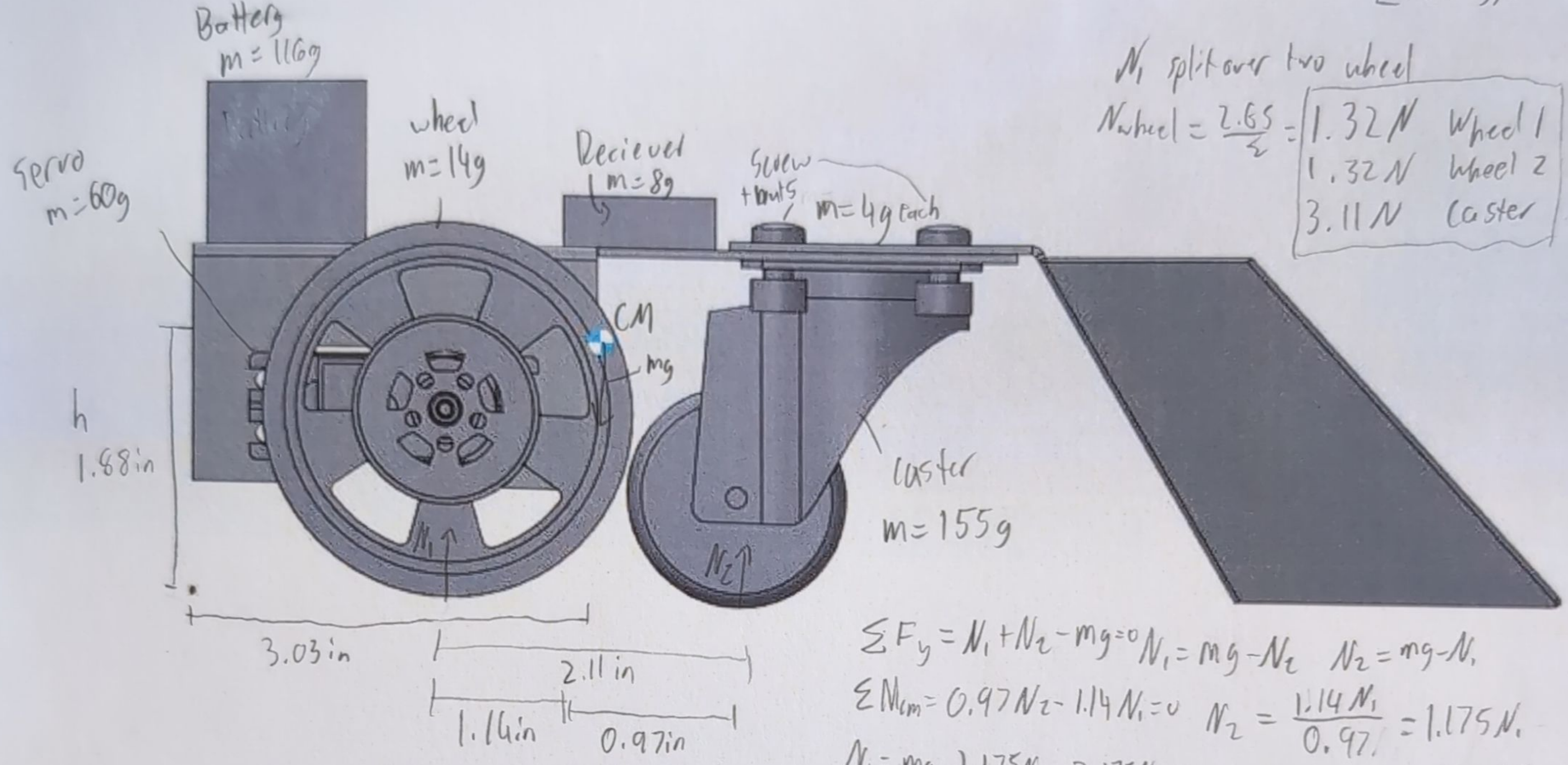
$\underline{l \geq h\tan\theta}$

$h\tan\theta \leq l \leq h\tan\theta + L - \frac{L}{\mu}\tan\theta$

$\underline{0.023\,m \leq l \leq 0.044\,m}$

Total Mass = 587g

Sheet metal: 5052, density = 2680 kg/m³



N_1 split over two wheel

$N_{wheel} = \frac{2.65}{2} =$

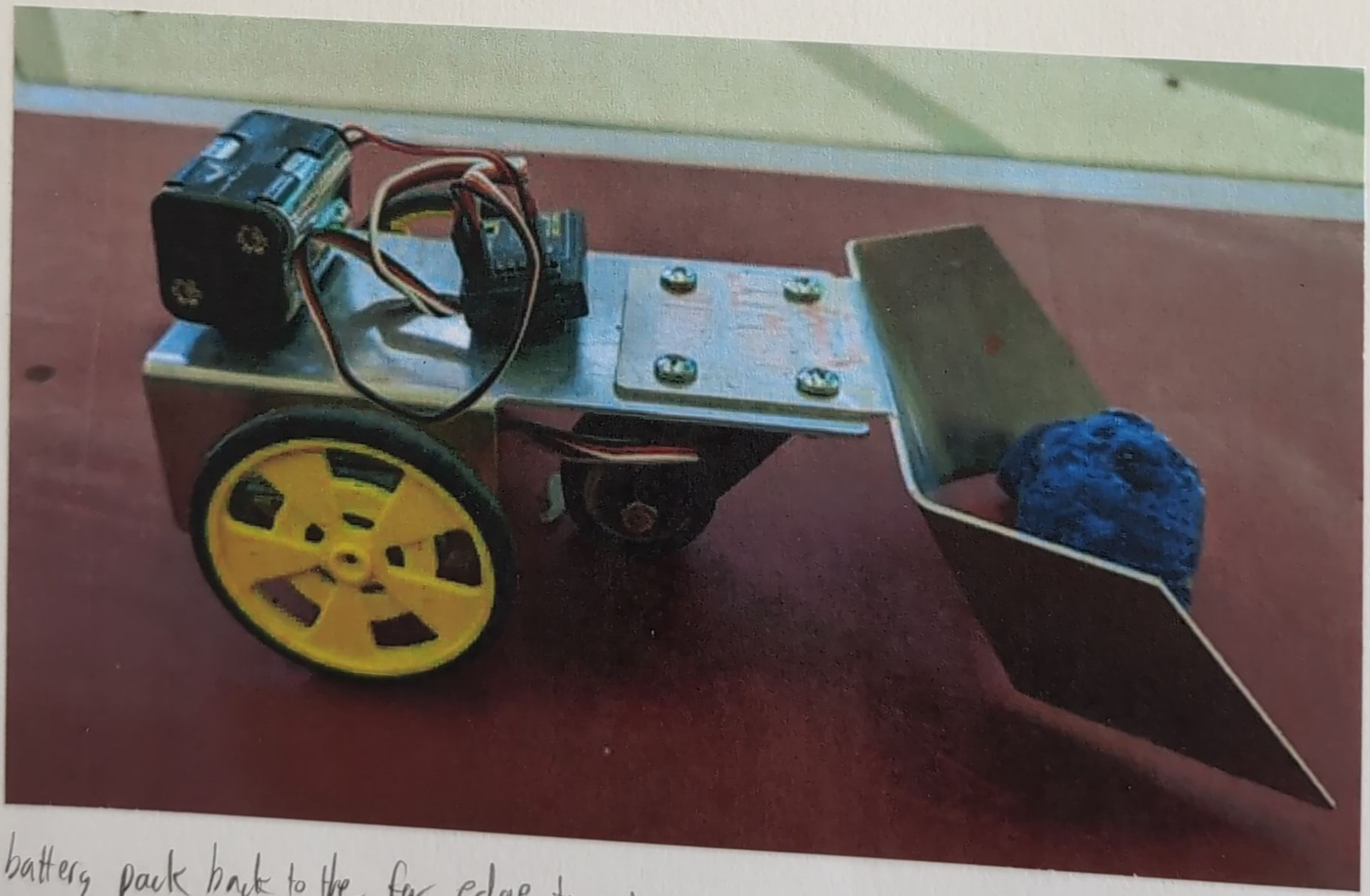
1.32N	Wheel 1
1.32N	Wheel 2
3.11N	Caster

$\Sigma F_y = N_1 + N_2 - mg = 0 \quad N_1 = mg - N_2 \quad N_2 = mg - N_1$

$\Sigma M_{cm} = 0.97 N_2 - 1.14 N_1 = 0 \quad N_2 = \frac{1.14 N_1}{0.97} = 1.175 N_1$

$N_1 = mg - 1.175 N_1 \quad 2.175 N_1 = mg \quad N_1 = \frac{mg}{2.175} = \frac{.587 \cdot 9.8}{2.175} =$

$N_2 = 0.587 \cdot 9.8 - 2.65 = 3.11N \qquad N_1 = 2.65N$



- Moved battery pack back to the far edge to put more weight on driven wheels
- Wiped off the wheels to increase μ.

2.007 Milestone #4 – Most Critical Module and Intro to Arduino

LEARNING OBJECTIVES: Learn how to identify the most critical module (MCM) of your strategy; use design + analysis + prototyping to validate the viability of your MCM.

INSTRUCTIONS:
This milestone centers on the design of your most critical module (MCM). You want to select one **important but not trivial** subset of your concept and design it in detail. Choose one of the most critical tasks that facilitate scoring points in the contest. Consider that you have to demonstrate your prototype MCM achieving a task in just three weeks, for MS6. The chosen task should be different from any PHWs. Plan carefully how to use the next 2 weeks to test your ideas. You should be able to assess the performance of the MCM based on its demonstration, and the success of its demonstration should provide critical feedback on the overall viability of your concept. For this milestone, please complete the following.

1. **An overall graphical depiction of the module.** A hand drawing is acceptable. Describe why you chose the design among the ones you came up with in the previous milestone. I would strongly suggest building a couple mock-up prototypes QUICKLY using cardboard or foam core and hot-glue in the lab to test your idea.

2. **Supporting analysis.** Make some predictions about the performance of your module. You don't have to analyze every aspect of the module, just those aspects that most benefit from analysis. For example, you might check if your selected motor has enough torque/speed/power to achieve the function within the desired time period. Estimate the expected results of your demo.

3. **Design details.** Identify the mechanical subsystem from "Bill's Build Demos" that is closest to your MCM design. Draw an exploded view of your design and point out all of the important mechanical elements within the subsystem. Identify any important functions parts serve, like reducing friction or ensuring proper constraint. Pick two parts and draw a FBD for them.

4. **Fabrication.** Describe enough details required for the fabrication of the module, FOCUSING on achieving the DESIRED TASK. To minimize fabrication time, feel free to use prototyping materials (foam core, cardboard) in your module, if it does not diminish the function of the robot. Once you achieve the task, replacing them with more rugged materials is very easy.

5. **A solid model of at least one part of your most critical module.** Paste into your notebook printouts of your SolidWorks Part(s) Document (.SLDPRT) and any other possible CAD files or other graphical representation, such as assemblies. Use CAD as a design tool. Sketches in SolidWorks can be very useful for checking geometry and/or kinematics of your design. Choose a part that requires design thought and has features you will need to fabricate; do not include a simple part like a specific length of L-extrusion.

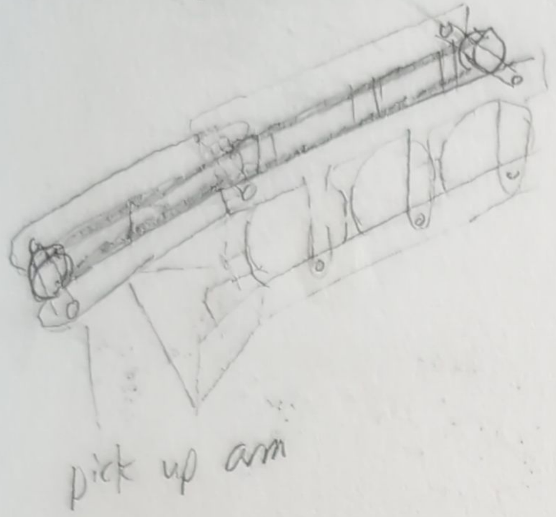
6. **Design Requirements.** Write down the list of design requirements that must be achieved for your MCM to be successful. Remember, be as quantitative as possible.

7. **Plan.** Organize your fabrication/testing schedule to be ready to demonstrate your MCM in 2 weeks. Record a detailed fabrication plan for your next lab.

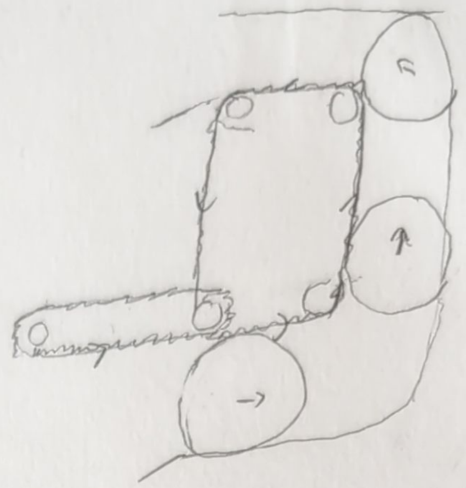
DELIVERABLE: Report at least 5 pages in your notebook.

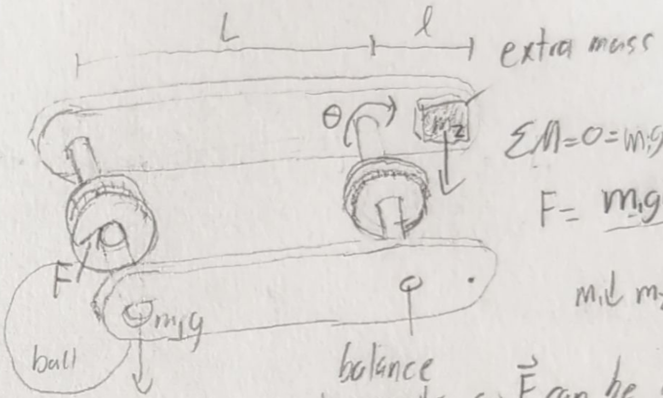
MCM overview:

Straight:



Curved:





$$\Sigma M = 0 = m_1 g L - F L - m_2 g l$$

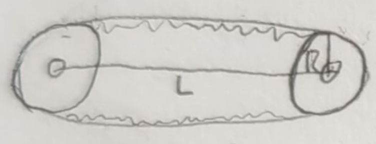
$$F = \frac{m_1 g L - m_2 g l}{L}$$

$m_1 \downarrow$ $m_2 \uparrow$ $l \uparrow$

balance moments so $\vec{F}$ can be lower

Sketches + CAD + Supporting Analysis:

Belts come in 18" & 24" sizes $R = 1.1"$



Belt Length $= L_B$

$$L_B = 2 \cdot L + 2 \cdot \left(\tfrac{1}{2} \cdot 2\pi R\right)$$

$$L_B = 2L + 2\pi R$$

$$\frac{L_B - 2\pi R}{2} = L$$

Radius of pulleys = 1.1"

Possible Ls:

18": 5.54" ☆

24": 8.54

set value: $\frac{\text{intake in}}{\text{sec}} = \omega r = \omega$

set $2 = \omega \cdot 1.1$ $\omega = 1.82/\text{sec} \Rightarrow 109$ RPM

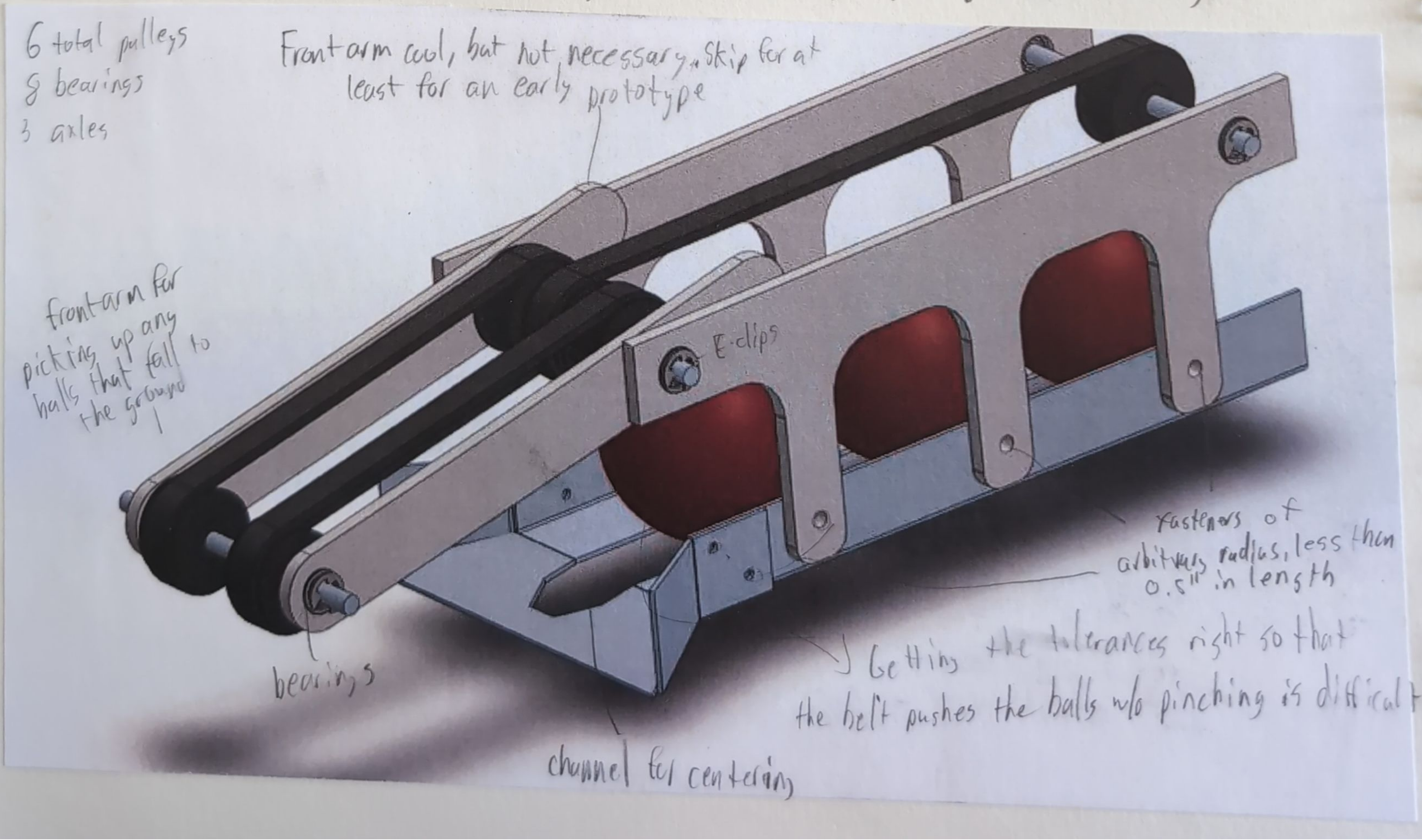
margin $0.5 = \omega \cdot 1.1$ $\omega = 0.45/\text{sec} \Rightarrow 27.3$ RPM

want ± 0.5"/sec for control

Need motor that operates between 109 RPM ± 27 RPM

Any motor should work as torque requirements are tiny

Early CAD:



6 total pulleys
8 bearings
3 axles

Front arm cool, but not necessary. Skip for at least for an early prototype

front arm for picking up any balls that fall to the ground

E-clips

fasteners of arbitrary radius, less than 0.5" in length

bearings

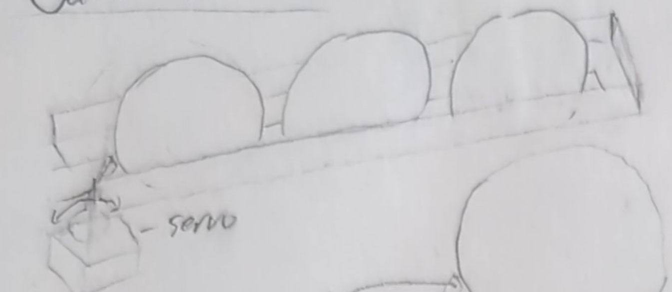
Getting the tolerances right so that the belt pushes the balls w/o pinching is difficult

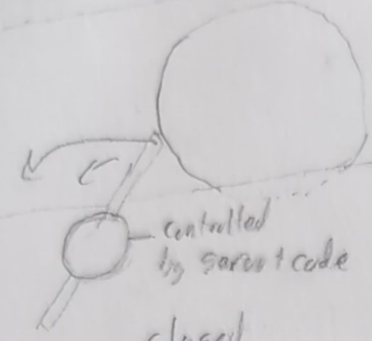
channel for centering

Other Ideas: KISS

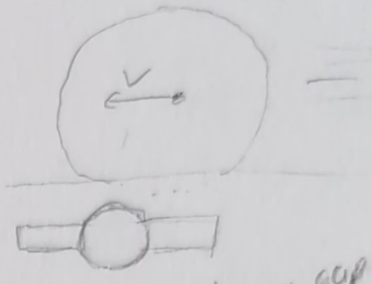
Gated Channel

Might be tricky to get timing correct
Simple and light

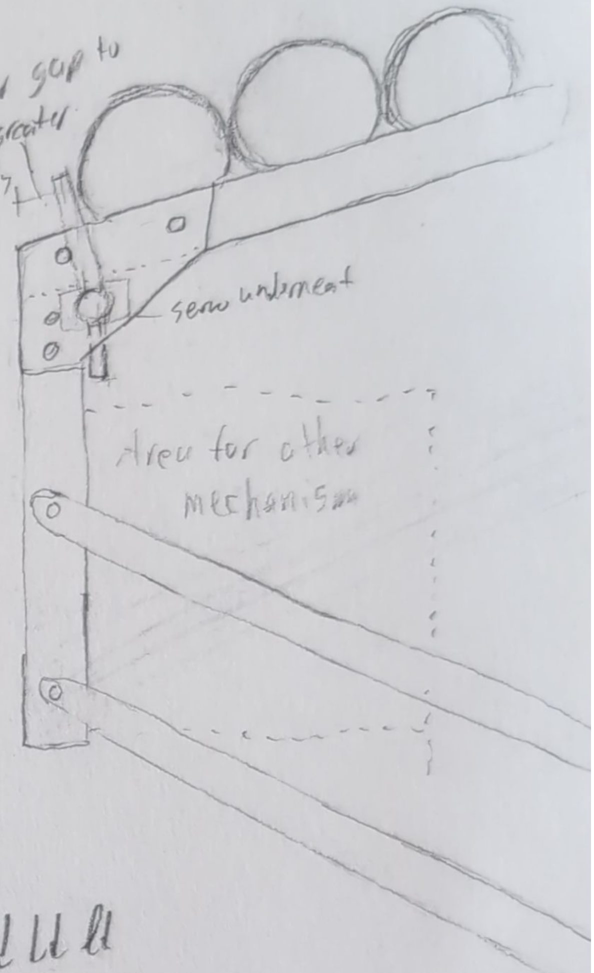




closed



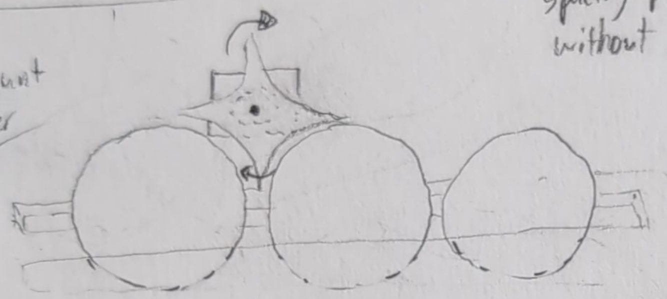
open

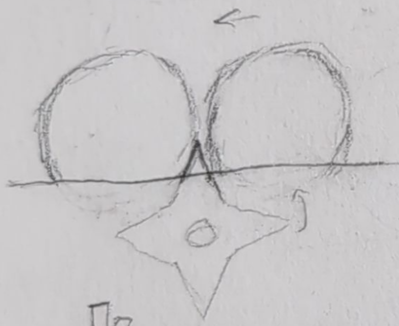


Star Gate:

spacing probably hard to get right without jamming

Top mount better

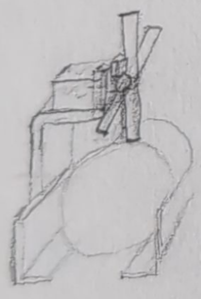




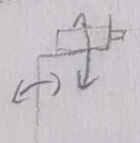
top requires extra weight for support

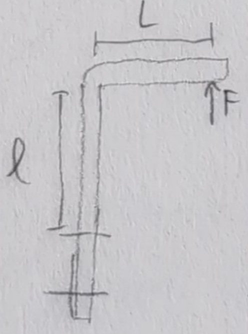
On Top:
ball pinched

On Bottom:
If ball has enough momentum, might hop gate

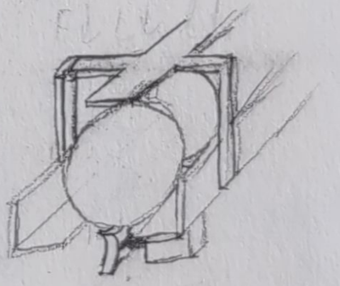


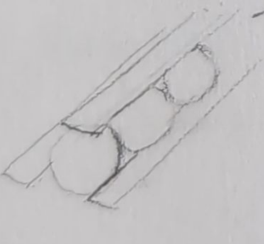
- could flex:



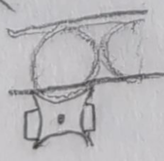


Bending reduced when FL ⟂ Ll ll

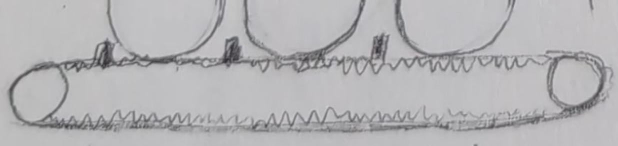




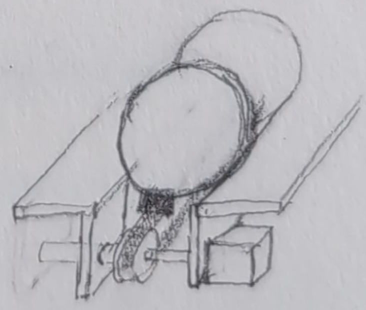
- upper bar prevents hopping



Underside Conveyor:



tabs attached to a belt

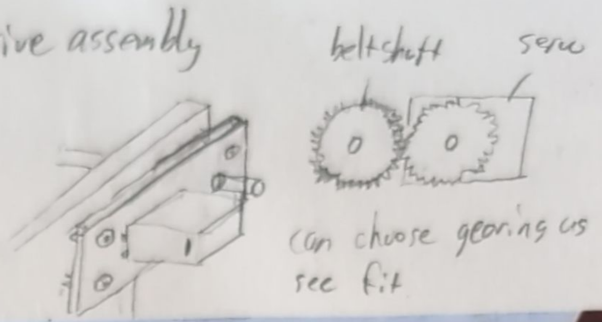


- Glue plastic tabs onto belt
  - Sharp radius of curvature at pulleys might put stress on tabs and break them off

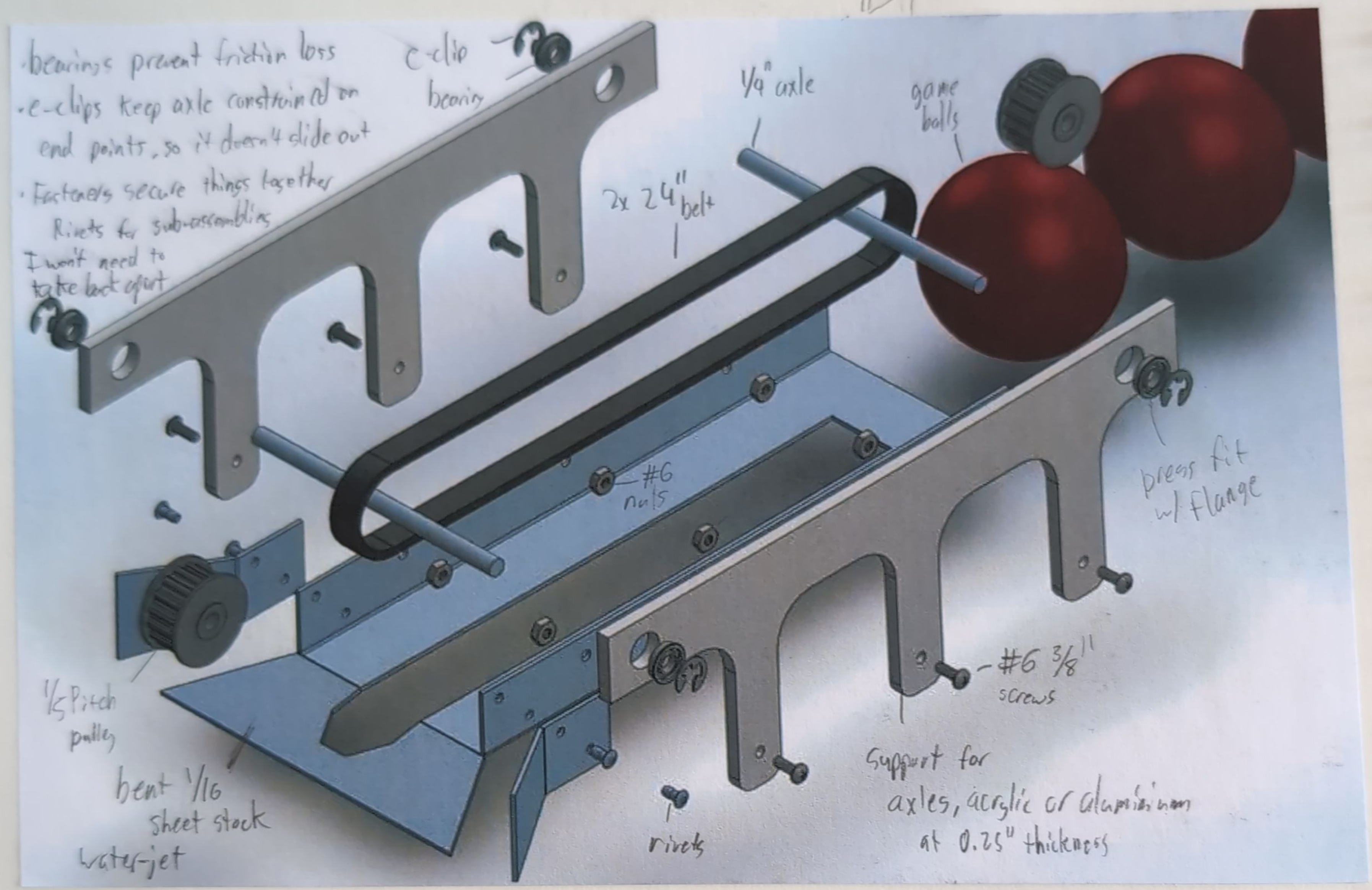
Design Details:

The "Bill Build Demo" most similar to my design is the Belt Drive assembly

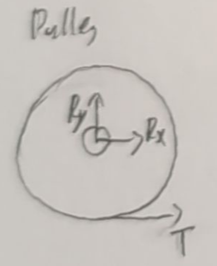
CAD currently missing motor, but that could just be implemented as '

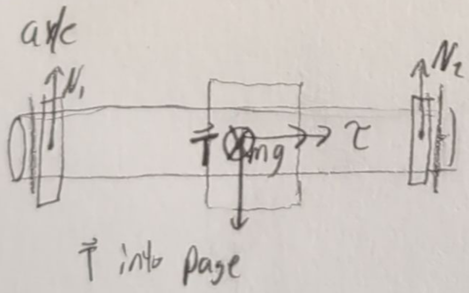


can choose gearing as see fit

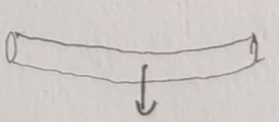


- bearings prevent friction loss
- e-clips keep axle constrained on end points, so it doesn't slide out
- Fasteners secure things together
  Rivets for sub-assemblies
  I won't need to take back apart

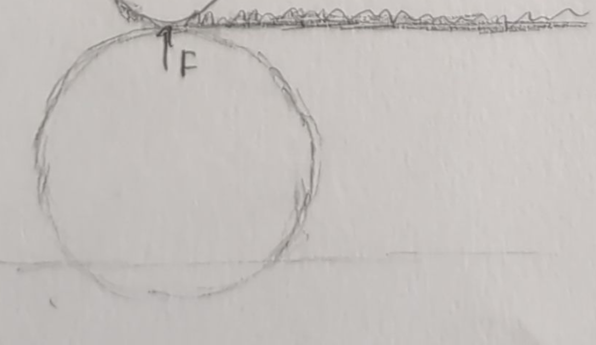




Axle must be strong enough to prevent excessive bending form weight & tension



Need to ensure pulley fixturing to shaft is strong enough to prevent pulley slip when torque is applied



Need to account for ball fitting under pulley.

- Either build in compliance by
  - letting the pulley move up
  - let the ball move down
  - Make the interface between them soft so it can compress
- Or be very very precise in construction

Roll pin through pulley and shaft to secure

Better than set screw

Design Requirements!

DNA spins at 1rev/30sec:
Ball manipulator must be able to, with control, deploy 3 balls within 30 seconds.

Chance to place ball 3 sec:
Must be able to completely deploy ball within 3 seconds

Hold 3 balls at game start

Work Reliably → less than 5% error or unexpected behavior
Be able to pick up a ball (or two) from the ground and place it on the DNA

Plan:

Th March 9th	Milestone 4 (Most Critical Module) due
Fr March 10th	Spend several hours in shop testing simple proof of concept prototypes. This could be as simple as a belt between two pulleys with no other structure
Sat-Mon March 11-13th	Review and improve CAD
Tu March 14th	Spend time getting parts waterjet/laser cut
Wed March 15th	Finish the first prototype of MCM
Th March 16th	Mile stone 5 (Fabrication of MCM) due
F March 17th	Spend several hours reconsidering design and talking with staff about suggestions
Sat-Mon March 18-20th	Make new CAD
Tu March 21st	Try to get bulk of work done by Tuesday so that Wednesday can be used for bug fixing and minor adjustments. Also allows for things inevitably going wrong
Wed March 22nd	Stay up all night catching up on Milestones after getting a working MCM
Th March 23rd	Demonstrate MCM

2.007 Physical Homework #4 – Autonomous Driving

LEARNING OBJECTIVES: This physical homework will teach you how to program an autonomous robot. It will give you the baseline skills to create a robot that can compete during the 30 sec autonomous period in the competition.

INSTRUCTIONS:
The goal of this physical homework is to implement Arduino programming in your robot. To demonstrate your basic skill, you will program your mini-me (or a prototype of your competition robot) do a U-turn around the Simmons Bracelet post.

The following tasks are due as part of your PHW#4. Make sure you document and label each in your notebook.

1. Program your robot to do a controlled U-turn. The robot needs to start in the starting area, drive forward, make a turn around the Simmons Bracelet post, and then turn again and return to the starting area. Print out your Arduino code and paste it in your notebook. The code should include comments (followed by //) that explain each line of code. This should be a quick and simple task to give you an opportunity to practice autonomous driving. You will learn some limitations of 'dead reckoning' without having wheel odometer.
2. **You will physically demonstrate your robot on the game board or send a video to your instructor.** To get full credit for this assignment, your robot must start in the starting area of the game board. This demonstration will take place at the beginning of your Lab #5, or you can email a video to your lab instructor beforehand. The physical demonstration is worth 50% of your grade on this assignment.

```
#include <Servo.h>

Servo motor1;
Servo motor2;

// Set variables for solving for speed
float turn_radius = 6.0;  // Radius of turning
float wheel_dist = 4.683; // Distance between wheels
float R1 = turn_radius - wheel_dist/2.0; //Inner wheel radius from center
float R2 = turn_radius + wheel_dist/2.0; //Outer wheel radius from center

// Set speed variables
// Motors are placed in mirror orientations, so they spin in opposite directions
// This has to be accounted for in code to get the bot to drive forwards
float speed = 30.0;
float v1_a = -speed;
float v2_a = R2/R1 * (-v1_a);

// function to map floats in one range to floats in another range
float mapf(float x, float in_min, float in_max, float out_min, float out_max)
{
  return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
}
// Balancer accounts for the motors on my Mini-Me being slightly different
float balancer = 5.6;

// Map values from the -100 - 100 speed range to servo 0 to 180 degrees
float speed_servo_1 = mapf(-speed + balancer, -100.0, 100.0, 0.0, 180.0);
float speed_servo_2 = mapf(speed, -100.0, 100.0, 0.0, 180.0);
float v1 = mapf(v1_a, -100.0, 100.0, 0.0, 180.0);
float v2 = mapf(v2_a, -100.0, 100.0, 0.0, 180.0);

// Variable to detect when to stop driving
bool Done = false;
void setup() {
  // Attach motor 1 communication to the pin it's wired to, D2 in this case
  motor1.attach(2);
  // Set motor 1 servo to stationary.
  motor1.write(90);

  // Do the same for motor 2
  motor2.attach(3);
  motor2.write(90);
}

void loop() {
  // if loop() hasn't completed a loop through yet
  if (Done == false) {
    // set both motor speeds to the same thing, adjusted for servo orientation
    motor1.write(speed_servo_1);
    motor2.write(speed_servo_2);
    delay(3000); // drive straight for 3 seconds

    // set the motor speeds to the turn speeds calculated above
    motor1.write(v1);
    motor2.write(v2);
    delay(6300); // turn for 6.3 seconds

    // set motor speeds back to equal
    motor1.write(speed_servo_1);
    motor2.write(speed_servo_2);
    delay(3000); // drive straight for 3 seconds

    Done = true; // Set done to true to stop loop
  }
  else{
    // Set both motors to stationary
    motor1.write(90);
    motor2.write(90);
  }
}
```

2.007 Milestone #5 – Fabrication of the MCM

LEARNING OBJECTIVES: Learn how to execute details of your MCM design in physical hardware through engineering drawings/CAD, prototyping, and fabrication.

INSTRUCTIONS:
This milestone centers on the fabrication of your most critical module (MCM). Ideally, you should have an idea for your MCM and a detailed plan to fabricate your MCM this week. Try to plan your time this week to achieve the next milestone (#6), which requires a demonstration of your MCM in front of your lab instructor during the lab. We expect to see a convincing demonstration of the finished module.

In recent weeks, your deliverables have mostly been focused on documentation in your notebook. Your deliverables will increasingly transition to **working hardware**. Show what you did in photos and CAD models. We highly recommend you continue using bench-level prototypes to develop your ideas. Quick, simple demonstrations using cardboard, plastic, and foam core can be a great way to validate your designs. About 3-5 pages of recording in your notebook should probably suffice.

One of the great opportunities you have in building your MCM is the chance to consult with the machine shop staff. We suggest you make an engineering drawing and bring it to one of the machinists. They can help you think through the best ways to make the part you've designed. You'll find the staff has more time to help you when there is no lab section, such as Monday morning, Tuesday morning, Thursday morning, and Friday afternoon.

Your deliverables (both writing and hardware) include:

1. **Update your design requirements.** Based on the feedback you got from your instructor, and your continued design iterations, update your list of design requirements for your MCM. Remember to make them as quantitative as you can.
2. **A solid model of a second part of your most critical module.** At least one graphic depiction of the part (different from MS#4) should be printed and pasted into your notebook.
3. **An engineering drawing of a part of your most critical module.** Ensure there is enough information to fully describe the completed part – dimensions, materials, datums, thread specs, etc. Choose a part that is critical to your MCM design, not something easy like L-channel cut to length. Use this drawing to help you fabricate your prototype.
4. **The finished part.** Have at least one part of your MCM built by the end of lab this week. Show your section instructors the finished part. Take a picture of it and paste it into your lab notebook.
5. **Detailed Plan**. Write down a detailed plan and preliminary bill of materials (BOM) for the rest of the semester, considering the rest of the robot fabrication. After your experience completing physical homeworks, you have a good idea of how long fabrication takes. Planning your lab activities is critical for the success of a project. Please give yourself time to iterate.
6. **A plan for testing your MCM.** Define the procedure to be used to show that your MCM is working properly. Describe the testing protocol and the performance expected for each element of the protocol. Be quantitative. For example, state the time within which a telescoping MCM will achieve its full height or the number of objects a pusher will push into a specific location in a given time. Indicate how many consecutive times and with what varying conditions the MCM will have to achieve the performance goal in order for the tests to be considered successful.

DELIVERABLE:
About 3-5 pages of writing and pictures in your notebook.

OTHER ACTIVITY:
There are two types of equipment that we have not yet discussed with you in detail: the milling machines and the lathes. These could be a big help to you as your design begins to take shape. They enable you to machine parts much more precisely than you could with hand tools. We suggest you get into groups with your classmates and arrange for an introductory review of these two machines.

Updated Design Requirements:

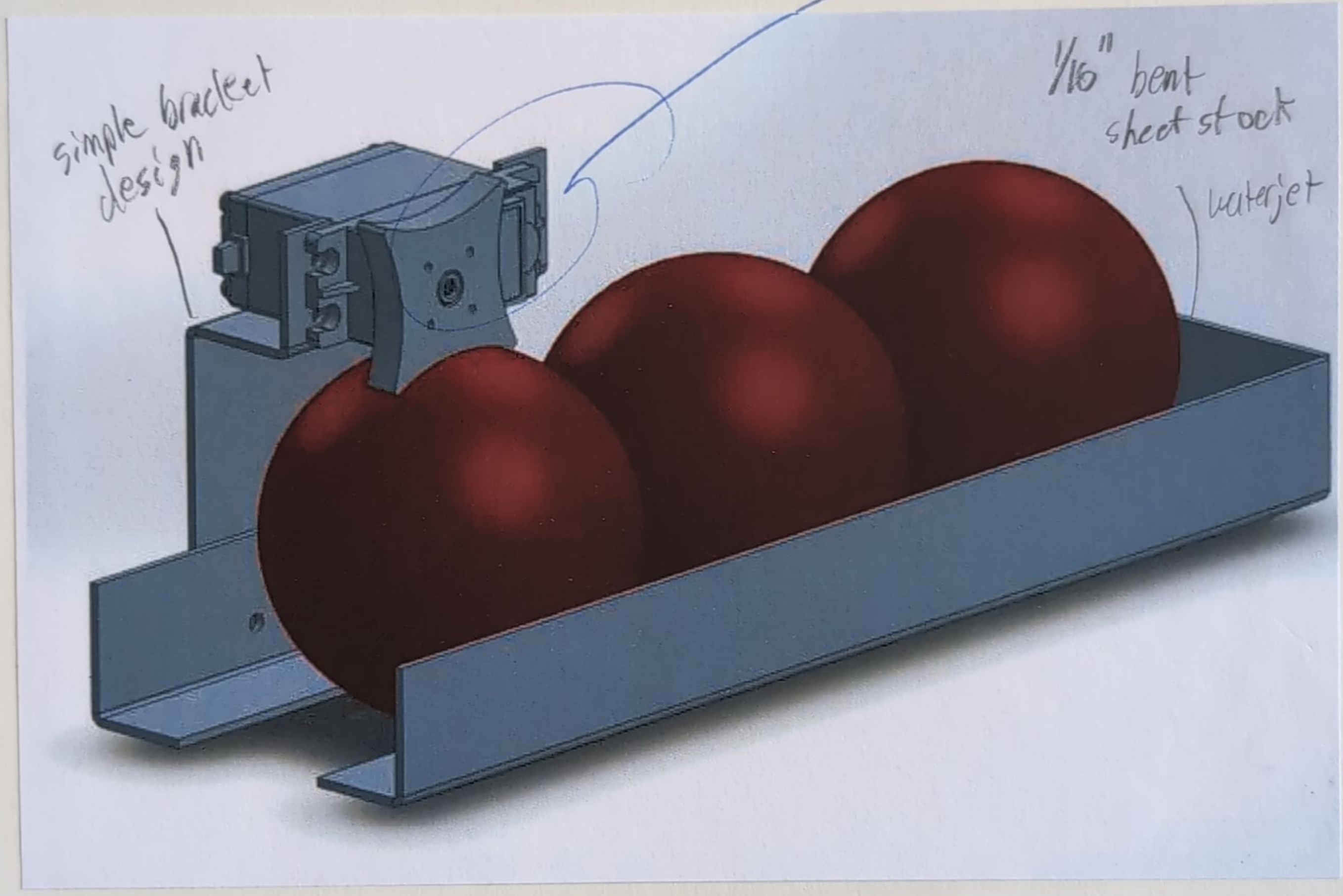
Spoke with Prof. Sangbae Kim about design for MCM, and while it would work, and is cool, it's likely too complicated, especially with my time crunch.

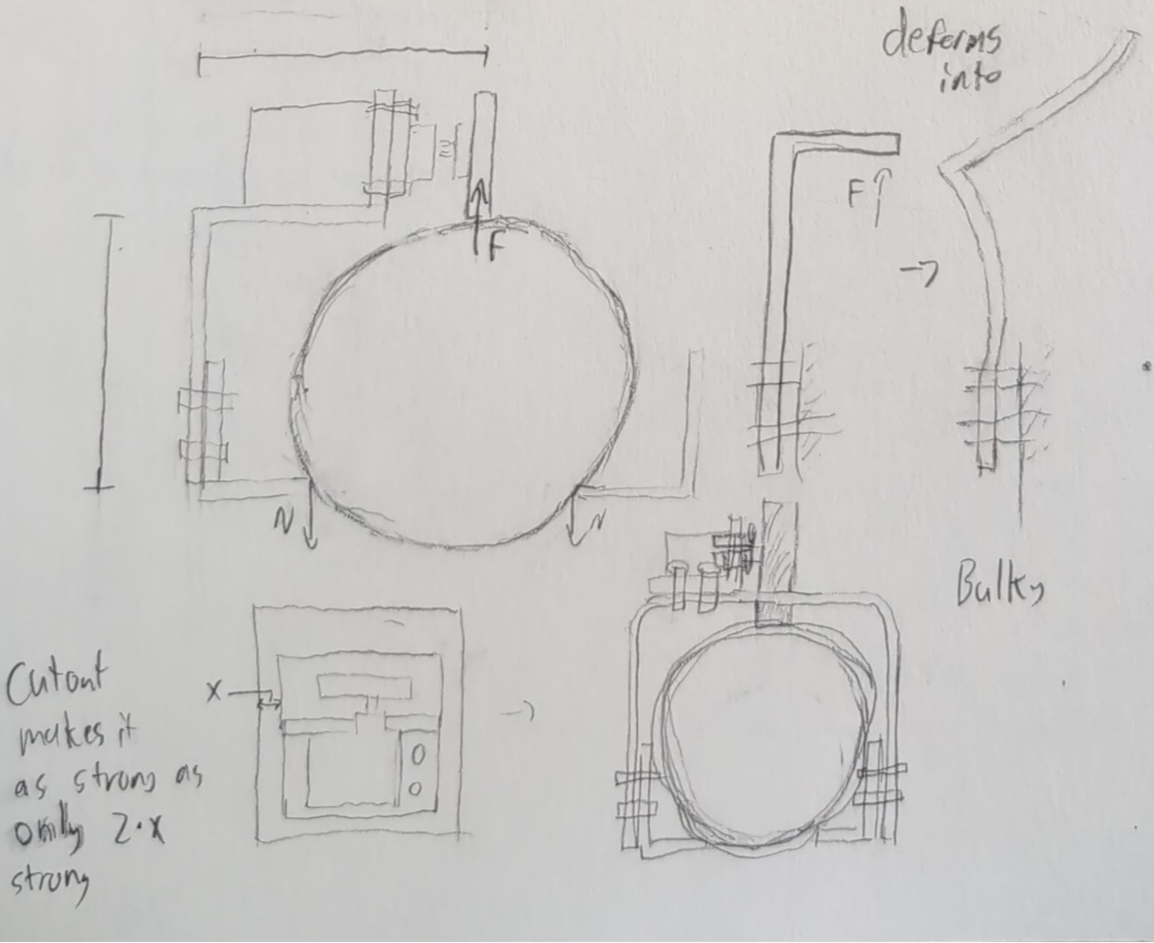
The design requirement list remains almost the same as Milestone #4, the only change is that it loses the last requirement about picking up balls.

Redesign:

I decided to pursue the simpler mechanism from last week that I sketched. The simpliest of those sketches is the top mounted servo

Does this work? Be mindful of gearing.

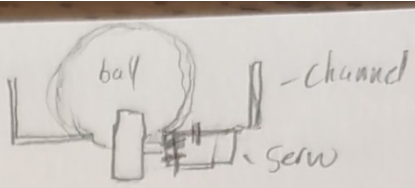


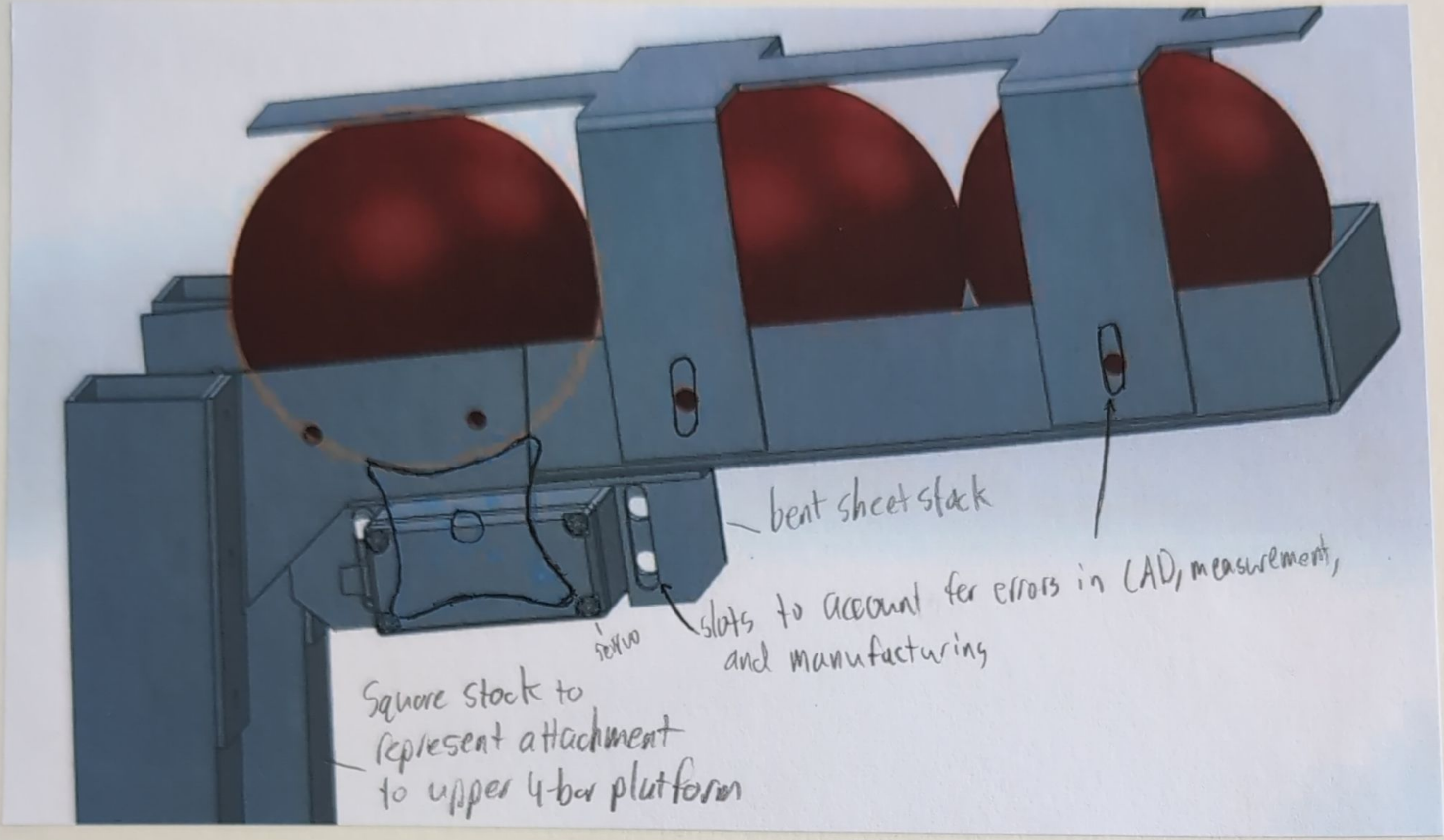


- would easily bend, probably unreliable,
- Ball could get stuck between spinner and channel
- Gut tells me to change to a different design

Redesign:

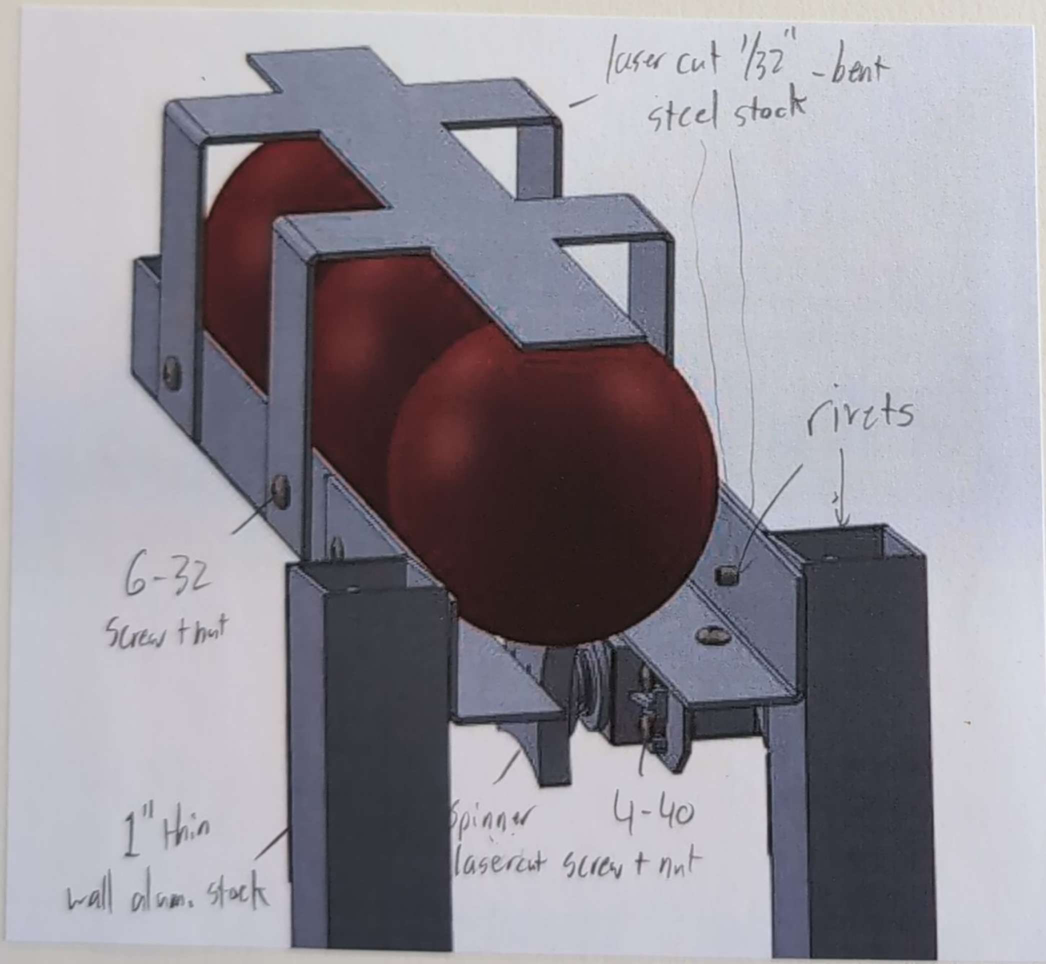
Placing spinner on bottom instead:
- Can support spinner easier
- Simplier wire routing

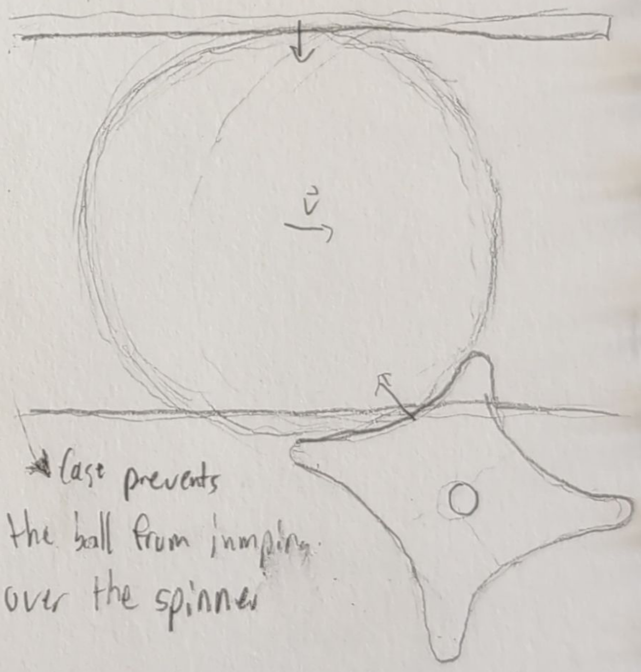




slots to account for errors in CAD, measurement, and manufacturing

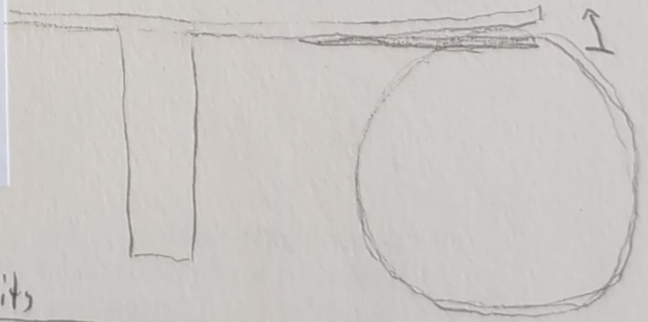
Square stock to represent attachment to upper 4-bar platform





Case prevents the ball from jumping over the spinner

allows for bending to account for tolerance mismatch

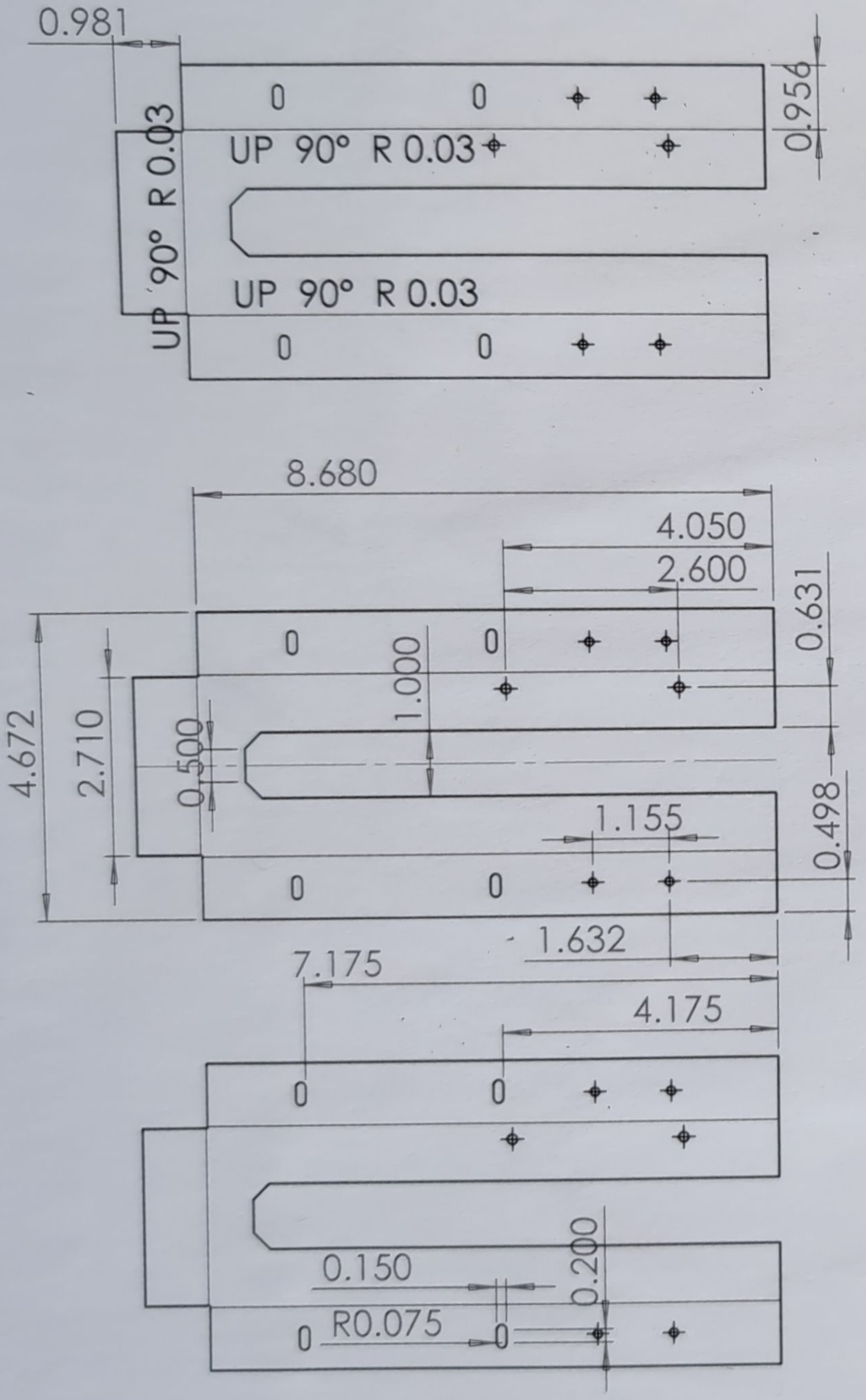


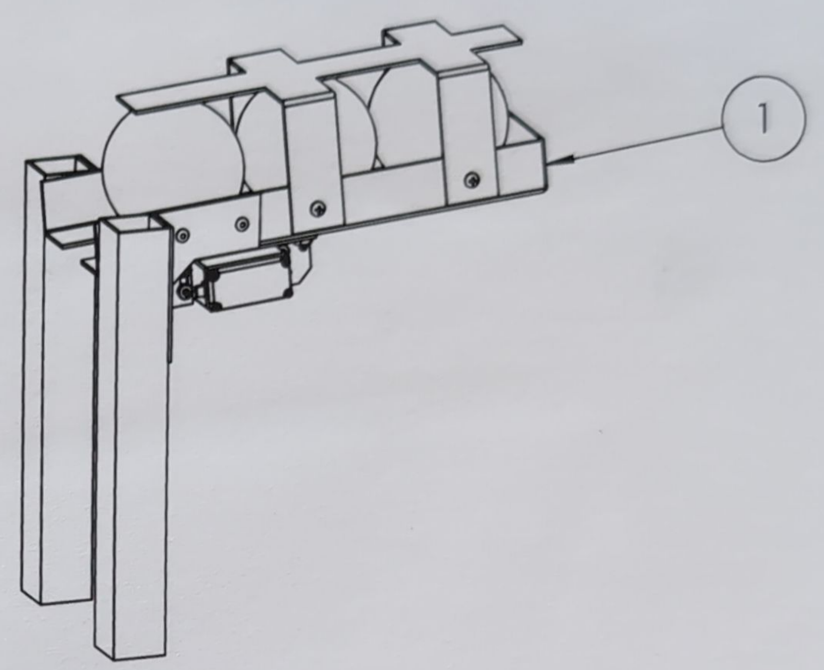
BOM:

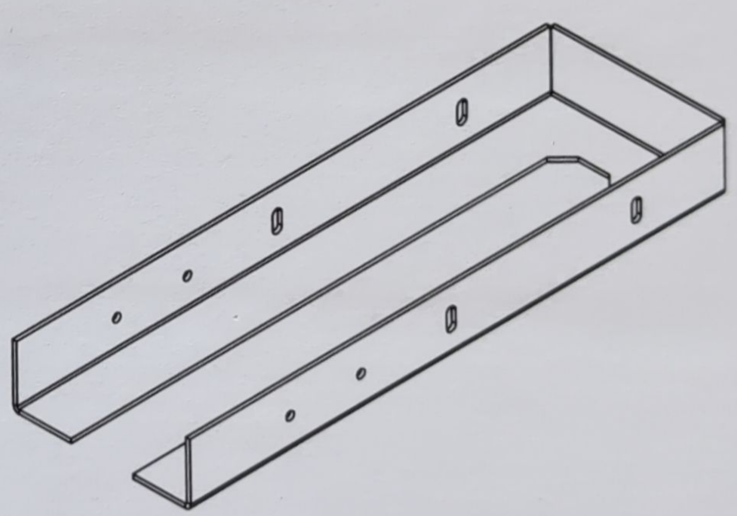
Name	Quantity
Bent Ball Channel	1
Star Spinner	1
25-3 Servo Speed	1
Servo Horn Circle	1
1/16" 1" bar stock	2
Support Brackets	2
Servo Bracket	1
Case	1

BOM Fasteners:

Name	Quantity
6-32 3/8" Screw	6
6-32 Nut	6
4-40 3/8" Screw	4
4-40 Nut	4
Rivet	10







MIT 2.007

TITLE:

Ball Channel MCM

COMMENTS:

SIZE	DWG. DESC	REV
A	Ball Channel	1

AUTHOR: ELIJAH BELL	INCHES	SCALE: 1:3	Modified: 4/5/2023	SHEET 1 OF 1

Finished Part:

One of the support Brackets for attaching the channel to the bar stock.

Made out of 1/32" steel sheet stock, waterjet to shape. Couldn't use shop break out of shop hours so part bent in vise

In order to ensure proper alignment along important dimensions, the bracket was clamped to the bar support after being laid flat on a table. The Holes for rivets in the bar were then marked using the support as a guide. Since the support was imperfect, this accounted for errors by tilting and translating the piece but ensuring that the long face's plane was coincident with the inside plane of the bar.

Detailed Plan:

Plan from Milestone #4 +

Spring Break + April 3rd + 6th	CAD a preliminary overall design and a prototype-ready Lift design
April 7th	Spend time in lab building lift
April 8th-10th	Finish first Lift iteration, noting improvements to be made, Make prototypable chassis design
April 11th-14th	Construct chassis and any modification needed to the lift design
April 15th-17th	CAD prototypable spinner
April 18th-19th	Build spinner iteration #1
April 20th-24th	Adjust, integrate, and ensure things work together
April 22nd-24th	Make prototype-able winch CAD
April 24th-28th	Make winch prototype and integrate
April 29th-May 4th	Testing, tweaks, adjustments

Overall BOM: (excluding fasteners)

Name	Quantity
Ball Manipulator (BOM on previous page)	1
Chassis + Drive train	1
2 Torque servo	2
Wheel	4
Belt	2
Pulley 1/5 P	4
Axle 1/4"	4
Frame Pieces	4 < ? < 12
Bearing	8
Lift	1
LDO motor	2
Gears	4
Frame Pieces	12 < ? < 16
Bearing	12
Rubber Bands	4
Spinner	1
Spinner Wheel	1
LDO motor	2
Gears	3 ≤ ?
Bearing	6
Axle	3
Winch	1
Torque Servo	1
Drum	1
String	1
Gearing	?
Hook	2

Keep developing in Excel
Do this as the design matures

MCM Testing:

Goal #1:

Dispense a single ball in a controlled fashion in under 2 seconds with, 95%+ efficacy

Goal #2:

Dispense all 3 balls without jamming in under 4 seconds, 90%+ efficacy

Goal #3:

Be able to load balls w/ human 100% efficacy

2.007 Physical Homework #5 – Motor Power!!

LEARNING OBJECTIVES: The goal of this physical homework is to learn how to measure torque and speed using tools included in the kits and estimate power of the servo motors.

INSTRUCTIONS:
There are two kinds of servo motors in your kits (Speed 25-3 and torque 25-2). You will measure the stall torque and no-load speed of these two motors and compare with the specifications.

1. **Measurement**

   a. Estimate the angular velocity of each motor. You can do this by recording the video of the servo motors to measure the angular velocity. Run the motors in a continuous mode with an attached horn at the output shaft(spline) and measure the period of time that takes 10 or 20 revolutions. You can try a stopwatch application in your phone or google stopwatch. Fully charge the battery pack. The 4 AA battery pack provides 4.8V and the Arduino carrier board provides 5V power source. Calculate the angular velocity when the motors are spinning at the maximum speed with no load.

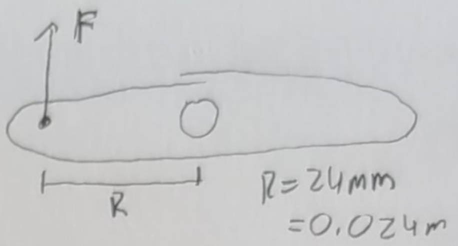
   b. Estimate the torque by measuring the force through a string attached to a horn with a known moment arm. Program the servo motor in servo mode for this. Make sure you put a M3 screw to secure the servo horn. Watch the instruction video for 25-2 (https://canvas.mit.edu/courses/18713/files/3182141?module_item_id=834835).
   Use spring scale in the lab instead of digital scale.

2. **Analysis:**

   a. Draw speed-torque curves of the two motors and compare them with the motors' specifications. How accurate are the specifications?

   b. Estimate the maximum power of the two motors from the two speed-torque curves. Are they similar?

Measurement:



Torque Servomotor: $\frac{10 \text{ revolutions}}{13.84 \text{ sec}} = \frac{1 \text{ rev}}{1.38 \text{ sec}} \Rightarrow \frac{2\pi}{1.38 \text{ sec}} = 4.55 \text{ rad/sec}$

$\vec{F}_{stall} = 5.5 \text{ kg}$ $= 54 N$ $\quad \vec{\tau}_{stall} = \vec{F}_{stall} \cdot 0.024 m = 1.296 Nm$

Speed Servomotor: $\frac{10 \text{ rev}}{6.75 \text{ sec}} = \frac{1 \text{ rev}}{0.675 \text{ sec}} \Rightarrow \frac{2\pi}{0.675 \text{ sec}} = 9.31 \text{ rad/sec}$

$\vec{F}_{stall} = 2.27 \text{ kg}$ $= 22.3 N$ $\quad \vec{\tau}_{stall} = \vec{F}_{stall} \cdot 0.024 m = 0.535 Nm$

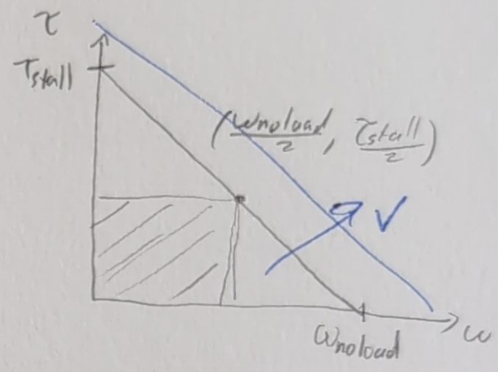
Analysis:

Torque:

	ω_{noload}	τ_{stall}
Measured	4.55 rad/sec	1.296Nm
Specification	4.19 rad/sec	1.68Nm

Speed:

	$\vec{\omega}_{noload}$	$\vec{\tau}_{stall}$
Measured	9.31 rad/sec	0.535Nm
Specification	9.42 rad/sec	0.775Nm



b) Max-power: $\frac{\omega_{noload} \tau_{stall}}{4}$

	Torque	Speed
Measured	1.47W	1.25W
Specifications	1.76W	1.83W
% error	16.5%	31.7%

Did you check the voltage?

Error is significant,
~~Measured values are~~ likely an underestimate on the torque
but not so much so as to account for all the error

remember mechanical power → V^2

2.007 Milestone #6 – Most Critical Module Demonstration

LEARNING OBJECTIVES: See how your analysis + synthesis manifested in your first original design in 2.007. Gain perspective on what could be improved, and what your game plan should be through the remainder of the semester.

INSTRUCTIONS:
This milestone centers on the demonstration of your most critical module (MCM). You are expected to perform a convincing demonstration of the finished module during the lab with your instructor. An incomplete module is a sign that you've fallen behind and is likely to result in a poor grade. However, it is possible to do well on this milestone with a module that is complete but fails to carry out its intended function, yet is informative for your design process and elucidates promising paths forward.

Much of your grade for this milestone will be determined from your MCM demonstration. During the presentation, you may be asked technical questions about your work. For example, we might ask you to draw a torque speed curve and explain how the performance of your MCM is related to the curve. Some questions might be related to the design process and project management, since we find that these issues are often critical to success.

For the MCM demonstration, please plan to run your device on the game board from a power supply used in the contest. However, you may make some aspects of the module's operation manual rather than automatic or remotely controlled. For example, you may need to manually position a gripper/arm into place, or trigger a launching mechanism. The key is to demonstrate those aspects of the MCM's function that you deemed most critical to the operation of your concept to achieve the goals of your strategy.

Your notebook entry should include:

1. **A picture and summary description of your MCM.** Explain the most important design features of your MCM. Things like degrees of freedom, gripping force, linkage kinematics, actuation methods, etc. You want to document what you have achieved to this point in the design process.

2. **Merits and drawbacks of your design.** Explain what worked well on your MCM and what could be improved. If your MCM did not perform the way you expected, please tell us why. What would you do differently next time? Include any design changes you may make to the MCM in the future.

3. **Integration into the rest of your machine.** Using simple sketches, show how your MCM will integrate into the rest of your competition robot. One way you could do this is to paste a picture of your MCM into your design notebook and sketch the remaining robot you will build around it. Please also point out the major other modules in your design that you will develop after spring break.

4. **Upgraded design requirements.** Describe how your design requirements may have changed after your MCM demonstration. Update the list of requirements for your MCM if they need to change, and for your entire robot(s). Please make your design requirements as quantitative as possible.

5. **Testing protocol**. Decide what it means to say that your MCM is performing successfully. Review the test protocol that you proposed in Milestone 5. Bring a copy of the updated test protocol to lab along with your MCM. The test protocol will serve as the basis for evaluating the performance of your MCM.

DELIVERABLE:
About 3-5 pages of writing and pictures in your notebook.

OTHER ACTIVITY:
It would be a good time to explore sensors and how to integrate them into your machine using the Arduino. Perhaps you can take a photo-resistor and devise a system that will recognize that the match has begun when it sees the light of your flashlight.

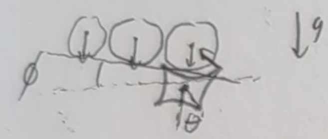
Summary:

Purpose: To dispense three game balls in a controlled manner

Design consists of a channel, cage, spinner, and servo. There is only one DoF which is the angle θ of the spinner.

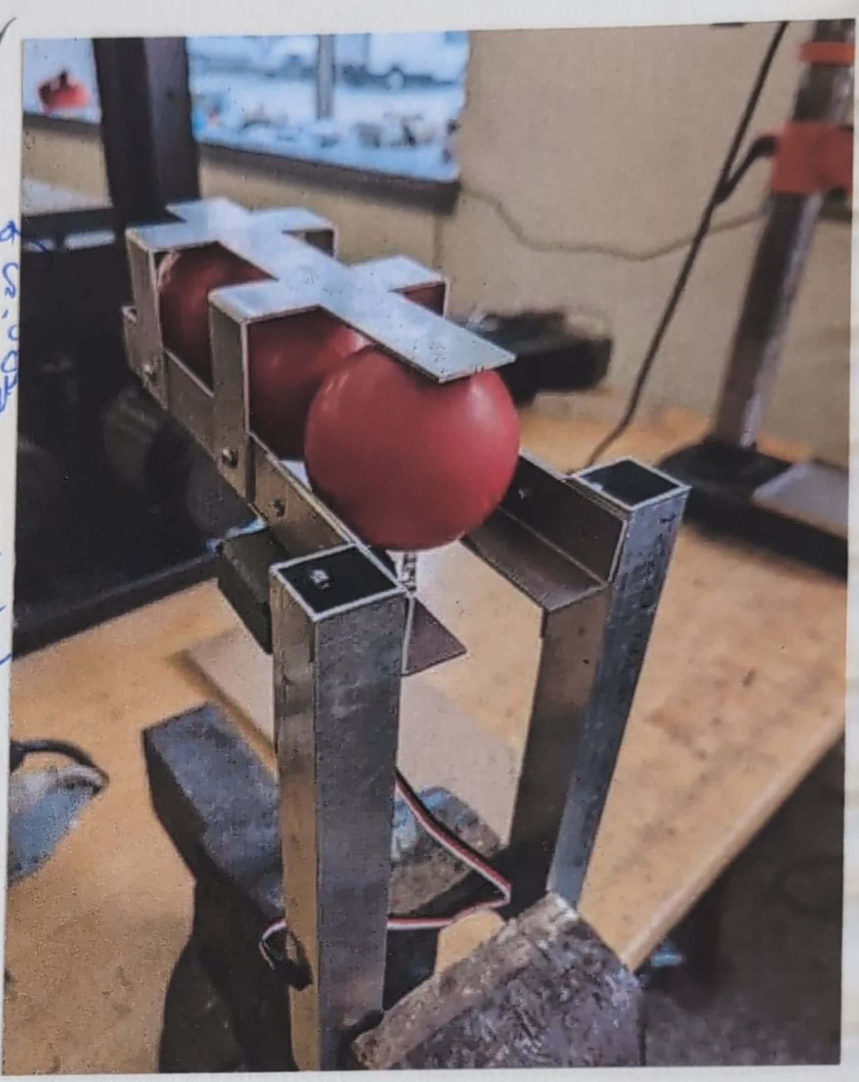
The balls are held trapped by the spinner and advance (from the force of gravity) once the ball in front is cleared

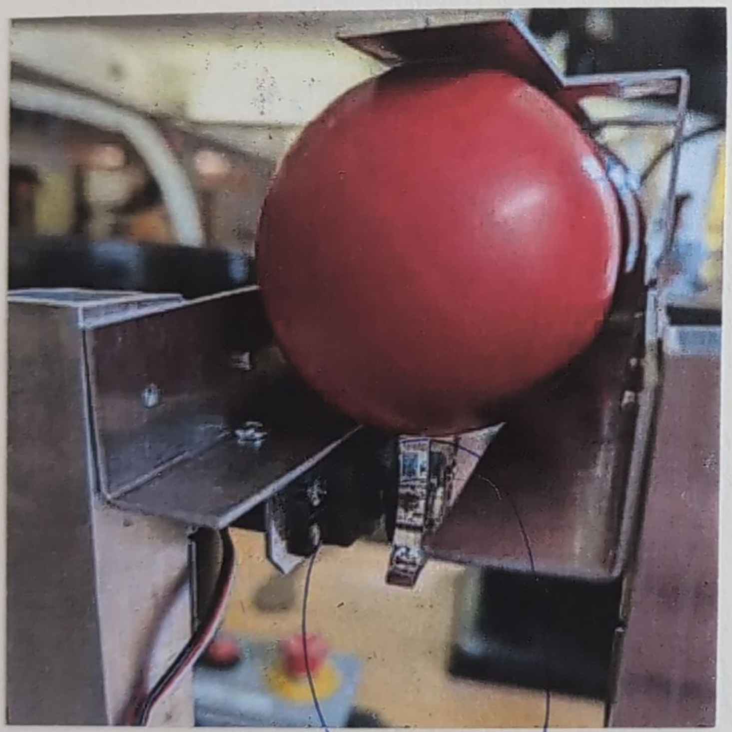
100 Ka
@
the
dispen
on
the
game
table



The servo is currently run off of the reciever, but in the future will be controlled by the Arduino such that timing can be specified so that exactly 1/4 of a rotation of the spinner is achieved whenever I want to release a ball.

It currently uses two 1" square bar stock tubes to act as stand ins for the lift's mounting points





Merits:

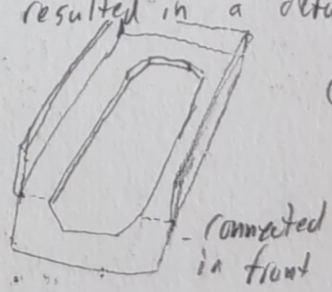
- Simple: Took only 1 iteration for a working prototype
- Tolerances generous: The slots allow for the tolerances to be sloppy while maintaining functionality
- Easy Control: Requires only 1D motion of a servomotor

Drawbacks:

Having the Ball Channel not being connected in the front makes the assembly much weaker.

In the process of bending (using a vice and hammer) this actually resulted in a deformed spread out channel

New:

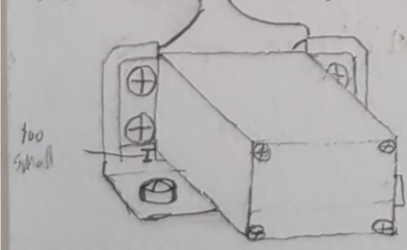


Old:

Edits:

Did it work?

Servo bracket not enough clearance on bottom



Do either (or both):

- need to increase spinner size.
- Move motor closer to the bracket's base

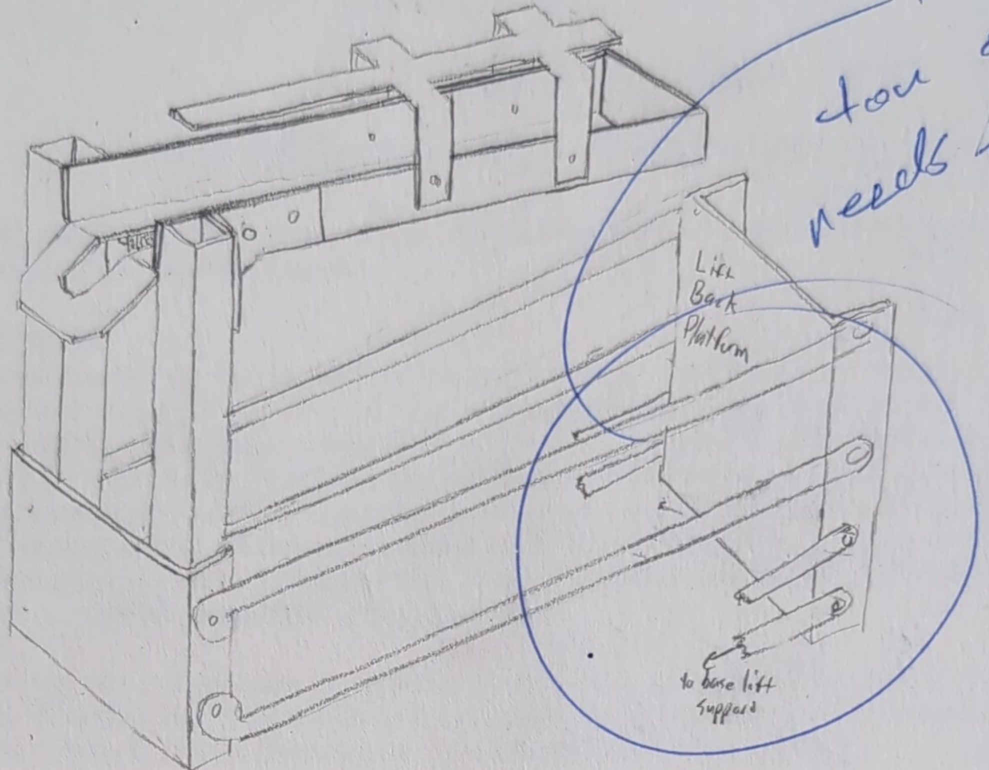
- Cage works well as is but the channel slots could be a bit larger or less bent more accurately

Make sure to use a proper break to make the bends to minimize deformation in unwanted dimensions and reducing manufacturing error.

- Update to use Arduino instead of radio reciever
- Have to calibrate timings and speeds for repeatable 90° rotations

Integration into machine:

Needs only to integrate with lift which then integrates with chassis.



There's a ton of stuff that needs to happen here.

Remaining Major Modules:

- Lift (foremost priority)
- Centrifuge Spinner
- Chassis + Drivetrain
- Winch
- Autonomy + Sensors

← In rough order of importance

Must be designing one as I'm prototyping another

Upgraded Design Requirements:

MCM design requirements stay the same

Robot:

Lift: Be able to lift ball manipulator to a height of 44 inches within 3 seconds and hold it for 25 seconds

Centrifuge Spinner: · Spin both centrifuges up to a speed of 225 RPM
· Take ≤ 15 seconds to reach 225 RPM

Chassis + Drivetrain: Reliably hold and move subassemblies without a chance for tipping or slipping

Winch: Hook onto the railing and multiplier ring and pull to 2x within 15 seconds

Autonomy + Sensors: With 95% efficacy drive from starting location up to Centrifuge and hit 225 RPM within 30 seconds

Testing Protocol:

MCM must:

- Dispense a single ball, no more & no less, in under 2 seconds with 95%+ efficacy
- Dispense all three balls, without jamming, in under 4 seconds, 90%+ efficacy
- Allow for 3 ball loading in under 20 seconds
- Be rigid to accelerations and function normally after jostling

low efficacy ratings at this stage, end goal MCM must reach efficacy of 98%+

Sensors:

Tasks that could use sensors for:

- Turning on in Autonomous mode: photodiode + phone flashlight
- Detecting Centrifuge Spinner Speed: encoder on spinner
- Driving from start to spinners autonomously:
  - Rotational position: IMU
  - Translational position: motor encoders

Autonomy:

- Could hard-code values but it might be unreliable
- Measuring Centrifuge spinner speed is likely not necessary if bot is calibrated properly and motor input signal and time are hard-coded accordingly

All of this is very cool, but there's a ton to get done.

① Dispense

② Reverse 4-bar

③ Driving.

What's the status of each? Take notes & sketch as you work to capture real-time information

Time is ticking. This is the official "Fire under your backside" get fabricating!

2.007 Milestone #7 – Design Integration

LEARNING OBJECTIVES: Reflect on your MCM demonstration and make a plan forward for your robot design and your tasks for the rest of the semester.

INSTRUCTIONS:
This milestone concerns the overall design of your system based on the results you attained in making your most critical module. For many of you, this will be an important juncture in your design process. Some of you will want to develop mechanisms that cooperate with the MCM you just created (e.g. an arm that can manipulate an object). Others may want to reconsider the module they just developed, and maybe even their entire strategy, to simplify their approach and begin executing a new plan. In either case, the decisions you make now can have a big impact on your overall success and the relative ease or hardship you'll experience in the upcoming weeks. From the time this milestone is assigned, you have four weeks until MS8 is due (including spring break), when you will present an oral design review of your integrated robot to your lab section.

For some of you, now is a good time to throttle back on building and return to the drawing board – literally and figuratively. Therefore, this week you are going to reflect and project your plan for the future, leveraging your design skills, notebook, and the people around you. Deliverables for this week are:

1. **Oral design review of your integration plan with your lab instructor.** Per the instruction of your lab instructor, you will do a brief oral review on how you plan to integrate your MCM into your completed robot. You should discuss what additional modules remain to be designed and fabricated, how all of them integrate together, and the time required to design, fabricate, integrate, and troubleshoot your machine.

2. **Some reflective discussion regarding the MCM demonstration.** In your notebook, briefly state the result of your MCM demonstration and what you learned from it. Explain the reasoning behind the results you attained. Sometimes small changes can make big differences. This is particularly important if the demonstration was not entirely successful.

3. **A representation of your integrated system.** In your notebook, make a graphical depiction of your most critical module along with the other modules/supporting systems that will be integrated to form your complete 2.007 robot(s). We strongly encourage using CAD to accurately estimate weight, center of mass, dimensions, and features/locations of parts. In particular, your CAD drawings with annotated dimensions will drastically expedite your fabrication process. If you insist on creating hardware first, attach pictures of your progress.

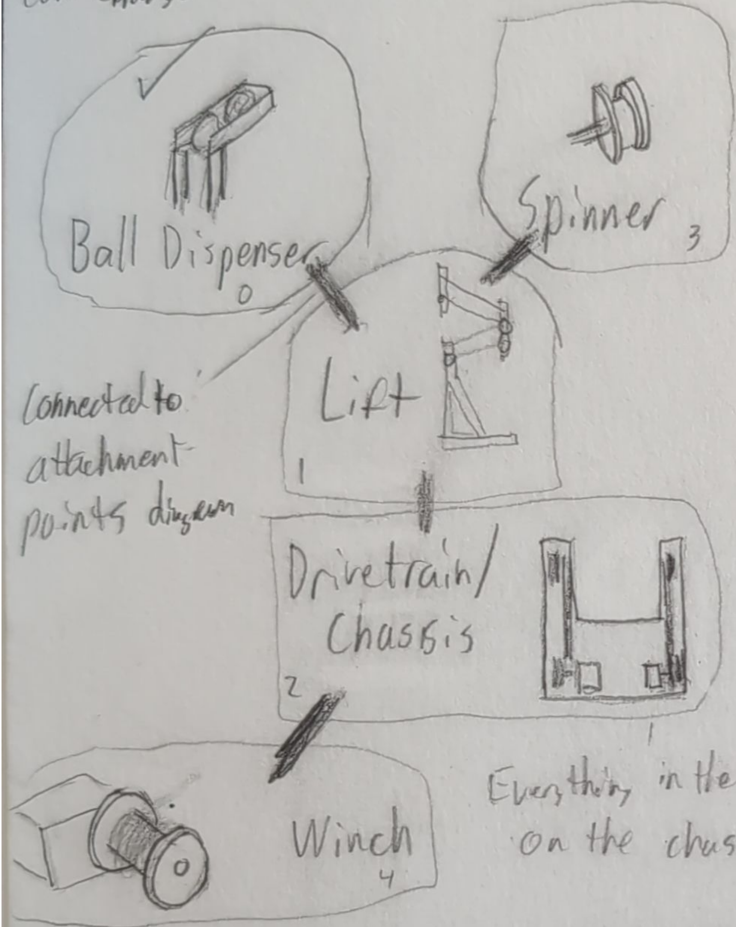
4. **A plan for the next four weeks.** Lay out a 4-week schedule in calendar form, covering the period from the assignment of MS7 to the "impound" of your robot during the week of May 1. Include details in your plan such as parts to be made, modules to be validated, driving practice (don't forget this!), and associated timelines. Plan for your machine to be complete and ready for practice only the day your lab meets during impound week. If your schedule slips, you may continue to develop and fabricate your robot through the week of May 1, provided you impound by the end of the week, per the guidelines of the course instructors.

Enumerate the deliverables of this assignment to effectively communicate with your instructors.

DELIVERABLE:
About 3-5 pages of writing and pictures in your notebook.

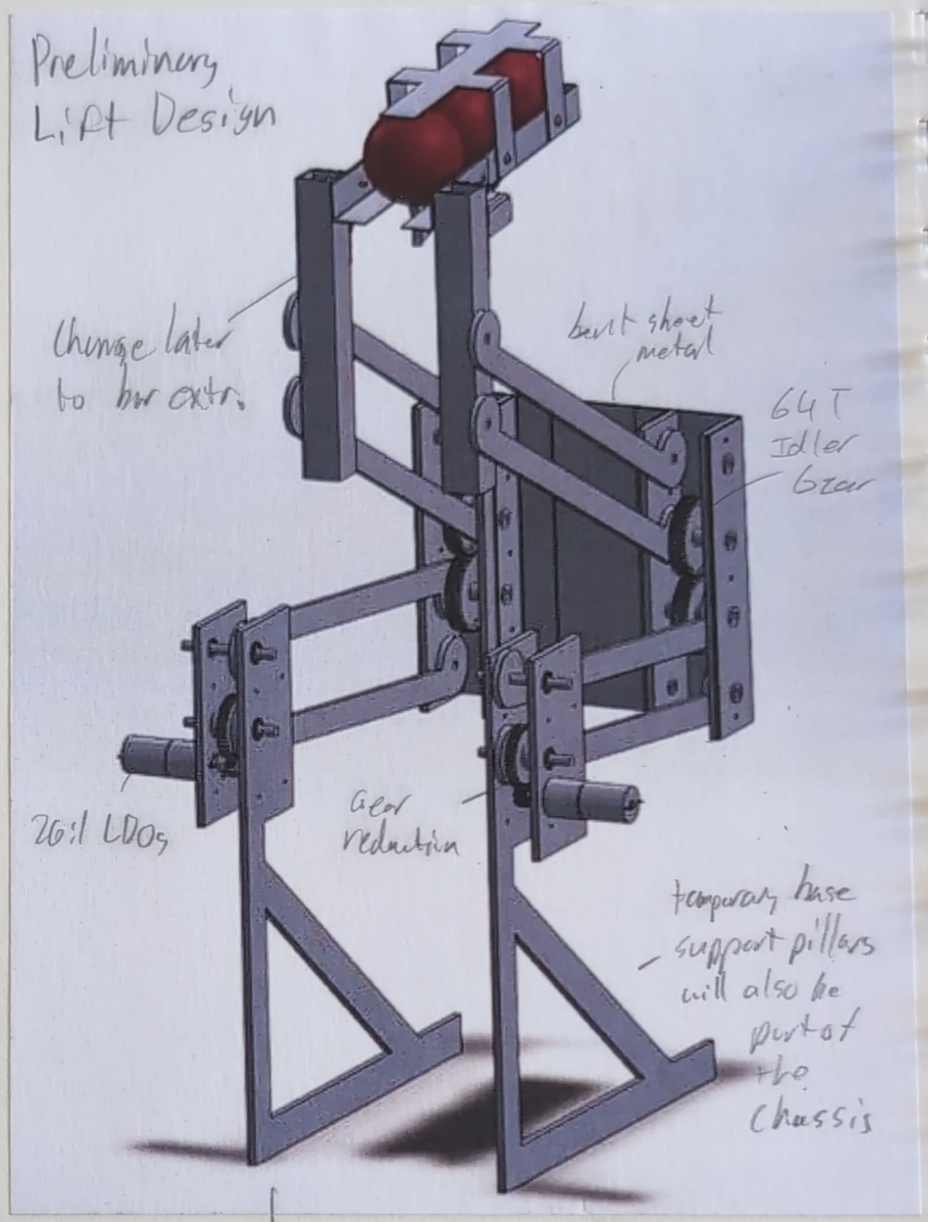
Integration Plan:

MCM (ball dispenser) integrates directly to the lifting mechanism's upper stage. The current box extrusions work as attachment points, but if I need to decrease width of the robot, I can change the box to bar extrusion.



Connected to attachment points diagram

Everything in the end relies on the chassis working correctly


Preliminary Lift Design

Rough CAD with various issues, but overall shape and structure will likely be quite similar.

<u>Lift</u>: Next up to be fabricated, most complicated part
- 1 week to go from nothing -> CAD -> prototype
- Try to design with spinner, ball dispenser, and chassis in mind so integrating them later is easier

<u>Drivetrain/Chassis</u>: Base of entire robot, large but not super complex
- 3/4 of week to do one iteration cycle
- Must integrate with existing lift and provide future attachment for the winch
- Once completed, robot will be able to compete, 100% necessary to get here early

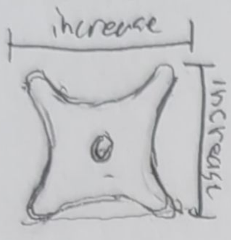
<u>Spinner</u>: Mounted onto lift mechanism, will affect back plate design.
- Not too complex, but from what I've heard must be well made to reach necessary speed
- Less than 10 parts, first prototype should be quick ≈ 1/2 week

<u>Winch</u>: Very important to be competitive, must Must do well & consistently
- Spend some good time drawing designs in notebook to try out many designs
- ≈ 4/5 of a week for iteration
- Constant force spring tape measure style?

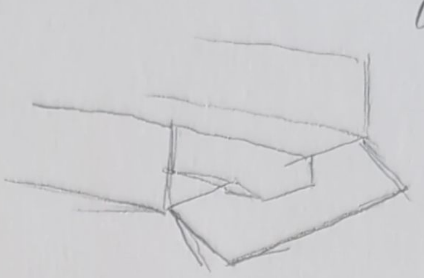
MCM Reflection:

MCM worked well, only minor tolerance tweaks to be made
slotting the holes for fasteners made it far more tolerant to human (read"ing") error

Think about:



more surface area
more tolerance for servo
placement



connecting the front of
the channel to prevent
deformation in bending

System:

CAD of Lift + Ball Dispenser = 5.38 lbs

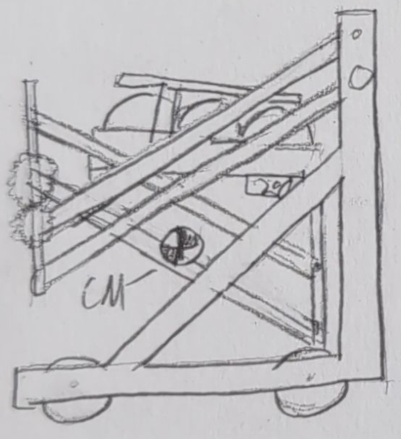
$\boxed{\text{max weight allowed} = 12\text{ lbs}}$

Estimated weights:

spinner assembly = 0.60 lbs
winch assembly = 0.50 lbs
Drivetrain/Chassis = 3.0 lbs
Electronics = 0.30 lbs
Total = $\boxed{9.78\text{ lbs}}$

Lift support pillars shared between
lift & chassis

Not in too much risk of surpassing limit
but good to be careful
weight also helps with pulling ring with wheels



Electronics:

Wire Routing from spinner and ball dispenser will be hell,

- Just have to use really long wires and route them along the length of the arms down to the control board

*Ask 2.678 Steve if this length of wire would cause any issues

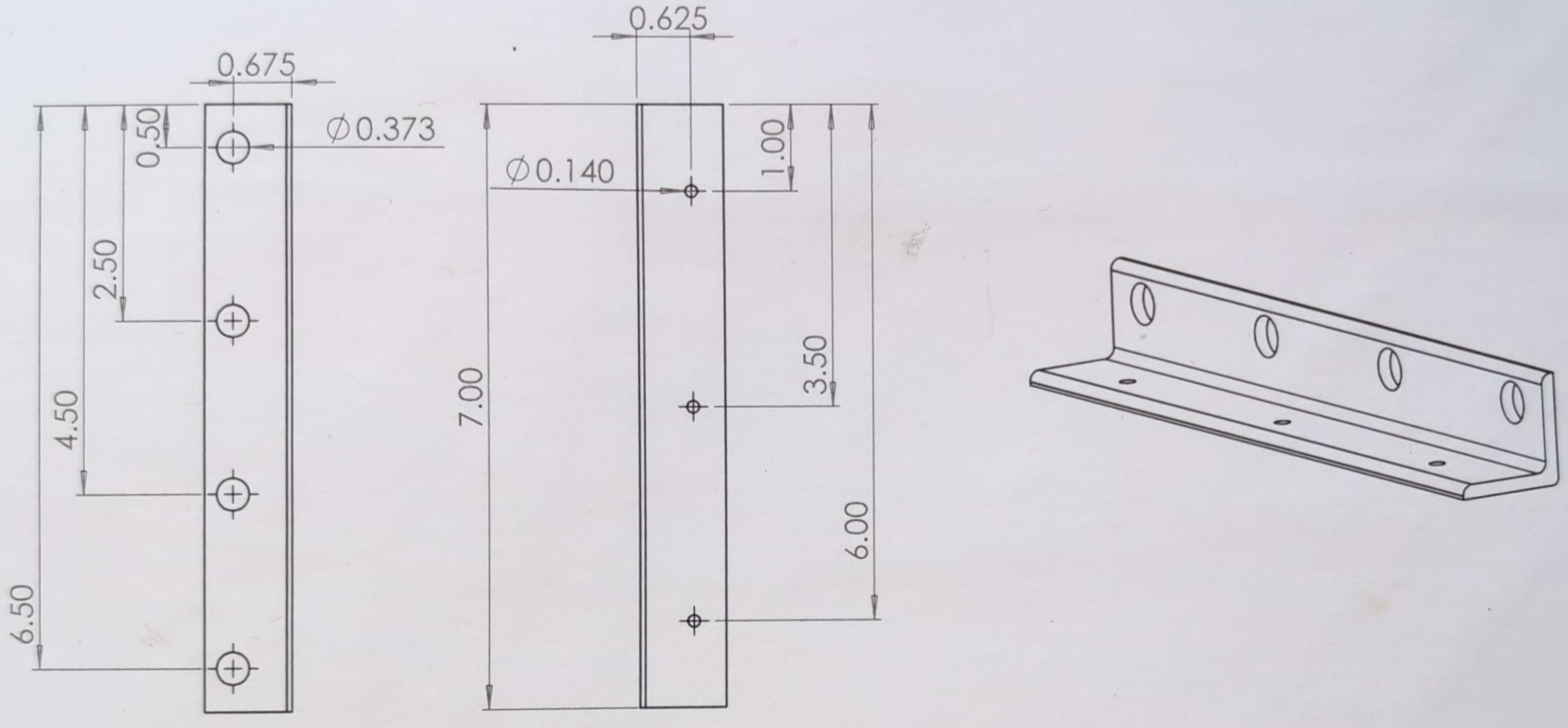
Controls:

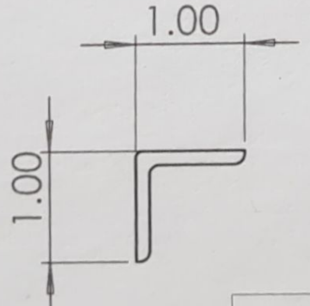
			Ideal input form	
Lift,	θ	up and down angle	Potentiometer or stick	
Spinner	ϕ	on & off is enough (speed maybe)	Switch	(only in autonomous might not be necessary)
Ball dispenser	β	from spinning to release balls	Button/switch	(activate on off-on change in code)
Driving	$\dot{x}_1$ $\dot{x}_2$	speed of each side of wheels	two sticks	
winch	$\dot{y}$	direction and on/off of spool	3-pos switch	

6 total DoF - goBilda Remote will work

I could use my Qx7 transmitter but it's not necessary and defeats some of the soul of the game

Will have to get creative with mapping of controls to the limited options on the





COMMENTS:

4x for lift assembly

2.007 MIT

TITLE:

L Bracket Hub

SIZE A

DWG. DESC Lift Back-plate

REV 1

AUTHOR: ELIJAH BELL

INCHES

SCALE: 1:2

Modified: 4/13/2023

SHEET 1 OF 1

Plan for remainder of semester

April 10th-14th Design and construct lift mechanism
15th-16th CAD fabrication-ready chassis/drivetrain
17th-19th Make chassis iteration #1
20th-21st Finish chassis and CAD for spinner
22nd-23rd CAD and think about Winch — Most uncertain step
24th-27th Make winch
28th Integrate, test, flex day
29th Adjustments, tweaks, practice, etc
May 1
4th IMPOUND
↓ Practice
15th GAME DAY

2.007 Milestone #8 – Oral Design Review

LEARNING OBJECTIVES: Learn how to articulate your design decisions and analysis to your peers, leverage their collective wisdom and gain feedback to improve your competition robot.

INSTRUCTIONS:
You will present a 10-minute design review of your integrated robot (with all finished and planned modules). This presentation will be given to your lab mates and your lab instructor during your lab section. Your grade will be determined by peer review feedback and your lab instructor's assessment. The oral design review is worth 10% of your final grade.

The purpose of this milestone is for you to explain the engineering and design decisions behind your robot. You should discuss what strategies you are trying to complete. You should be prepared to justify the form and function of different aspects of your robot, and justify the design decisions you made with analysis and good design reasoning. This presentation will also be a chance to get feedback, which you can use to improve the design of your machine. It will be a win-win! After Milestone #8, there is only a short time before impounding. This is a last chance to make any significant design changes.

We will expect to see the following in your design presentation:

1. A short description of what your robot is meant to do (function, competition tasks). Please bring your robot to the presentation so you can point out relevant features.
2. 4-7 powerpoint/keynote slides explaining the important features of your robot and the engineering decisions/analysis you used to complete your design. You can use your own computer to project these slides. Justify your decisions with good engineering reasoning. Elements in the slides may include: CAD models; pictures of bench-level prototypes; close-ups of important mechanical elements; videos of your robot completing tasks; critical calculations; and spreadsheets/MATLAB simulations you used to predict performance.
3. The evaluation of the design review is based on the following elements:
    - Strategy
    - Overall Design
    - Technical Details/Calculations
    - Lessons Learned & Next Steps
    - Presentation quality (organization, good articulation, image/figure quality)

4. Your plan for the remainder of the semester and how you will prepare your robot for the competition. Include any challenges you still face and your plans to overcome them.

DELIVERABLE:
Oral design review presentation about your robot. (Note: this presentation is worth 10% of your final grade).

2.007 Milestone #9 – Impounding

LEARNING OBJECTIVES: Complete and document your design.

INSTRUCTIONS:
This milestone is effectively the last one that addresses fabrication. You should be finalizing the last additions and improvements to your total system. The subsequent activity is the demonstration of your fully integrated machine at the competition!!!

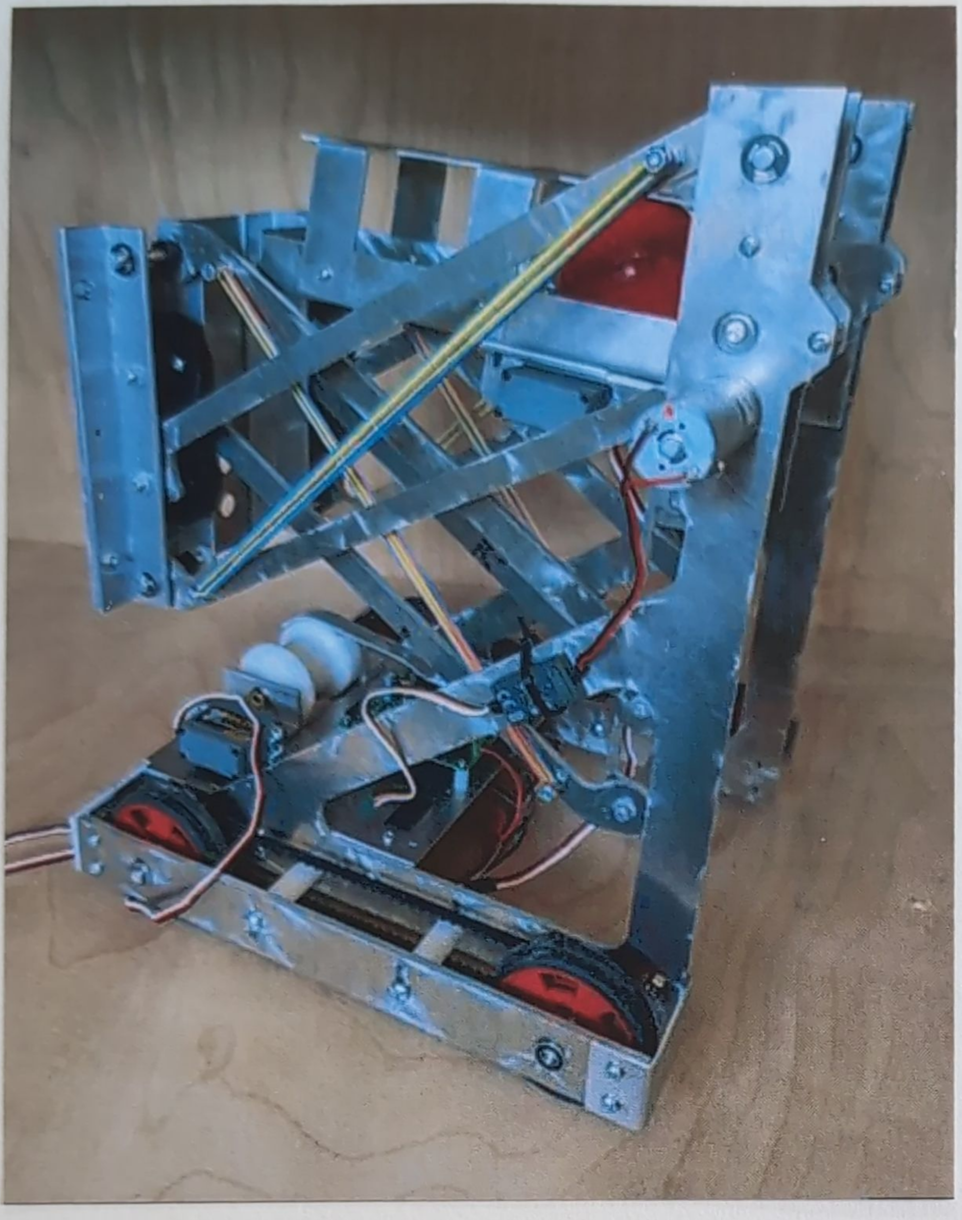
After the contest, we plan to grade notebooks one more time to see documentation of your final machine and your reflections on the competition (that is the next graded milestone). Please include the following items in your notebook for this milestone:

1. **Annotated photographs of the complete machine in its current state.** Please take a few photos showing different views of your machine. It would be good to show the two or three critical configurations such as arms extended or retracted. **Label** the photos with notes to indicate principal successes and major current concerns.
2. **Fabrication details.** Discuss the main steps you are taking this week to finish up your machine. What parts have been the hardest to build? It would be good for you to list out fabrication steps so you can efficiently complete them in lab.
3. **Stored energy calculation.** Present how much stored energy your robot has. Energy storage sources may be batteries, stretched elastic bands, etc.
4. **A pre-flight checklist.** You will need to complete a series of tasks to **prepare your robot for competition,** especially if you have an autonomous robot. They can be as simple as plugging in the battery and turning on the power, or as complicated as reconfiguring a mechanism for a certain task. In your notebook, list out every step required to make your robot ready for the competition. This list will be critical for reliable operation during the nights of the competition, when you may be nervous and thinking about many things at once. The pre-flight checklist will ensure you prepare your robot for successful operations in the competition. **Store a copy of your checklist with your robot so you remember to use it during the competition.**

IMPORTANT: As part of impounding, you will have to demonstrate your robot in a competition round, following the contest rules. This can be done live for your lab instructor or videoed and sent to your lab instructor. You may use your ladder score for your impound score. **Your lab instructor must sign off on the size and safety requirements for your robot; other instructors may fill in the remainder of the impound card before you submit it. Make sure you review all the categories on the impound card. Even if you are on the ladder, you still have to submit an impound card.**

An example impound card is available for download on Canvas under the Course Information Module.

OTHER ACTIVITY:
We highly encourage you to decorate your robot and give it an awesome name! Expressing your own personal style through your robot is always welcomed!



Overview:

Success: works well to complete various different, independent tasks

Name: STITCH

(as in Lilo & Stitch)

Concern: My sleep schedule

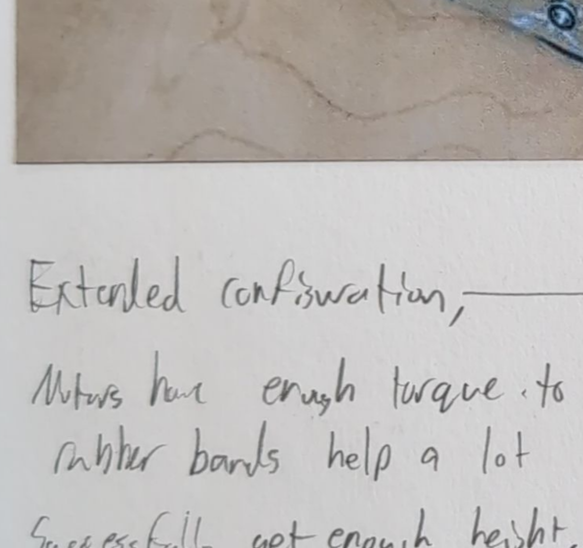
Very nice implimentation

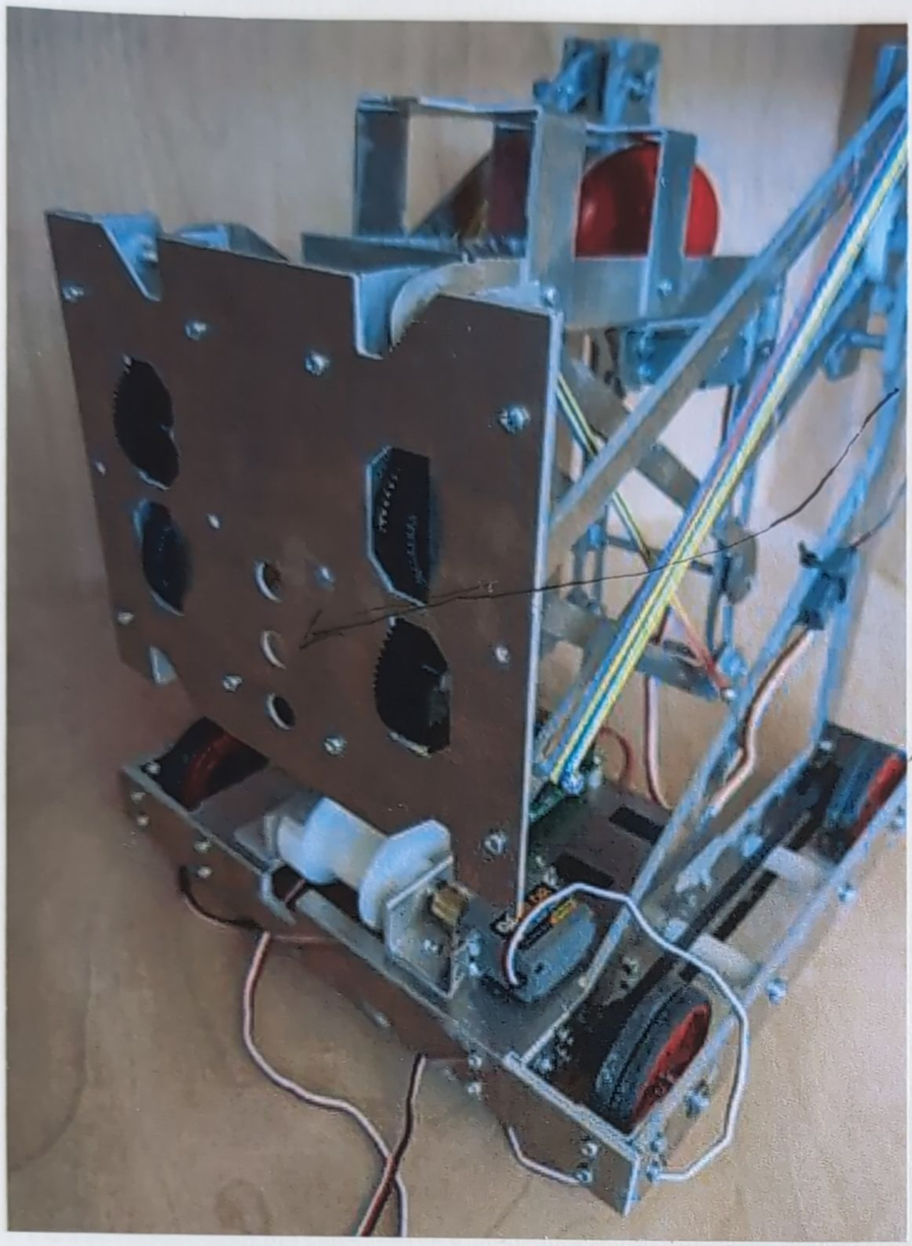
Extended configuration, →

Motors have enough torque to get there, rubber bands help a lot

Successfully get enough height,

Concern: need a fold downable gate to increase reach of ball channel





← Back plate view

Needs to be very tight to prevent arms from side-fumbling and misaligning the robot as a whole Yes. Some means for structural stiffness is important to avoid cracking & binding.

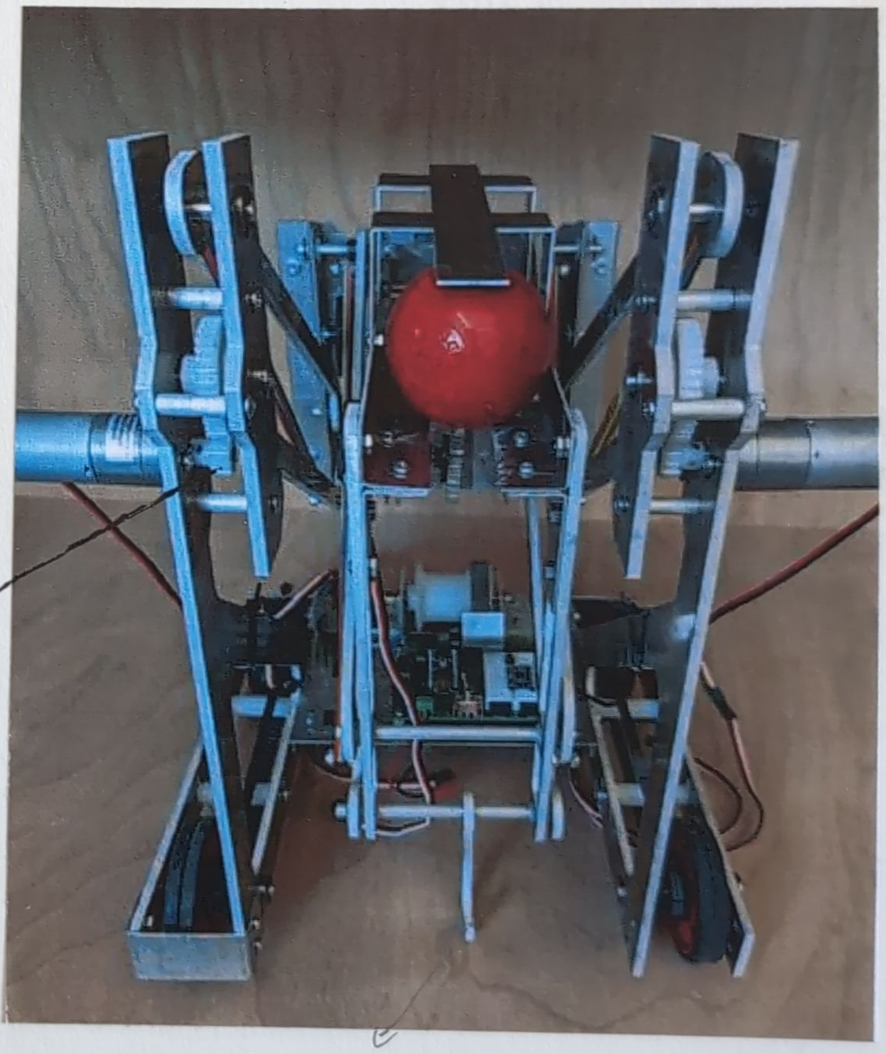
houses spinner mechanism concern still under design + construction

4WD belt driven with two speed servos works well, fast, reliable, stable drivetrain

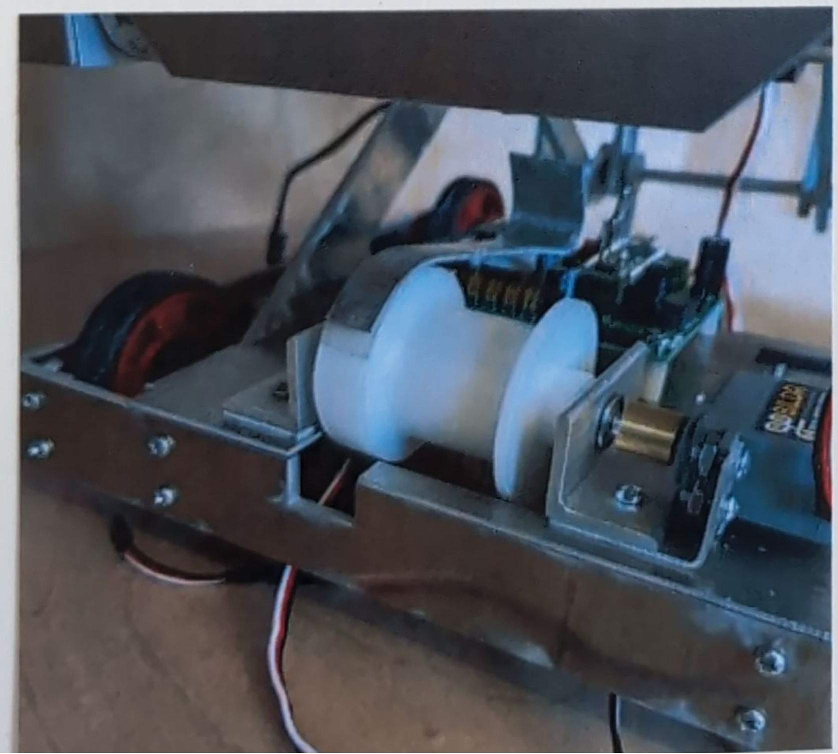
Frontal view of the assembly ←

Success: looks cool

Failure: tolerances are very tight and motor 12T gears lost some teeth early in assembly, too high torque on them



Front hook



← Winch + Back hook

Success: simple design, works well to deploy hook and winch back in

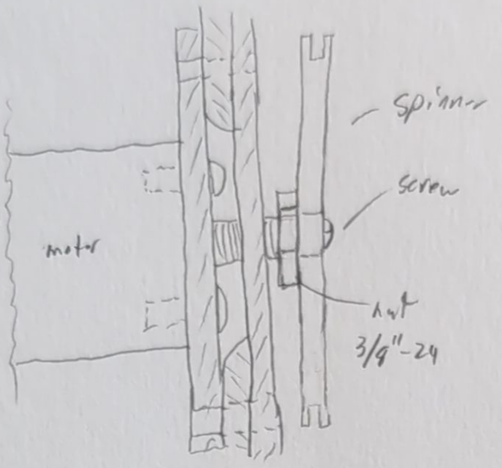
Concern: Tape loses stickiness over time, so it needs constant replacement or a new material

Fabrication Details:

Steps Left:

#1 Winch:
- Roll pin spool to shaft
- Attach string to spool and hook
- Replace double-sided tape
- Test!

#2 Spinner!
- Cut mounting plate
- Design spinner
- Make spinner
- Attach to assembly
- Wire to Arduino board



#3 Frame:
- E-clip all axles
- New end caps
- Glue wheels on
- Adjust, tweak rubber band

Hardest to build was the assembly and disassembly of the whole robot. It takes a lot of time. The lift mechanism was easily the most complex part of the design though

Stored energy calculation!

Battery: $7.4V \cdot .800\,AH = 5.92\,Wh = 21.312\,kJ$

Elastic Bands: $F = kx \quad k = \frac{F}{x} \quad E = \frac{1}{2}kx^2 \quad E = \frac{Fx^2}{2x} = \frac{Fx}{2}$

$F = 3kg \cdot 9.81\frac{N}{kg} \Rightarrow \frac{29.43}{2} = 14.715 \quad 0.28m$

$E = 14.715 \cdot 0.28m = 4.12J$

look @ order of magnitude pretty amazing (to me)

Total = Battery + Elastic = $21.312 + 0.004 = 21.316\,kJ$

Max energy = $50\,kJ$

Stored energy = $21.3\,kJ$

Checklist:

- ☐ Turn on Robot
- ☐ Verify Remote connection
- ☐ Set Remote to trigger bot's Autonomous mode
- ☐ Place 3 balls into holder
- ☐ Verify battery is fully charged
- ☐ Wind up spool and load hook
- ☐ Check "points of concern"

Type and bring

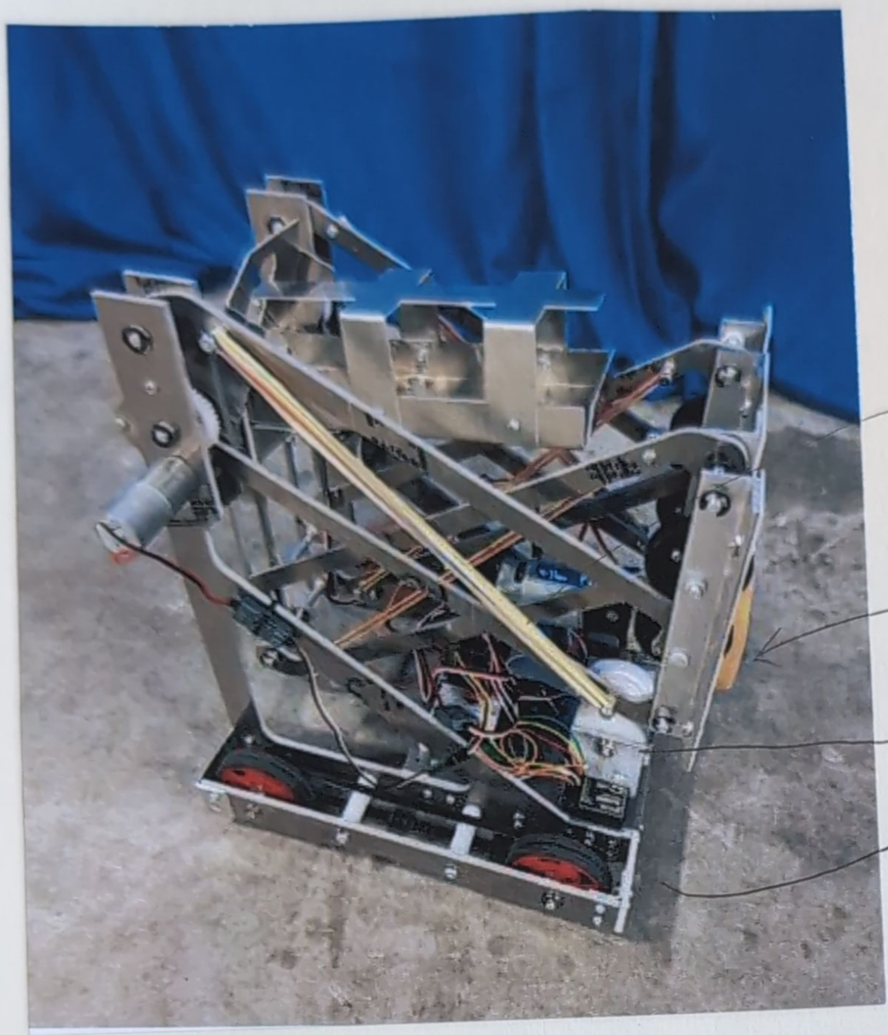
2.007 Milestone #10 – Reflection and Learning

LEARNING OBJECTIVES: Reflect on your design experience and how it impacted/prepared you as an engineer.

INSTRUCTIONS:
This milestone is the last one of the course ☹. You should devote ~3-4 pages to it in your notebook. During impound week, you will have the chance to observe lots of other machines in operation. You also may have some time to reflect on your own design effort and what it meant to you personally. In particular, consider what you have learned and how the experience may change your design approach in the future. Below are some suggestions on elements you may choose to include in your final milestone notebook entry:

1. **A description of the final machine.** Describe the features of your final machine and what it does. To answer these questions, you might use an annotated photograph and/or solid model and a detailed description of your seeding round results.
2. **Some comparisons.** Are there other machines that help us to understand your machine and your design process? How did other people approach the same tasks that you attempted? Are there any principles that can be generalized from these comparisons?
3. **Use of design tools.** What role did design tools such as CAD and computational tools play in your design? Did these tools help you foresee and avoid a problem? Did you make more use of the tools compared to those around you, or less? What was the impact of the tools on your design?
4. **Use of fabrication tools.** How did the kit of tools and materials you had at home help you grow as an engineer? How did you use these tools? How did your skills change over the semester? Were there any tools you didn't find useful, or any tools you wish you had that we didn't provide?
5. **What you learned.** Please describe in some detail a few key things you learned. The things you list might concern machine elements, fabrication, solid mechanics, the creative process, and/or decision making. An insightful analysis of a few things you learned is preferred to a long list.
6. **What would you have done differently?** Hindsight is 20/20. Looking back, how would you have changed the strategy of your robot? If you kept your original strategy, would you have changed the design of your robot to better execute it? Would you have changed your time management strategy?
7. **Suggestions for next year.** Please tell us any improvements you think we should implement in the course next year.

Final Machine:



↙ Collapsed View of robot

fits in 12"×12"×16"

Barely! But it fit!

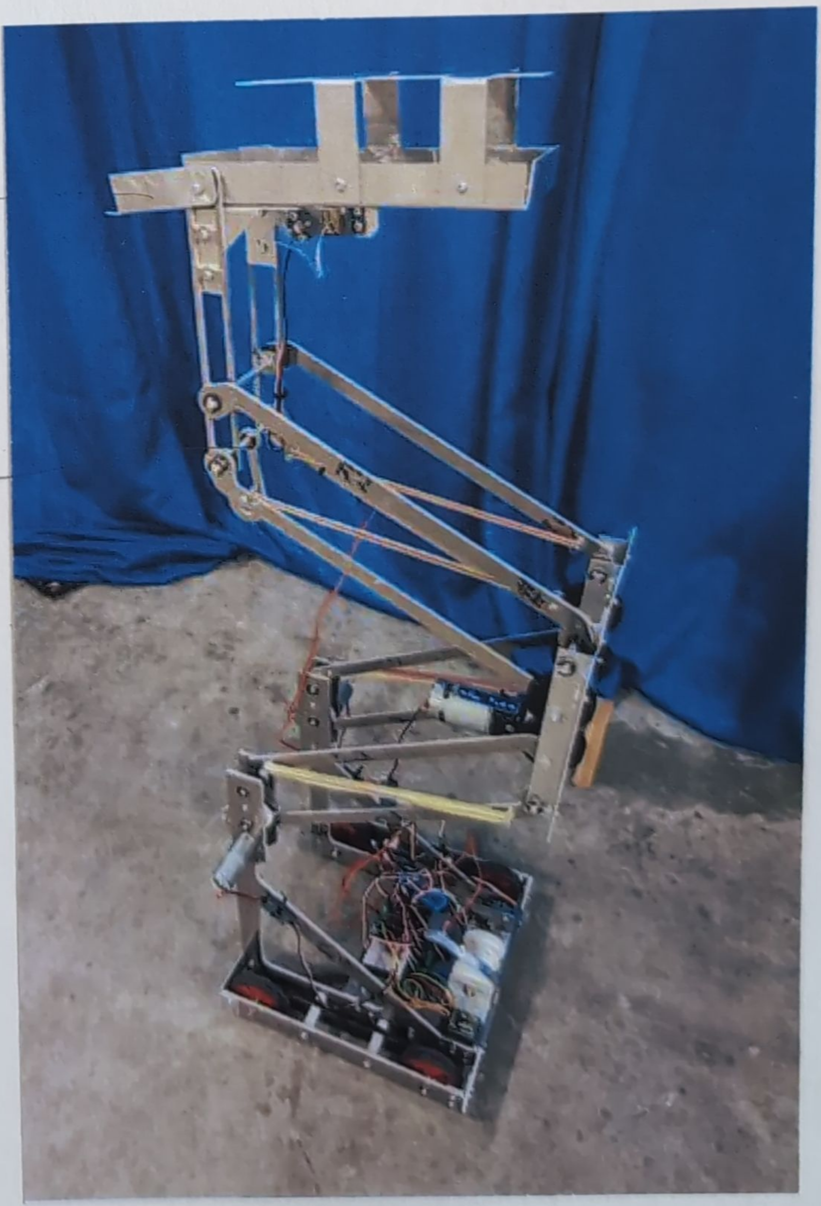
rubber bands to reduce lift force

Drill motor - driven

centrifuge spinner wheel

winch pulley

4WD Belt driven drivetrain w/ double stacked wheels



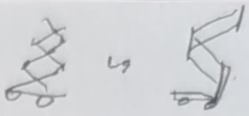
Ball dispenser with gate to reach deeper into DNA structure

- Indexable ball release, 1 at a time

Front hook for ring multiplier pull

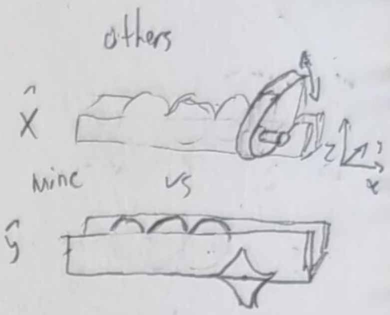
Seeding round got 0 pts as robot had fried all motors earlier in the day and didn't have time to repair it.

Some Comparisons:



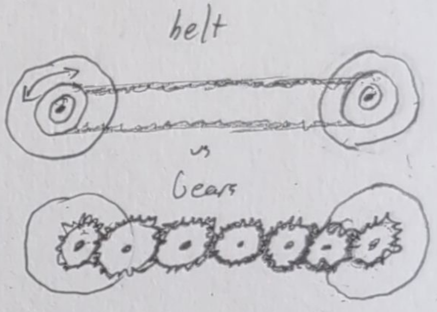
Lift: Relatively few lifts this year, most people opted for going after the centrifuges instead of the DNA. Out of the lifts I did see though, the 4-bars seemed to be the most reliable, although hard to construct. A good lift must be reliable, robust, tolerant to error, and easy to fix

Ball Dispenser: Most people went with a gate-based design. Of the robots I noticed, I was the only one to do the gate parallel to the flow of the balls. Good designs were simple



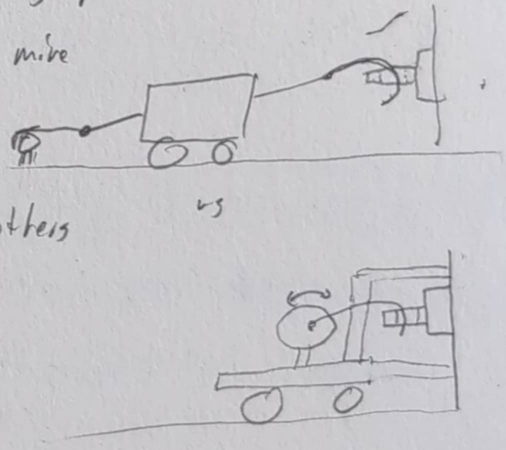
Chassis + Drivetrain:

All robots needed some way to move. Some robots were 2WD, others 4WD, others had more than 4WD. Of the 4+WD robots, there were two camps, those who used belts and those who used gears to transmit power. Gears worked, but they looked overly complex and like it had power loss due to friction.



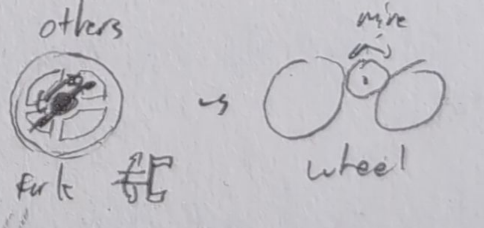
Winch:

I saw two camps for this as well, "brace against the wall" or "railing pull".
I think in isolation bracing against the wall is better, but I couldn't find a way to get it to fit on my robot.
The railing pull method is higher power though since you can engage the drivetrain for extra pulling force.



Spinner:

All spinners tended to have trouble getting up to full speed due to efficiency losses in the gear train so it was important to make those parts precisely.



Use of Design Tools:

I heavily relied on CAD as my robot had many components to it, 300+ fasteners included. CAD helped in planning greatly and fundamentally allowed for designs I am unable to store in my head.

The issue was that in fabricating some parts by hand, namely shafts, I missed the CAD dimensions and had to readjust things on the real robot as needed.

Matlab and Desmos were also used for calculating motor characteristics

Use of Fabrication Tools:

I'm chair of the Vassar Makerspace/shop and so I had access to the tools there as well. I also used The Deep.

Before 2.007 I had never really used a mill or a lathe, so I got far better at using those tools over the course of the semester. I relied heavily on the waterjet for as much of my robot as I could, as it was more precise and quicker than I am.

What I learned:

Use of the Mill and Lathe

Gears & shafts

learned how to fix and secure items to shafts and hold the shafts within bearings. E-clips, roll pins, push nuts, etc I had not used before

Motors

Finally learned about torque speed curves, now I can actually size motors accurately for what I need.

Project Planning

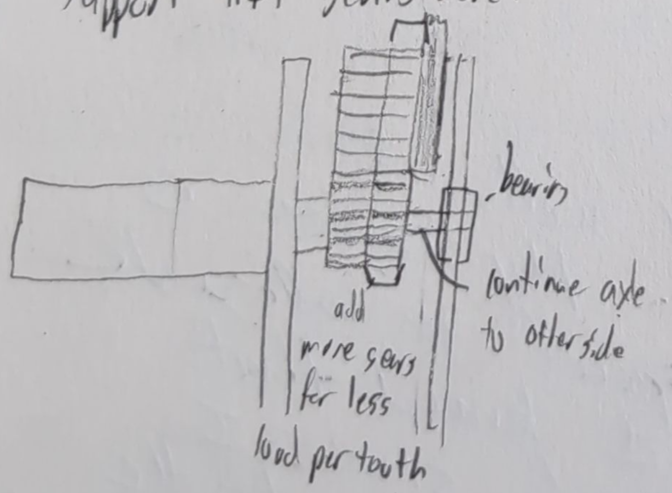
I like the idea of MCMs and splitting things into modules. I was able to evade integration hell in doing so

yes. Recall the lecture on the Wright Flyer. Break it down into pieces.

Done differently:

I really quite like my robot and I think its almost all there. The strategy and overall design I would keep. In the future I would change:

- Clean up cable management
- Support lift gears more:
- More clearence in length of robot to allow for a longer spinner



Suggestions for Next year:

Get a printer for Pappalardo - with so many people on the lathes and mills, you want to encourage the use of drawings but its difficult when there's no printer

WH & Exam: Unclear questions lead to an unfair feeling of grading. Refer to comments made during lab section

Lab hours: I understand that the hours are 8:30-5 to simulate a real manufacturing environment. But, quite frankly, it's not a job, it's a class and the point of the class should be to teach. When a good part of the class has conflicts during lab hours, what's the point? Most, if not all, of the other project classes at MIT prioritize lab hours that are accessible to students. These classes are also teaching students to be productive in a workplace environment; what's so special about 2.007? Since staff were able to work the extra hours during ladder week, it's not an infeasible request to ask to move the early morning hours to later in the day. Or, on weeks that have important deadlines at the end, add in extra hours like during ladder week.

Practice:

Emphasize practicing more and provide more days to practice after impound day.

Advice: I felt like I spent most of the semester doing the class by myself. It would be helpful if someone touched base with me at least once a week to provide critic and advice.

Elijah -

Your device turned out very well. Details were executed nicely. My sense is that you didn't (or couldn't) spend an adequate amount of time in lab and I know that feedback was challenging to provide since I seldom received your notebook according to the schedule. So I see the biggest growth area not in CAD or machining or concept work, but in planning. Focus on that and I think you'll become a formidable (In a good way) Engineer.

Have a great break & I'll see you in the Fall. Dave