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2.007
Design & Manufacturing I
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Spring 2024
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Milestone #1 (9)

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1) Design Constraints and Freedoms

↳ List of All Available Kit Components

(very useful...)

* plus 6 inches^3 of 3D Printed Parts + 4 inches^3 support material

Gears + Bearings
- Bushings (5/16", 1/4")
- Bearings (1/4" ID w/ 5/8" or 1/2" OD)
- Belt Loops (18", 24")
- Timing Pul. (1/5)
- Spur Gear (12 teeth, 24 teeth, 36 teeth)
- Bevel Gear (24 diam pitch 24T/48T)
- Splined Gear (16T/24T/32T/ 64T 32DP)

Motors
- LDO Stepper (26, 35, 57, 98, 217)
- Bilda Servo (Speed, Torque)

Wheel
- Wheels (Caster, SolarBotics, MiniMe)

Connectors
- Linkages (1"/2" Hose Clamp, Ball Link, Wheel Collar, Steel Hinge, Threaded Ball Link)
- Adapter (Hex Wheel, Hex Shaft, Motor Shaft (LDO), Servo)
- Springs (Large Comp., Large Extension, Med. Ext./Comp., Small Ext./Comp., Constant Force, Small/Large Torsion)
- Rubber (Feet, Suckers, Gromets, Stopper, Tubing, Bands, Balloons, Sheets)

Material
- Angled Extrusion (1x1, 1.5x1.5)
- Square Extrusion (1x1, 1/16" thick, 1x1 1/8" thick, 1x3" Box)
- Rods (1/4"-20 threaded/unthreaded, 5/16" steel hex, 5/16" unthreaded)
- Flat Stock (1/4" x 2")
- POM Rod (1", 2", 1/2", 3/4") [rod and square]

↳ observations
- There are few options for belts (2) or gears (≤4), so this constrains gearboxes or transmissions the robot can have
- There are many types of stepper (5) but few servo (2), which is not inherently bad but reduces options for servo. Also all are a standard size, so constrains size of robot
- Very few wheel options (3) which is very limiting...
- Spring and Rubber components very diverse and can help interesting designs

You can make wheels

↳ Game: Methods of Scoring Points, w.r.t. Components in Kit

1. Vat of Acid (collect balls, deliver to tubes)
   - Use speed servo to quickly pick up balls in net
   - Sit in vat and use belts to transport balls to shooter to lob balls into tubes

     Interesting to see.
   - Use balloons to push balls around or pressure to launch them
2. Gobble Boxes (press alternating buttons) (+ Portal Guns?)
   - Sit on upper rack, because why wouldn't you?
   - Use hammers moved by CAM shaft device? Maybe use belts or rubber bands to attach them
   - Store spring energy and use torque motors to repeatedly pull back hammer onto spring to launch onto button
3. Mind Blowers (remove tubes from shelf)

   (huge # of points.)
   - Build scissor lift with metal stock and torque servos to reach top? Approach from sides and grab w/ end effector or use rubber ~~belt~~ suction pads (if stick to curved surface)
   - Use robot to use tubes to climb up to top and remove, but super risky
   - Climb elevator (tbd) and use ~~[illegible]~~ spur gear + rack to lower claw from above and use torque servo to lift and lower. Maybe do multiple at once?
4. Car Doors (lift trapdoors to specified angles)
   - Again could use spur + gear to now instead lift mechanism up to push ~~[illegible]~~ doors open. Maybe have previous mechanism rotate 180° depending if reaching down or up?
5. Car Multiplier (push pendulum to 30° angle)
   - Probably a good task for autonomous time?
   - Hang from top like Ski Robot example
6. Elevator (crank wheel to lift robot 36" in air)
   - Use provided wheels and gears to create a gearbox w/ fly wheel, probably need a lot of torque for this one....
7. Bonus: Pickle Rick (Push down zipline)

Nice set of ideas.

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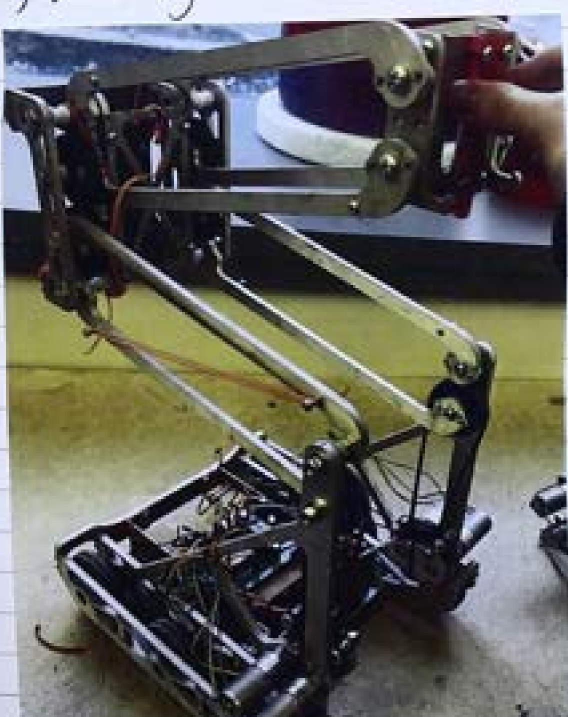
↳ Game: Rules & Constraints
- 120 seconds long (30 autonomous, 90 control)
- Control
  ↳ Can use radios and other wireless devices
  ↳ "Assistant drives" can be used (elaborate...?), can multiple people control my robot if I want?
- Volume is 12"x12"x16" starting, but can grow
- Can only use four gearhead motors and four rotation/position servos
- Weight is limited to 12lbs
- Total energy must be less than 50 kJ
  ↳ Batteries, compressed air, elastic strain, gravitational potential
- Batteries are 7.4V LiPO, must be fused

2) Learning From the Past



Key Features of Robot

Quad-Gearhead Powered Lift
- Two on each side connected to a series of timing pulleys, spur gears, and belts of varying size
- Upper gear on frame turns second segment of arm, which rotates gear at end, which in turn directly feeds to another gear which turns final segment at exact same rate
  ↳ Super impressive idea!!

Tank-Steering Wheel Setup
- 6 wheels (3 each side) all belted together controlled by servos

For 2.007 specifically, I forsee that this will also be a uniquely challenging design process. Firstly, I have seen that the "simple" step of defining the problem has a massive scope for this competition, and even though I have spent many hours deliberating components and reviewing game rules, I do not think the problems for each method of earning points has been resolved. I must also do background research on other 2.007 robots and subsystems, such as the ones with the QR codes. The requirements have already been specified in this book, which has been exhausting yet exhaustive (lol). The process of analytical evaluation and validation of ideas will obviously take the longest, which is a trend not unique to 2.007. I forsee many weeks of calculations, revisions, sketching, heartbreak, and triumph until I finally refine and prototype a working idea for my most critical subsystem.

yes!

This is a good way to conceptualize the process

Physical Homework #1

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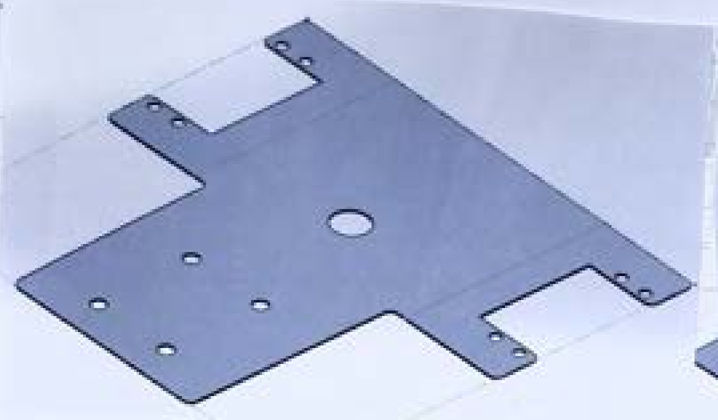

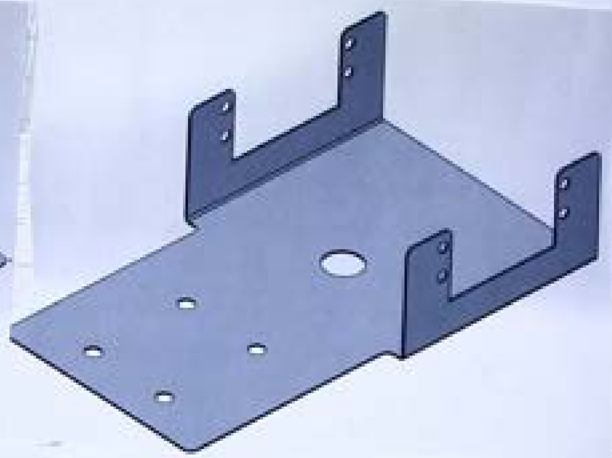

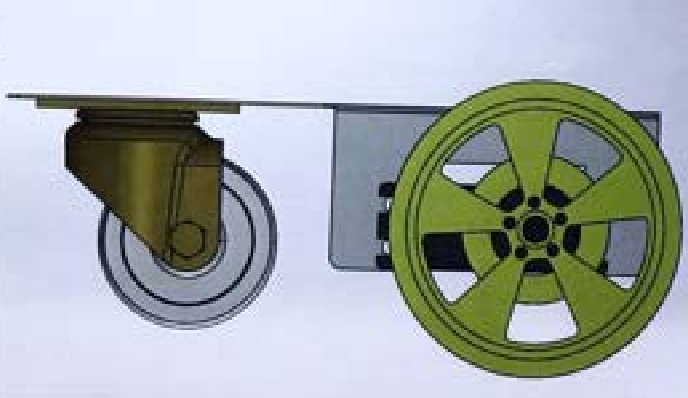

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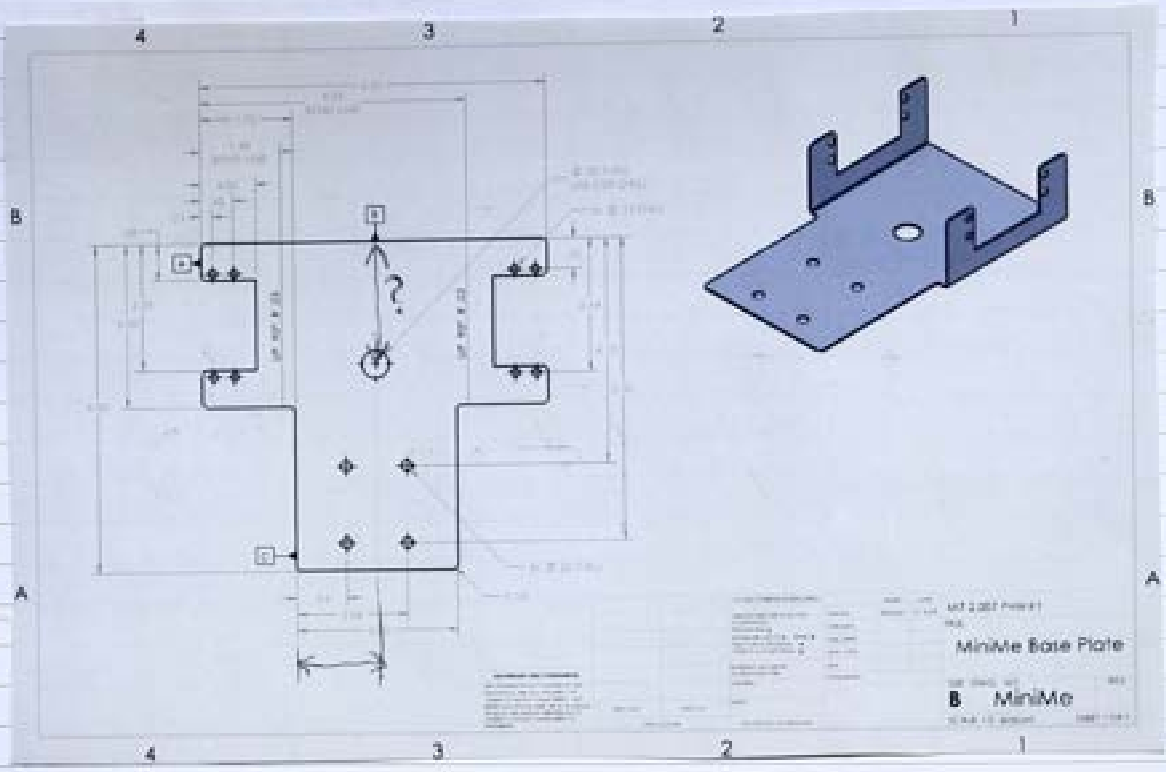

Physical Homework #2

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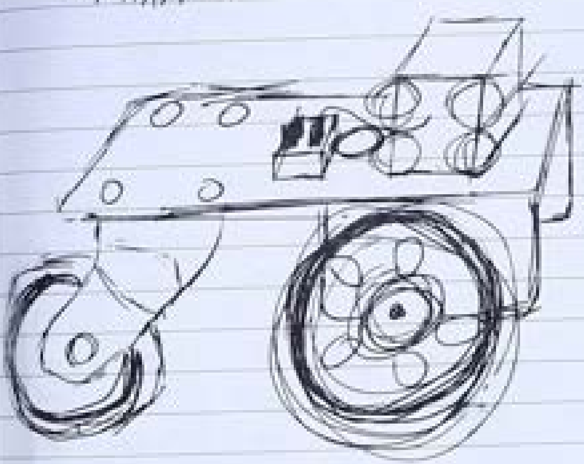
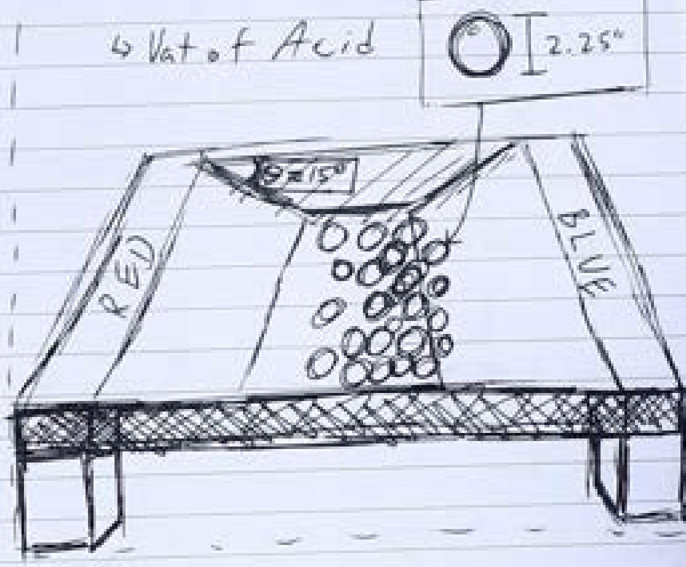
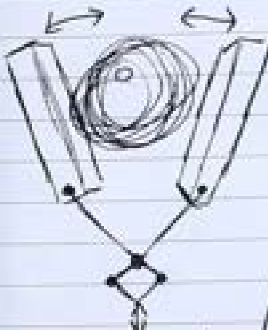
1) Prototypes for Vat of Acid
- References
  - ↳ Mini Me



↳ Vat of Acid

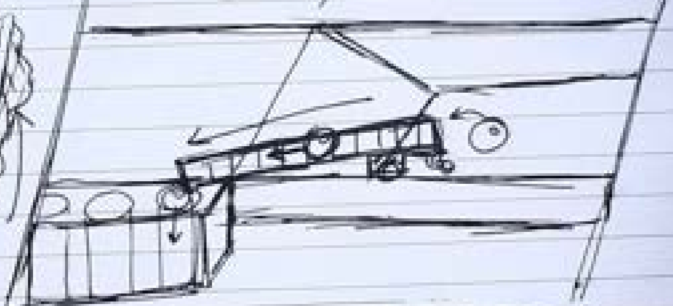


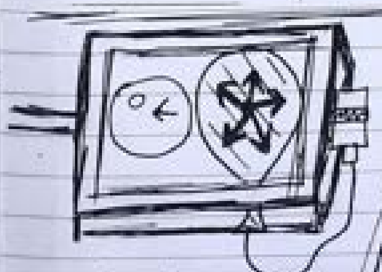


scizzor claw

net

conveyor belt (mounted)





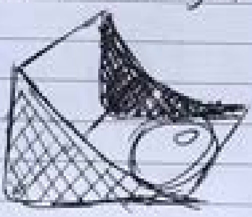
balloon claw

static claw

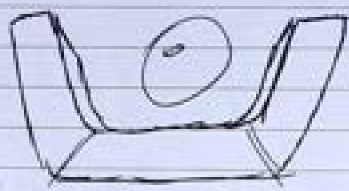
	simplicity	weight	speed	total
scizzor	0	0	0	0
net	+	0	0	1
conveyor	-	-	+	-2
balloon	-	-	-	-3
static	+	+	0	2

↳ (Build this!)

• Static Claw Designs

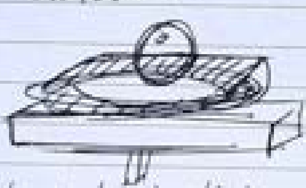


bulldozer

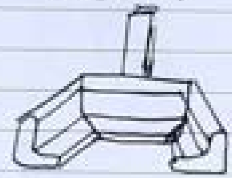


funnel

squeeze



(duct-tape) sticky

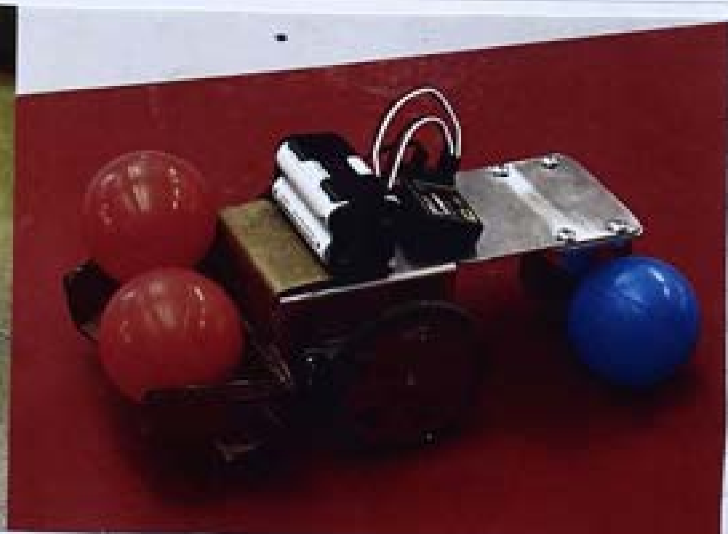


floor-funnel/bumper

		clearance	pickup	dismount
-1	bulldozer	−	+	−
0	funnel	O	O	O
-1	squeeze	O	+	− −
0	sticky	O	+	−
1	bumper	O	+	O

→ Cardboard Model

* angled flanges inward instead of outward had great results!!



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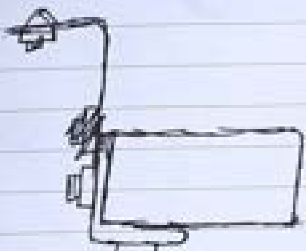
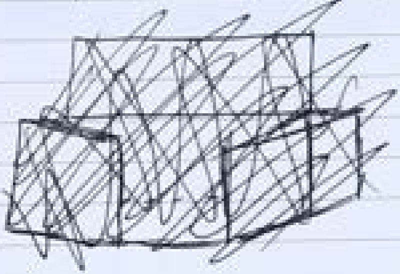
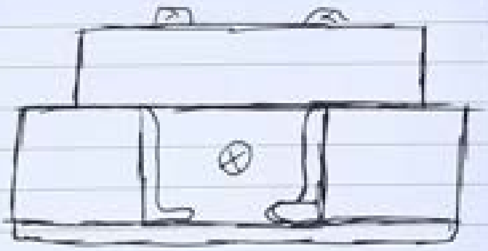
→ CAD ~~Model~~ Sketches (i know these aren't in the right position)

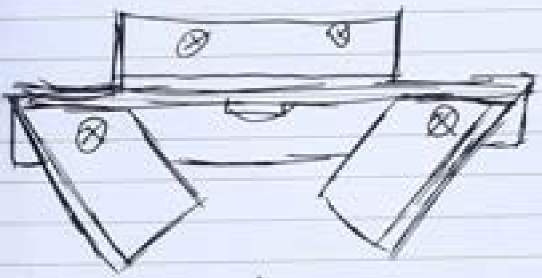


(Left)



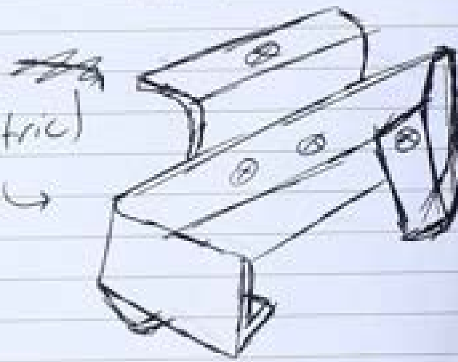


(front)

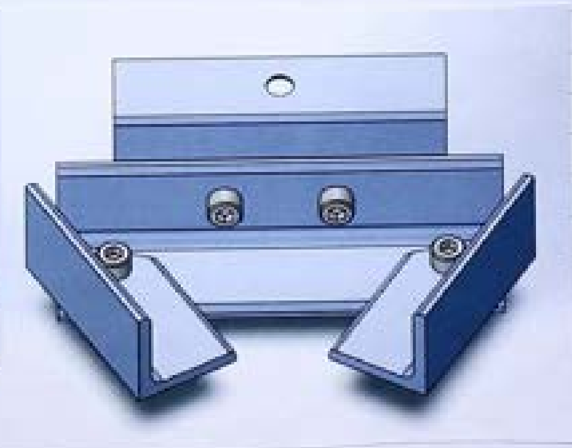


(top)

(isometric) →



→ CAD Model & Assembly



→ Final Gripper on MiniMe

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Thomas, Nice job of documenting the flow of your work.

Milestone #2

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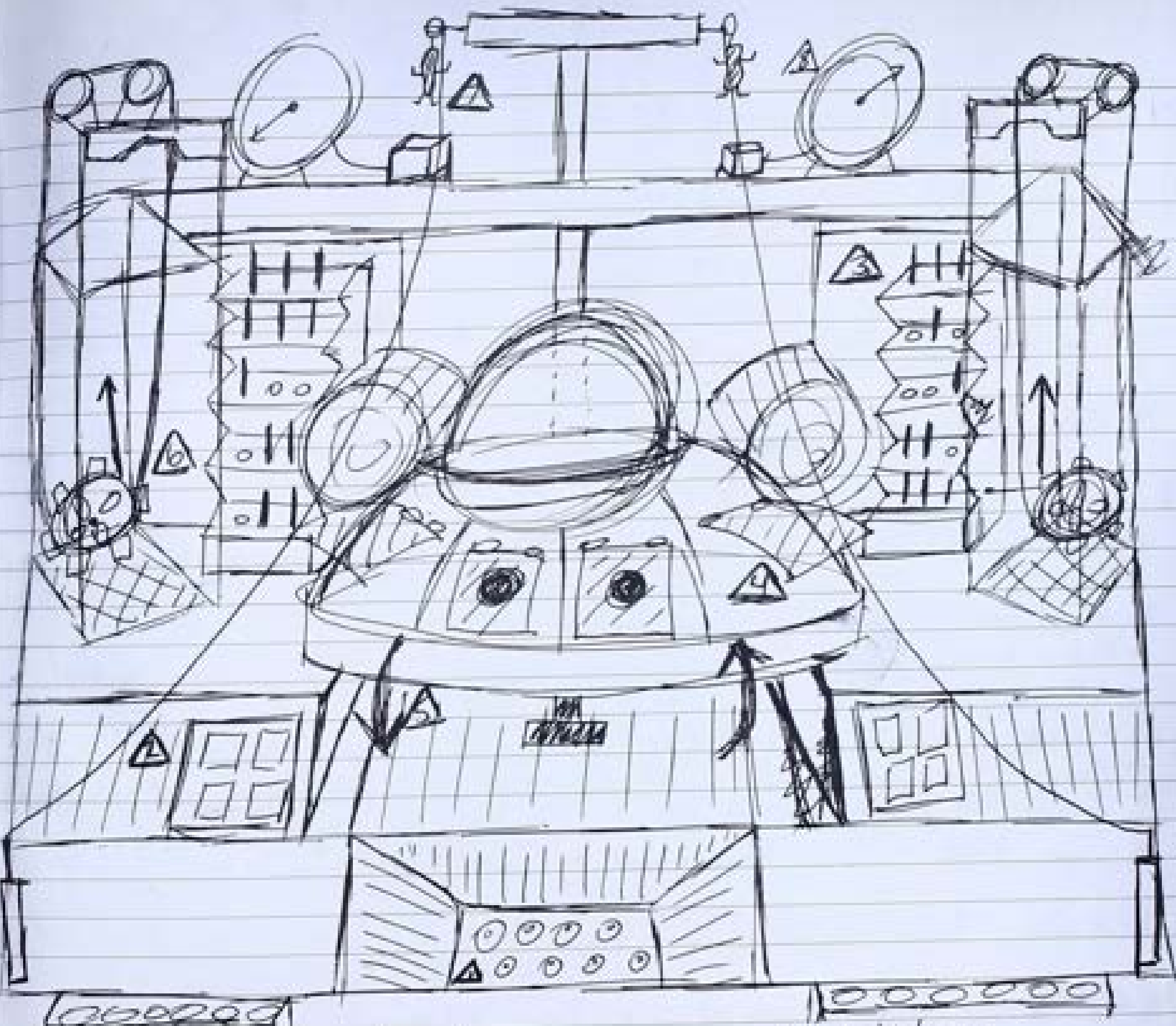


Game Board Locations:

1. Vat of Acid (deliver balls to tubes)
2. Gooble Boxes (press buttons)
3. Mind Blowers (remove mind blowers from storage)
4. Car doors (lift doors to angle)
5. Car Multiplier (tip car to angle)
6. Elevator (reach top by cranking wheel)
7. Pickle Rick (push down zipline)
8. Portals (press button to stop spinner)

Point Values:

4x balls/tube; (0.5/1.0/1.5/2.0/2.5/3.0)
0.5/1.0 pt/press (per 250ms)
3x memory/level (9/17/26/37/41)
2x panels/type (5/13/21) / (31/35/40)
1.2x / 1.5x / 1.8x / 2.0x (30°)
(15/26/34/39) (36")
50 pts
0-35 points

→ Strategies (30 sec autonomous, 90 sec manual) (maybe use multiplier during autonomous instead! requires more testing)

1) △ Vat of Acid (Autonomous) [30 seconds]
↳ 2 trips, 4 balls/trip, drop only into tube #6 ⇒ 24 pts ℓ
△ Gooble Boxes (Manual) [90 seconds]
↳ Drive up to top platform, (10 sec) press alternating buttons every 250 ms (80 sec)
↳ 4 × 1.0 × 80 = 320 points

↳ Strategy Total: 344 points

2) △ Gooble Boxes (Autonomous) [30 seconds]
↳ Start on platform, center over top buttons (5 sec), spam each 250 ms delay
↳ 4 × 1.0 × 25 = 100 points
△ Elevator (Manual) [30 seconds]
↳ Drive onto platform, use flywheel to grab wheel & spin to top
↳ 39 points
△ Pickle Rick (Manual) [30 seconds]
↳ Raise "stick", push pickle rick off hook (drive = 10 sec) (alignment = 10 sec) 50 pts
△ Portal (Manual) [30 seconds]
↳ Lower "stick" to push button and stop portal → ≈ 25 points avg

↳ Strategy Total: 214 points

3) ~~[illegible]~~ △ Car Doors (Autonomous) [30 seconds]
↳ Start lower level, drive to front doors, raise "stick" to push up on doors (2×)
↳ 2 × 40 = 80 points
△ Vat of Acid (Manual) [90 seconds]
↳ Build magazine that can hold 9 balls, drive back and forth to fill up all tubes (4 × (0.5 + 1.0 + 1.5 + 2.0 + 2.5 + 3) = 94.5)

↳ Strategy Total: ~~[illegible]~~ 174 points

→ Basic Quantitative analysis of key game features ("be the thing!!")

• Vat of Acid

(θ of Vat: 15°)

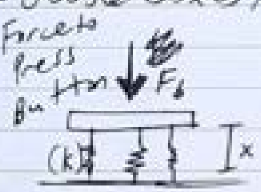
Coeff of friction ≈ $\mu_s = 0.68$

$F_f = \mu_s mg\cos\theta = 0.68\cdot(m)\cdot 9.81\,m/s^2\cdot \cancel{\sec(15°)} \approx 0.966$

↳ $F_f = 6.44m$ ⇒ (friction required as a function of mass to not slip down hill)

[function]

• Gooble Boxes / Portals



Force required to press down Gooble Buttons or Portals

↳ $F = KX = mg$

↳ $= (200g)(9.81\,m/s^2) \approx 2000N$

N = kg m/sec² 0.2kg

• Elevator

$\tau = r F_e$

F_e → Force required to spin gear

r → radius of wheel

τ → Nm required by motor output

$\tau = (0.15m)(9800N) = 1470\,Nm$

much too big ≈ 1500 Nm 1.5 Nm

→ → Best Strategy Decision & Design Requirements

↳ Honestly, the Gooble Boxes seem so easy to just press the entire time that it makes the most sense to simply sit and press those the entire time..

↳ It has, by far, the best points to time ratio, even surpassing a machine that can remove all the Mind Blowers
- 390 points < 420 points

↳ This could be even more powerful in combination with the car multiplier, but more testing is required to see if a heavier car is worth it

Method	Complexity	Point Potential	Time Required	Points
Δ	0	0	0	0
Δ	−	++	+	2 ★
Δ	0	−	−	−2
Δ	−−	+	−	−2
Δ	0	+	0	1
Δ	+	−	0	0

Not sure what these 6 rows are. I only found 3 strategies

→ Speed of Robot doesn't matter, as it will be "parked" the entire game with this strategy

8

→ Use mallets of mass 100 g ($F_g = mg$) attached to a CAM shaft (⊙) to lift up and down

→ Must have a cycle of 500ms each, but alternating perfectly offset by 250 ms to optimize points!

Physical Homework #3

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1) Coeff of Static Friction

↳ $\mu_s = F_f / N$

↳ Normal Force $(mg\cos\theta)$

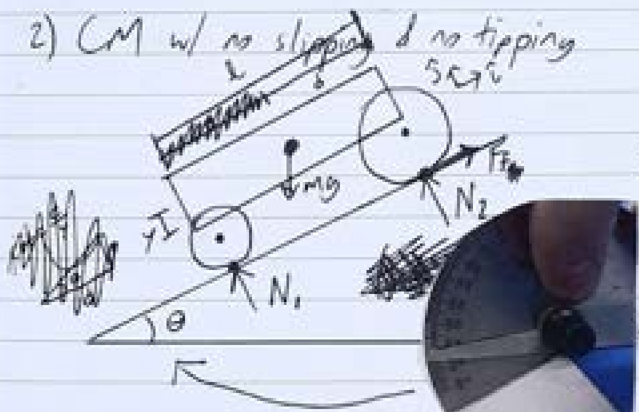
↳ Static force of Friction

↳ $N = (3296.41 g)(9.81\ m/s^2) \approx 32.34N$

↳ $F_f \approx 27N$ (on average)

↳ $\mu_s = \frac{27N}{32.34N} = \boxed{0.835}$ ✓

2) CM w/ no slipping & no tipping



$\Sigma F_x = \overbrace{F_f}^{(\mu N_2)} - mg\sin\theta = 0$

↳ $N_2 \geq \frac{mg\sin\theta}{\mu}$ $\quad N_2 \geq \frac{mg\sin\theta}{\mu}$

$\Sigma M_2 = mgd\cos\theta + mgy\sin\theta - l N_1 = 0$ ✓

↳ $mg(y\sin\theta + d\cos\theta) = l \underbrace{N_1}_{\geq 0}$

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

↳ $N_1 = mg\cos\theta - N_2$

↳ $N_1 = mg\cos\theta - \frac{mg\sin\theta}{\mu}$ $\Rightarrow l\left(mg\cos\theta - \frac{mg\sin\theta}{\mu}\right) = mg(y\sin\theta + d\cos\theta)$

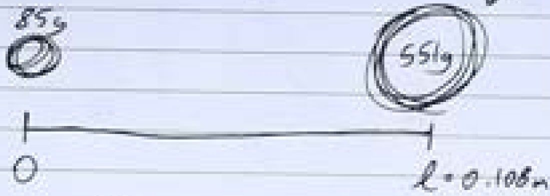
↳ $d = \left(\frac{lmg\cos\theta - \frac{lmg\sin\theta}{\mu}}{mg} - y\sin\theta\right) / \cos\theta$ $\quad$ ↳ $\frac{y\sin\theta}{\sin\theta} \geq \frac{-d\cos\theta}{\sin\theta} = -d\cot(\theta)$

$d \leq \frac{l\cos(\theta) - \frac{l\sin(\theta)}{\mu} - y\sin(\theta)}{\cos(\theta)}$ $\quad$ ↳ $y \geq -d\cot(\theta)$

↳ With initial conditions...

- $\theta = 25° \approx 0.436$ radians
- $l = 0.108\ m$
- $\mu = 0.835$

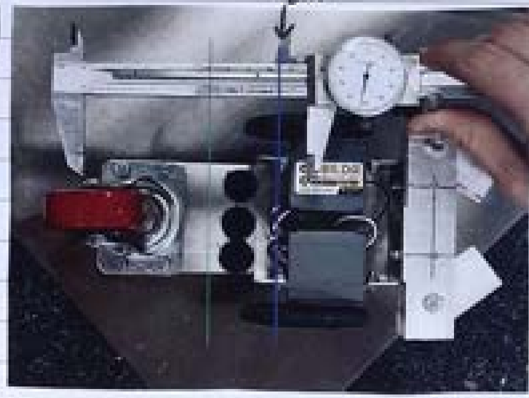
- Measurement of Current Mini-Me
  - ↳ Front Wheels: $(278 + 273)g = 551g$
  - ↳ Back Wheel: $85g$



(lower x-bound from desmos)

$4.25in - 1.88in = 2.37in$

X_{cm}



↳ $X_{cm} = (85g \cdot 0m + 551g \cdot 0.108m) / (551g + 85g)$
$= 0.0937m \approx \underline{3.69in}$

↳ y_{cm} calculated using desmos + x_{cm} intercept

↳ Desmos X-lower: $(0.04769, 0)$ m
Desmos Y-Upper: $(0, .1023)$ m
$X_{cm} = 0.0937m$
$Y_{cm} = 0.0716m$ (from Desmos)

CM: ↳ $(3.69in, 2.82in)$ [x=0: caster, y=0: ground]

...would be the limit of CM before slipping

↳ this mini-me's CM is <u>above</u> this threshold, which means it slips and <u>does not climb</u> the ramp.

CM line

desmos y-upper

desmos x-lower X_{cm} Y_{cm}

↳ this is probably due to the very high battery placement, so moving it down (+ forward) should be able to help

(as opposed to backward due to d5...)

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• Modifying the Mini Me

• Cardboard Model (worked great!) Nice solution.

→ to preserve both claw functionality, and to push CM down + forward, installing battery behind claw made sense

→ this model uses hot glue + cardboard like a hinge to give robot ground clearance

• Metal Model (steel hinges)

(hang test) → CM directly behind axle of front wheels
↓
in tolerable range according to Desmos

(also very low on y-axis)

← mass per wheel, updated

→ CM successfully pushed down + forward

→ Claw moves up + out of the way when colliding with ramp

Thomas, Nice way to approach the problem.

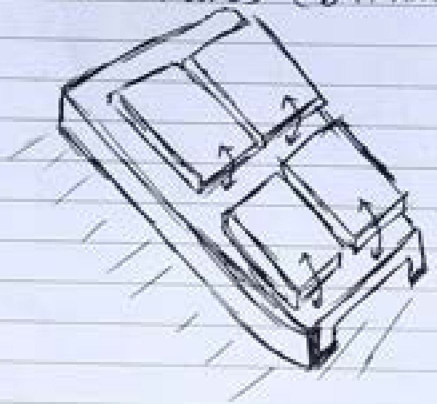
→ Climbs up without slipping or tipping!

Milestone #3

Feb 28

1) Problem Statement

• Gooble Boxes (buttons) – Design Requirements



1) Speed – should be able to move up and down (a full cycle) every 500ms (at least)

2) Timing – buttons must be alternated every 250 ms exactly, or suffer time loss

3) Button Pairs – should be able to press upper & lower level simultaneously

4) Durability – Should be able to withstand thousands of cycles of use without fatigue (10^4 cycles)

5) Power Efficiency – should not use excessive power consumption to adhere to the 50kJ total limit

6) Ease of Control – should be easily controlled and easy to automate (synchronizing important)

7) Scale – should fit within the bounding box size (12×12×16) and should be wide enough to cover both buttons (or at least be able to hit both)
* smaller the better

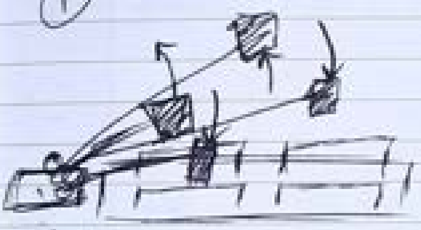
8) Weight – should not exceed 1/3 of robot weight (4 lbs)

9) Complexity – system should be easy to manufacture & maintain, and generally not overcomplicate the process

Good set of design requirements.

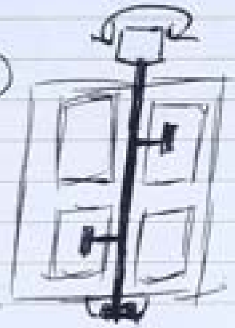
2) Concept Generation

1



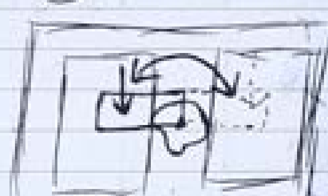
large-arm hammers

2



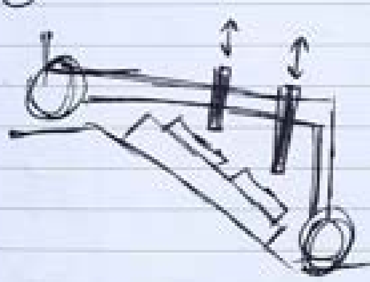
inner-rod hammers

3



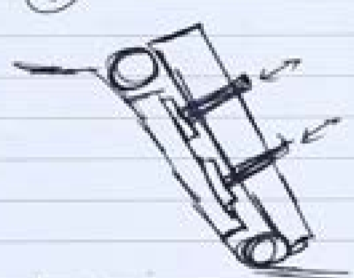
pivoting-press

4



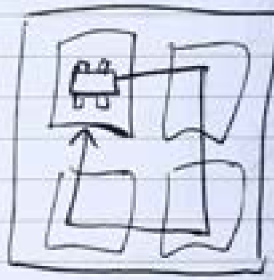
linear-actuators on L-shape

5



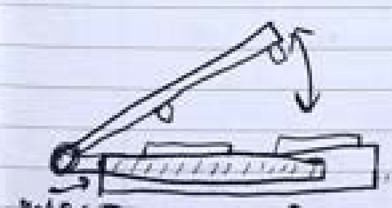
the "drive-over-it" strategy

6



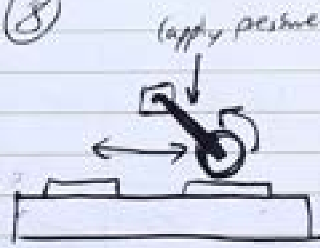
mini robot (autonomous) drives over buttons

7



"stapler" arm (use bottom as leverage)

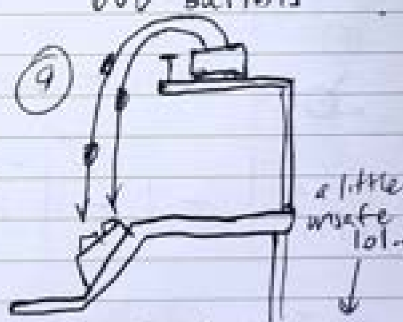
8



Wheel on hinge (drive across buttons)

Maybe toss them from the lower level.

9



lob metal balls (use gravity to push buttons)

3) Selection Rationale

Concept	Speed	Tipping	Pains	Durability	Power	Control	Scale	Weight	Complexity	Total
① 	0	0	0	0	0	0	0	0	0	0
② 	+	+	+	+	+	+	0	0	−	6
③ 	0	−	−	−	+	−	+	+	−	-2
④ 	+	0	+	+	−	0	−	−	+	1
⑤ 	+	0	+	+	−	0	0	0	+	3
⑥ 	−	−	−	−	−	−	+	−	−	-8
⑦ 	−	−	+	0	+	+	−	−	0	-1
⑧ 	+	−	−	0	−	−	+	+	+	0
⑨ 	+	−	+	0	0	+	+	0	−	2

→ Inner-Rod Hammers highest score

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Good choice

→ Justification

- Slides down middle of track and twitches back/forth, pretty simple
  ↳ doesnt require much torque because arms ('r') are very short! (~0.5N of force, ~2in length)

$\tau = (2in)(200g) \approx \underline{0.025 Nm}$

per hammer → (x2)

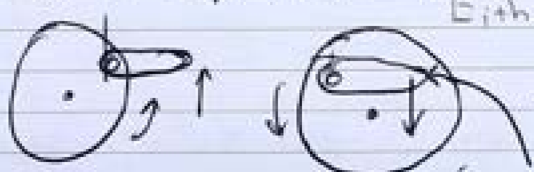
- Can be easily timed & synced with a timing belt at one end of rod on a gear to swing hammer back and forth
- Can easily be automated on a timer (one torque motor)

→ Countermeasures

↳ Can rigidly attach to platform by using similar logic to 7 which used the bottom of the platform as leverage to press harder

↳ Must change motor direction every 250 ms on timing belt, could use some kind of circular translation to keep motor always spinning one way

Either seems like a reasonable way

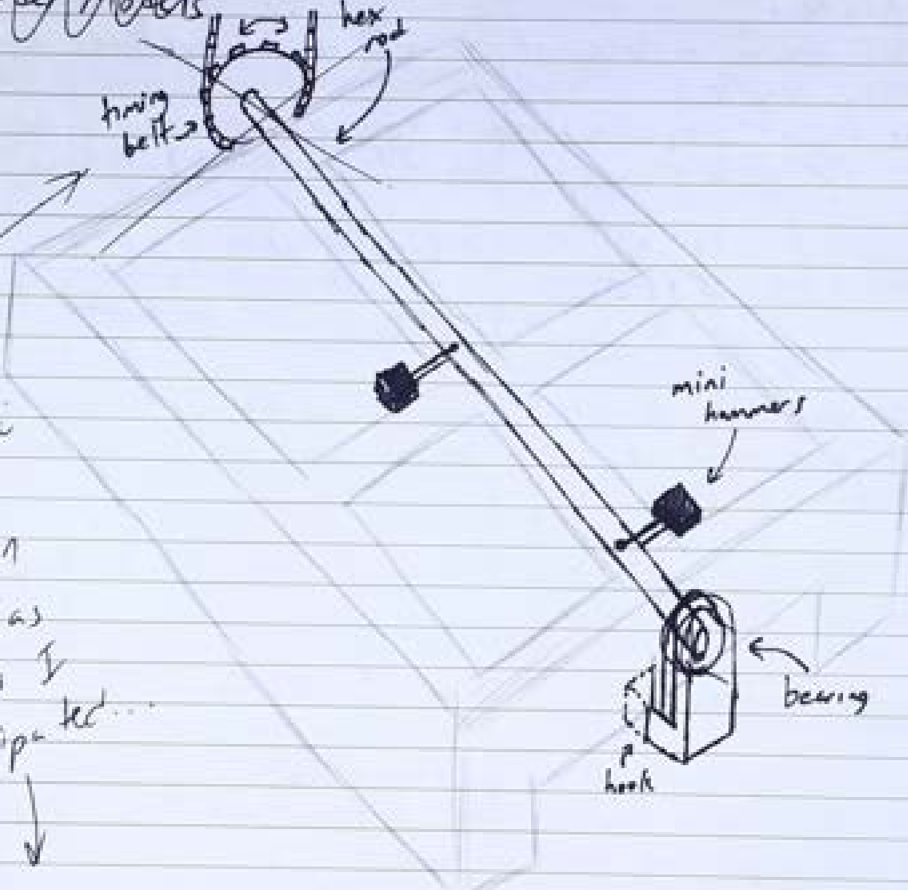


rotational → translational

(attached to belt)

4) ~~First Order Models~~

→ Sketch



Problematic

↓

this design is not as good as I anticipated...

↓

✱ Issue: ~~this would require changing~~

→ Circular → Linear motion translator will mean the hammers actually slow down when approaching platforms ... no good

→ Having to change motor direction 4x a second very quickly w/ a lot of torque is infeasible.

Don't be too quick to underestimate what these motors can do.

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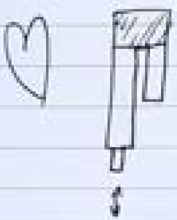
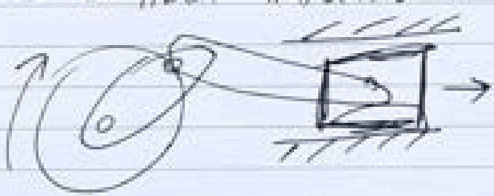
- Next - Best Idea according to decision matrix is (5), the "drive over it" strategy

↳ essentially just using pure linear motion at a very short Δx to press buttons.
- Should not use much power, no torque required

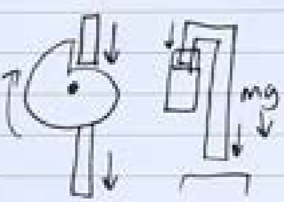
→ Ways to create such linear motion??

(1) • Linear Actuator (2) • Rotational → Translational Converter





(3) • CAM Shaft (gravity) ~~(4)~~ • CAM Shaft (Spring-loaded)



→ Counters

→ (1) is very slow & requires ~~[illegible]~~ switching motor directions every 250 ms still → also requires one motor/button (heavy!)

→ (2) has the same issue as the inner-rod hammers which slow down when approaching buttons

→ (3) relies on (mg), meaning very heavy masses... (heavy...)

($F=kx$) → (4) relies on strong springs to thrust mass (lightweight) into button

↳ overall seems to be strong, quick, lightweight, simple

↳ can chain multiple together in-line (less motors)

~~Justification~~ → Countermeasures

However (4) is also problematic because the CAM shafts can get misaligned easily moving so fast & jam up system...

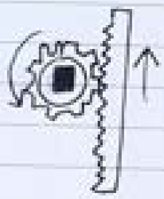
Also, limited by choices of springs in lab, and may not be powerful/compressable enough to push buttons

(1) doesn't actually have to move too much because it only has to trip a physical limit switch

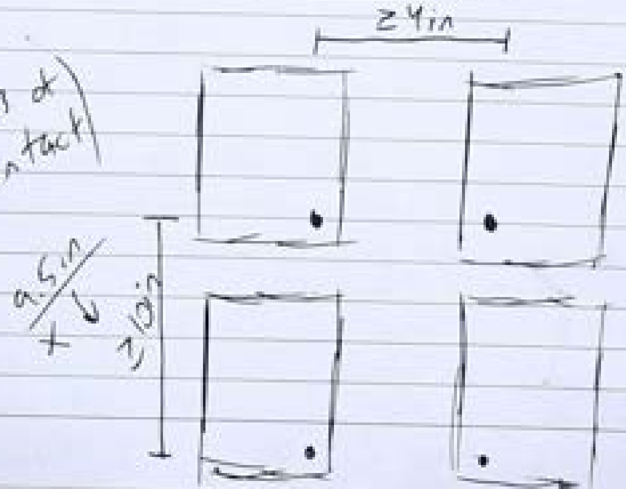
Also can be constructed with only one motor which perfectly syncs all four buttons!

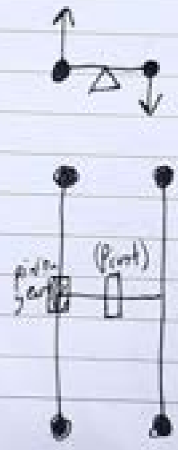
→ Justifications

a lot of leverage



Points of Contact





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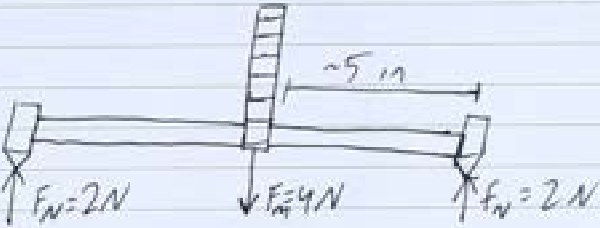
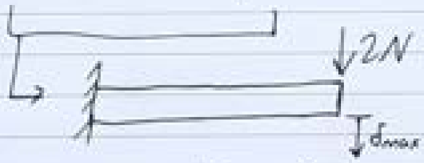
(just for button press..)

- Motor must be able to push with $2N \cdot 2$ buttons = <u>4N force</u>
  + enough to lift structure mass



<u>optimizing h</u>

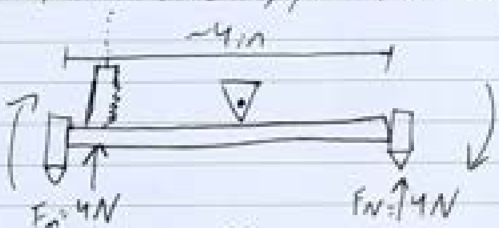
$\delta_{max} = \frac{PL^3}{3EI}$



$I = \frac{1}{12}bh^3$

$$1mm = \frac{(2N)(0.13m)^3}{3(70.3 \cdot 10^9 Pa)(\frac{1}{12}(0.0015)(h^3))} \leftarrow [b = 1.5mm \text{ b/c sheet metal } 1/16 \text{ in}]$$

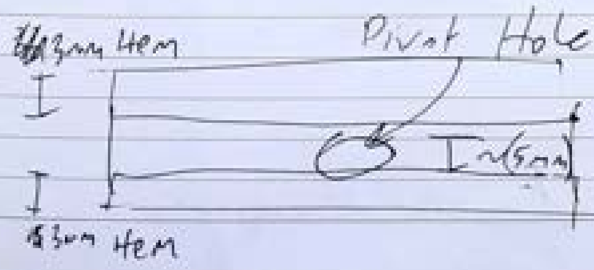
↳ to achieve < 1mm deflection, you need an $h \approx$ ~~[illegible]~~ $\boxed{1mm}$



SS

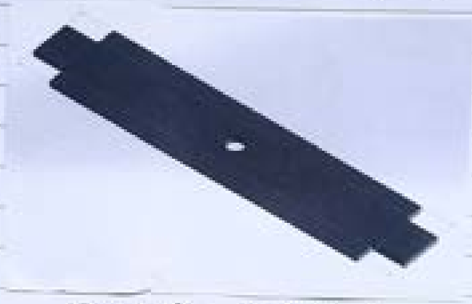
$$\underset{1mm}{\delta_{max}} = \frac{PL^3}{48EI} = \frac{(8N)(0.1m)^3}{48(70.3 \cdot 10^9 Pa)(\frac{1}{12}(0.0015))}$$

↳ $h \geq 12.5mm$ for < 1mm def.

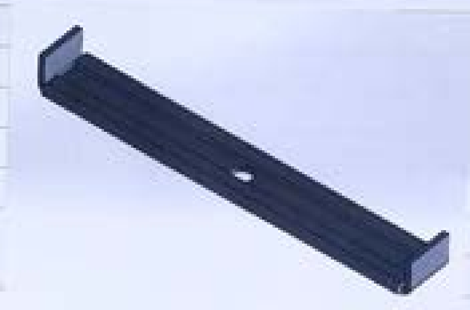


4) Bench-Level Prototypes

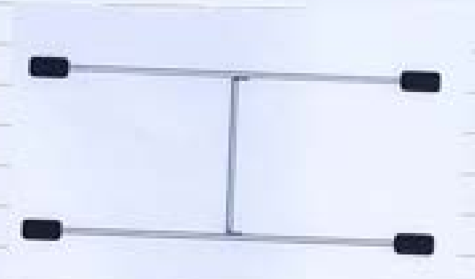
1) Solidworks Mockups



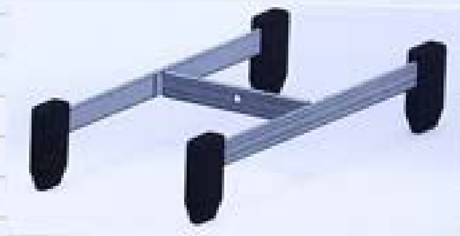
Pivot Bar, Unfolded



Pivot Bar, Unfolded



Quad-Presser Assembly (Top)



Quad-Presser Assembly (Iso)

Implementation Assembly (Front)

↳ shows tilting → pressing mechanism
(blue = pivot)

Implementation Assembly (Iso)

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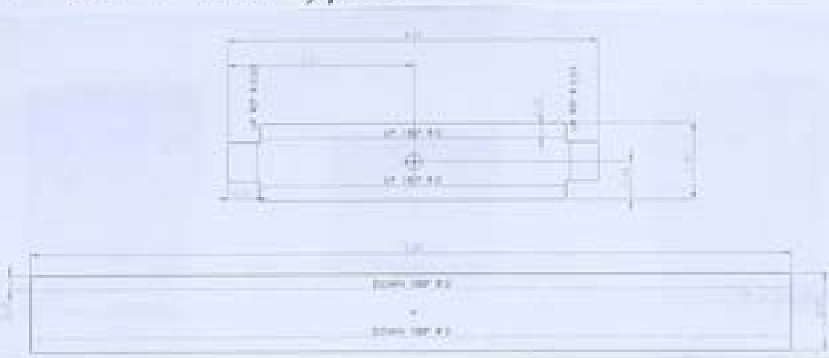
2) Bench-Level Prototypes



5) Most Critical Module

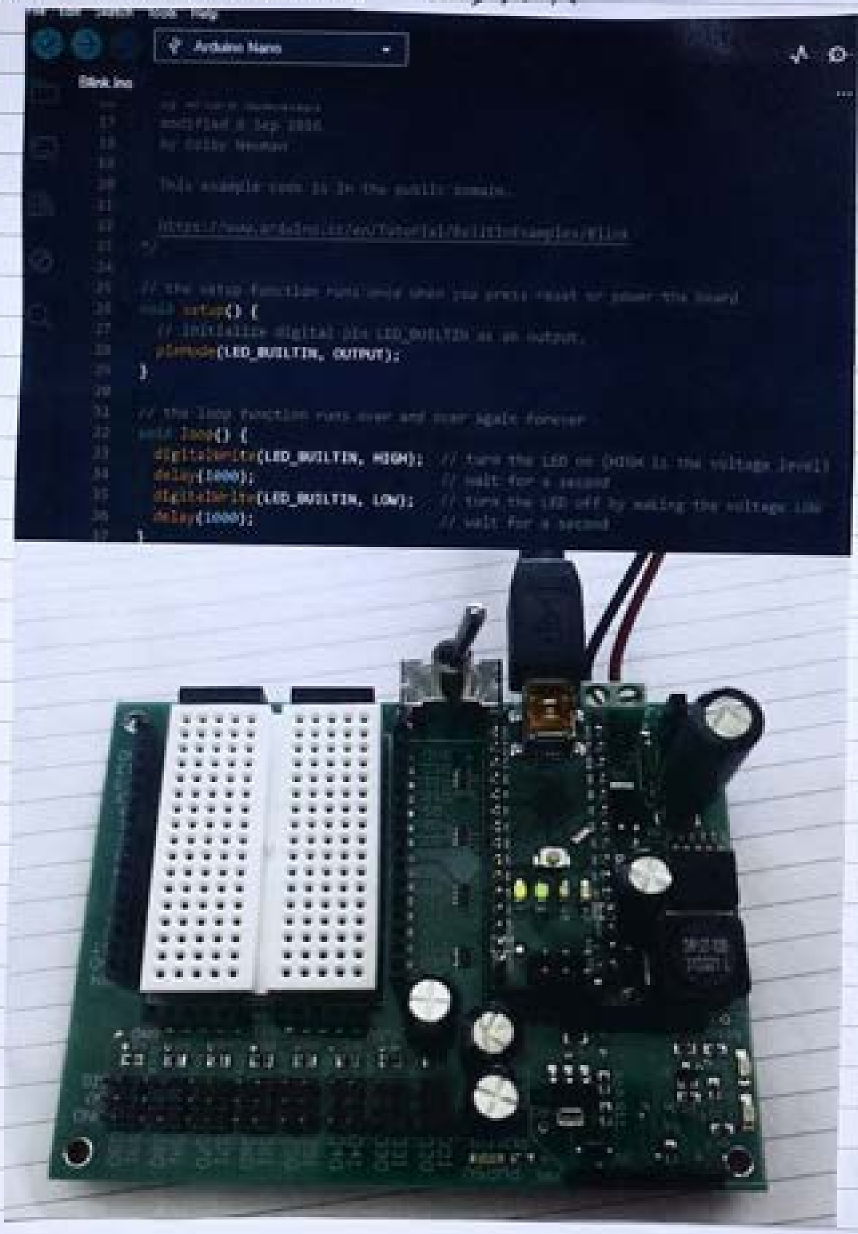
- Gear & Pinion System to generate enough torque & force to press all buttons (2x at a time) ☑
- Quad-Presser assembly, ensuring it does not deflect beyond reasonable limits and does not fatigue the metal for at least 10^4 cycles ☐
- Pivot Superstructure, essentially allowing the pivot to act as a fixed member in space so the Quad-Presser can function ☐

Thomas,

Lots of good thinking captured in your notebook. This MCM has good potential. Have you thought about how you would get it in place?

(10)

6) Arduino Installation & BLINK



Physical Homework #4

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→ Arduino Code

Abstracted Code with Functions

→ Turning Function with parameters direction (cw/ccw) and # of 90° turns

→ Moving Function with parameters direction (forward, backwards, neutral) and time (# ms)

→ Potentiometers ~~[illegible]~~ for adjusting turn time & wheel alignment

→ Circuit and Climbing

↓ Potentiometer circuit diagram

↓ goes up (& down!) the hill

Looks good.
Worked well.

Milestone #4

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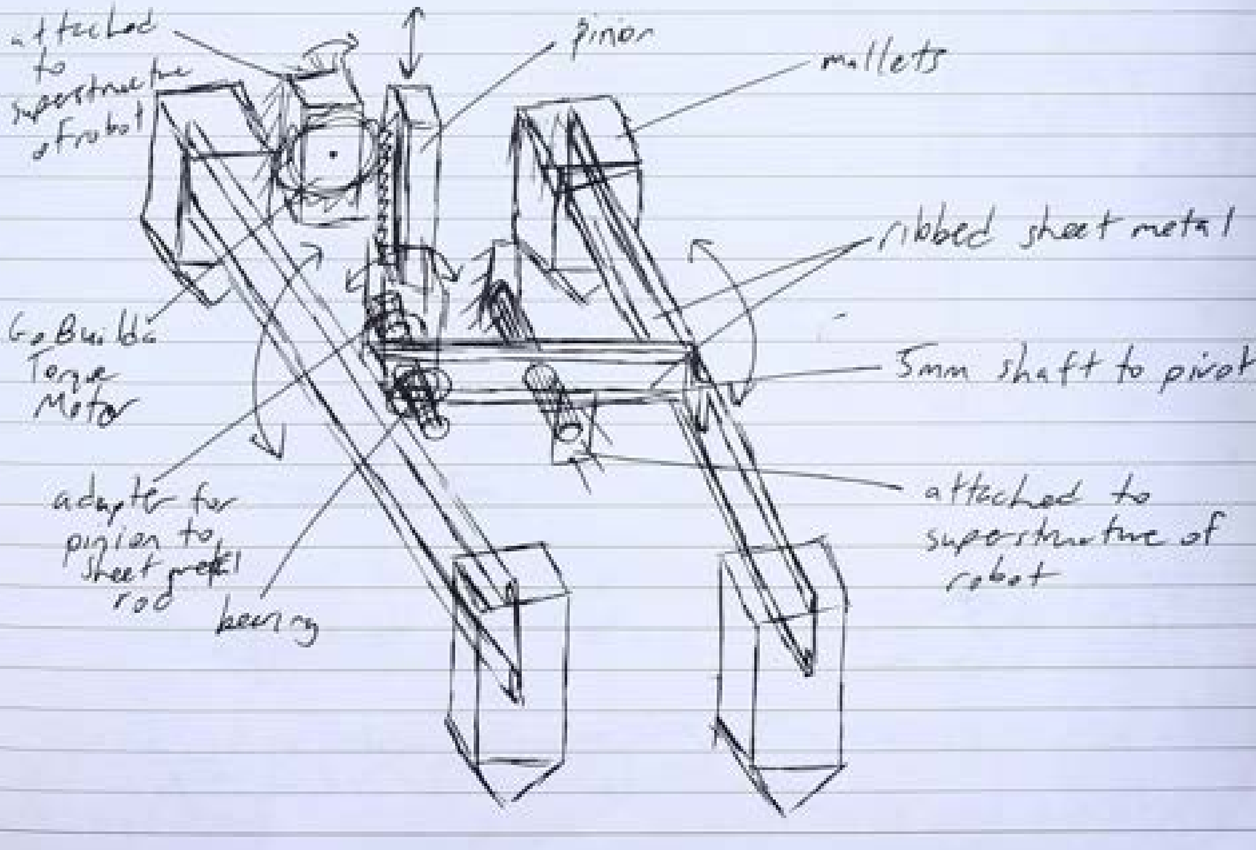
1) Depiction of the Module

→ As Discussed in MS3, this design was chosen over other options due to its simple design & operation, linear motion for the motor, and its reliability

→ Gear & Pinion connected to bearings on a pivoting H-~~##~~ shape, with mallets to press button (lightweight)

→ Can be constructed with very little material & mechanisms



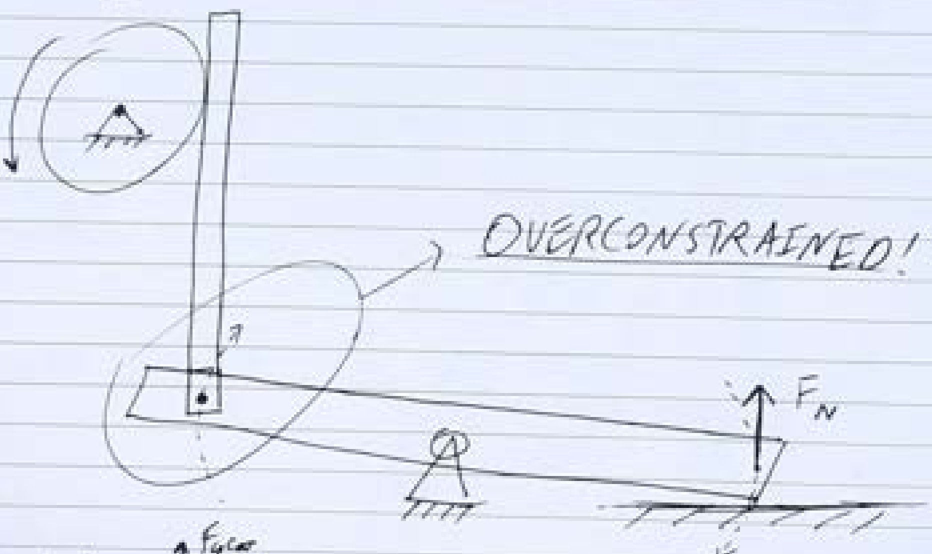
2) Analysis

→ From previous milestone...

- Deflection of rods for 1mm total deflection requires sheet metal of thickness <u>12.5 mm</u>

$$\left(\delta_{max} = \frac{PL^3}{48EI} = \frac{(8N)(0.1m)}{48(70 \times 10^9 Pa)(\frac{1}{12}(0.0015)(h)^3)} = 0.001\right)$$

→ Gear-Pinion DoF Sketch



<u>OVERCONSTRAINED!</u>

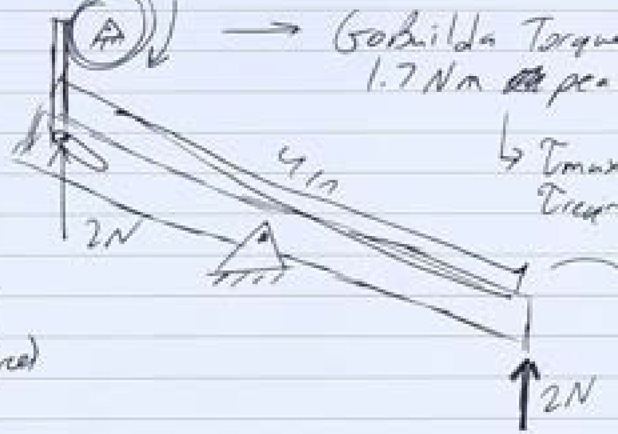
Slot instead of Pin!

<u>friction</u> might be an issue...

can be. yes.

↳ probably need <u>nylon brim</u> on slot to reduce μ_s

→ Required Torque on ~~#~~ Gear Pinion



"be the thing"

(used my pen on the corner of a table to feel direction of force)

→ GoBuilda Torque motor has 1.7Nm peak @ 5V
(gear direct)

↳ $\tau_{max} = 1.7m$

$\tau_{required} = (2N)(0.025m)$

$= 0.05\,Nm$ (...?)

[uhh seems quite small...]

↓

I could even get away with Speed Servos, this is tiny! (lmk if this is wrong) Worth trying

→ What if I don't do pinion and direct-drive it?

↳ $\tau_{req} = (2N)(0.05) = 0.1\,Nm$ → still really small...

↳ Can direct drive a speed motor, apparently

↳ Consider this...

↳ Speed Builda can move @ 90 RPM @ 5V

↳ Need to move pinion ~ 2cm every 250ms

↳ $\frac{1.5\,rps}{4}$ = 0.375 revolutions per 250ms

(1 in gear good)

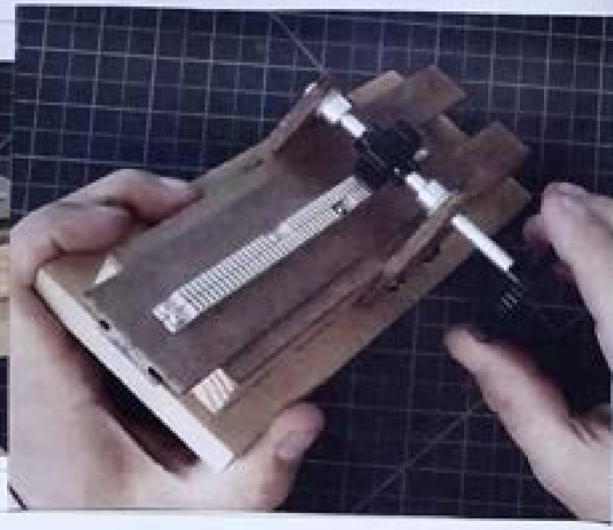
r = 0.5in

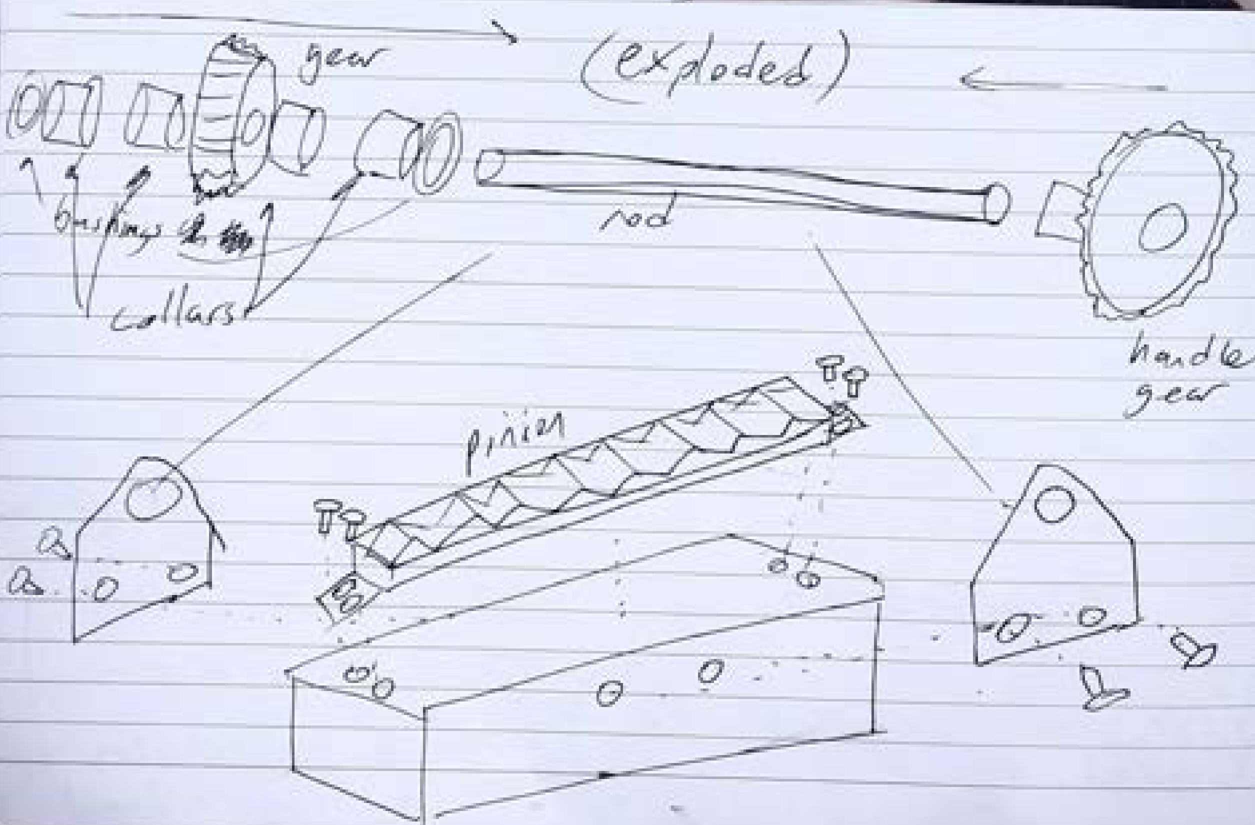
$C = 2\pi(0.0127m) = 0.08m$

↳ $0.08 \cdot 0.375 = 0.03m$

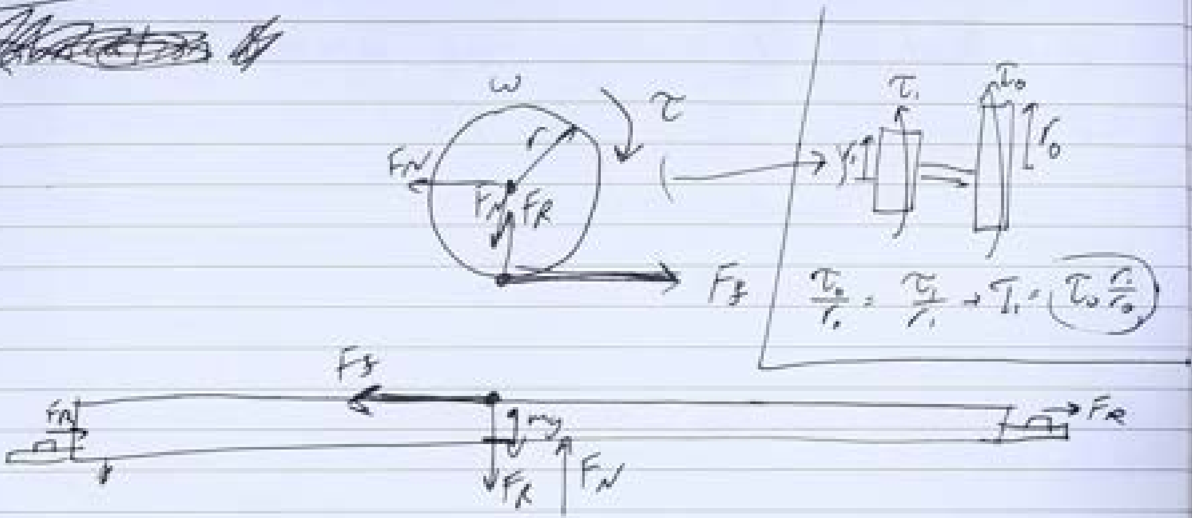
↳ 1.18 in > 2cm!

3) Bill Build Demo





FBDs



$\frac{\tau_0}{r_0} = \frac{\tau_1}{r_1} \rightarrow \tau_1 = \tau_0 \frac{r_1}{r_0}$

4) Fabrication

→ My MCM primarily uses sheet metal
- ↳ I will use bandsaw to make rougher cuts
- ↳ Press to make outside perimeter
- ↳ Rivet Gun to attach sheet metal segments
- ↳ Drill Press w/ Clamp to make holes
- ↳ Hand diamond saw to make slot ( )
- ↳ ~~Foat~~ Foam for mallets at ends

5) Solid Module of one part of MCM

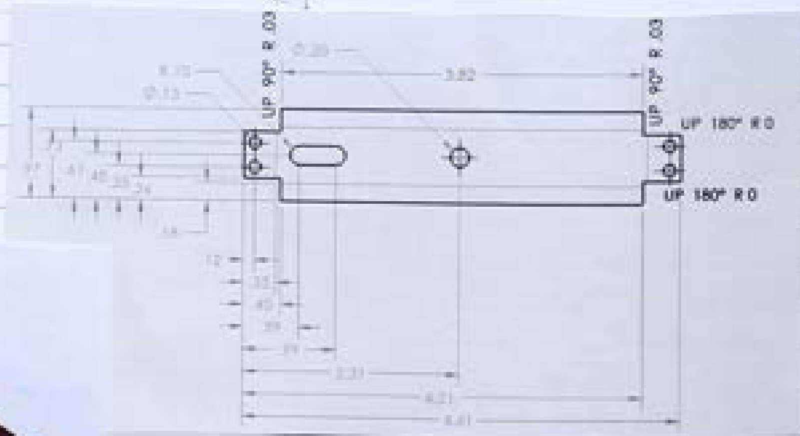
Folded

→ Center brace

added slot

added rivet holes

unfolded



Integration

Dimensions

(1/16 in sheet metal)

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6) Design Requirements

→ δmax (max deflection) of 1mm (12.5mm thickness)

→ Should be able to exert 2N force downwards at both ends

→ Speed servo b/c it can do 1.18in per 250ms which is more than the 2cm min required

→ Torque must be around 0.1 Nm, which shouldn't be a ~~p~~ problem for either motor

→ Must fit in the bounding box of 12"x12" and align with superstructure

→ Machining tolerance of < ~~[illegible]~~ 0.01mm

7) Plan

Date(s)	Task
3/08~~P~~-3/12	Finalize CAD for MCM ↳ should do all analytical calculations
3/13-3/16	Fabricate Sheet metal components
3/17-3/20	Assemble, Test on Gameboard
3/21	Demonstrate in Lab section

Thomas, You have a very good start on this. Your analyses all look sound to me.

10

Physical Homework #5

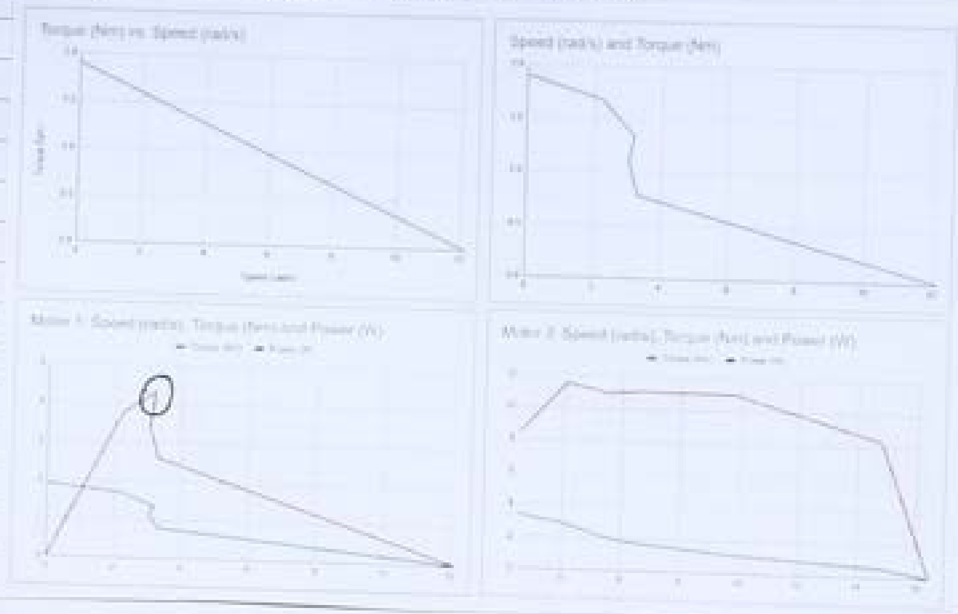
MAR 13

1) Torque-Speed Curve of Wrist

a) No-Load: 12.14 rad/s (@ 0 Nm Torque)

b) Stall-Torque: 1.91 Nm (@ 0 rad/s)

c)
d)
e)
f)



→ Motor 1 and 2 share many characteristics while the slope and scale of the graphs differ, they both feature a decreasing Torque-Speed curve with an x-intercept at the no-load speed and a y-intercept at the stall torque. Furthermore, the Power output also peaks in both graphs (around a similar point, too) and decreases on both sides, leading to a negative concavity.

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2) Gear Ratio & Power Source

a)

Shaft	1	2	3	4	5 ?
Ratio	1	3	9	81	6561

b) I predict Shaft 3 will be the best, with a time of 20 seconds

	Ratio	Time	Speed
c) d)	1	–	–
e)	3	7.2s	2.33 rad/s
	9	8.48s	1.97 rad/s
	81	86.5s	0.32 rad/s

Time → always increases (exponentially); Speed → always decreases (exponentially)

* My prediction was quite off, as the third shaft was overkill for this situation, as shaft 2 lifted it quicker

Yes

3) Optional – no data collected

4) The performance of the system varies with the source and load because an inefficient matching leads to ineffective energy transfer, therefore wasting energy.

Bicycles have many gear options because it allows the biker to always be able to pedal at a comfortable speed (max power output) with the best load to speed ratio, increasing comfort and making the ride much more consistant despite the surrounding terrain

For the elevator, I would size the motor such that the ~~[illegible]~~ Power output is maximized by comparing the lifting speeds of the various gear ratios.

10

8/10. I really liked the demo, learned a lot. Wish it could've been quicker & with smaller groups. Good suggestion

Milestone #5

March 13

1) Design Requirements – Updates & Amends

↳ All same from before, no instructor comments

↳ I want to add a requirement that going forward, holes should be sized to appropriate rod/bearing/bushing ~~sizes~~ sizes available. Too much work to be machining custom rods & fixtures

↳ General goals of simplicity in designs. For instance, minimizing unnecessary decoration features (like my items from the previous milestones) that don't serve structural purpose. They look nice in CAD but massively slow down manufacturing process.

↳ ~~Finally~~ I wanted to stress the importance of machining all parts slowly and carefully with precision. Many of my attempts at MCM component 1 failed due to rushing measurements or getting sheet metal bending order incorrect. Slow down!!

↳ Also, don't overengineer components. Some non-structural or non-load bearing components could easily ~~be~~ ~~a~~ cardboard or nylon/plastics, such as my contacts on my H-bridge arm for the Gobble Boxes.

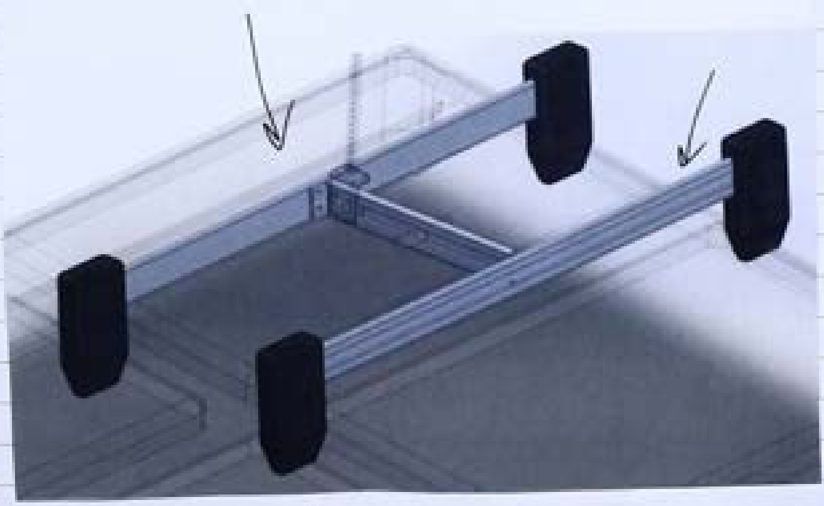
Good point.

↳ Finally, be a lot more careful with physics calculations and measurements. PHW4 made me realize I hadn't been using the spring scale the best, so putting care into obtaining values for calculations is vital

↳ * I should recheck my button Newton values!

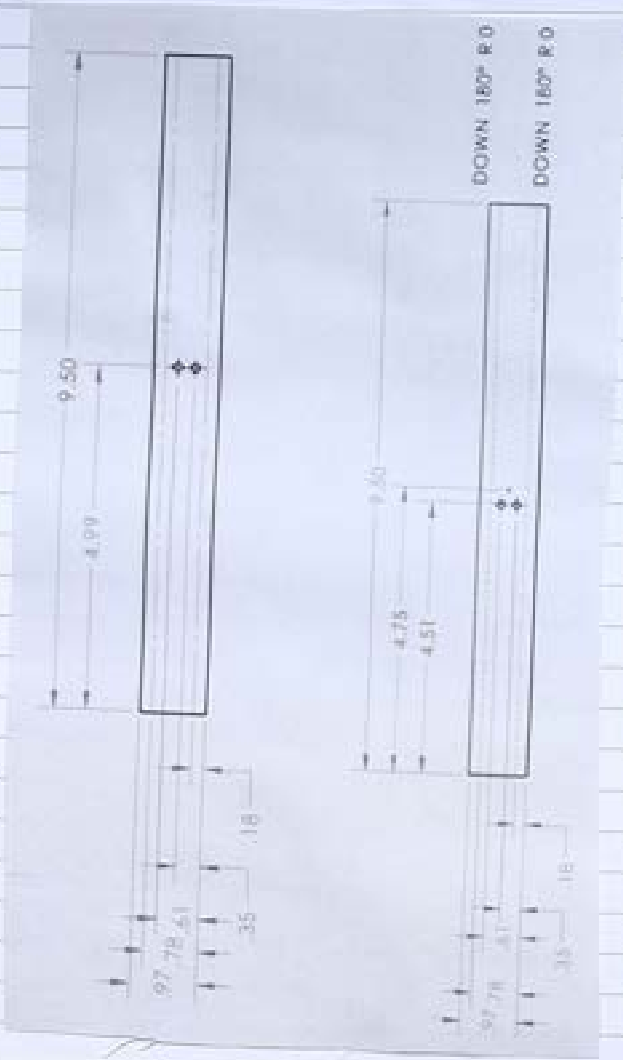
2) MCM ~~[illegible]~~ Component #2

Button-Masher Extension Arms (2x!)



Subsystem Integration into MCM

3) Engineering Part for MCM



(same part, milled to each side)

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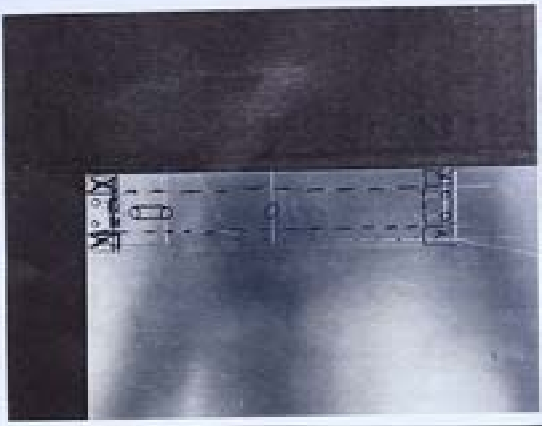
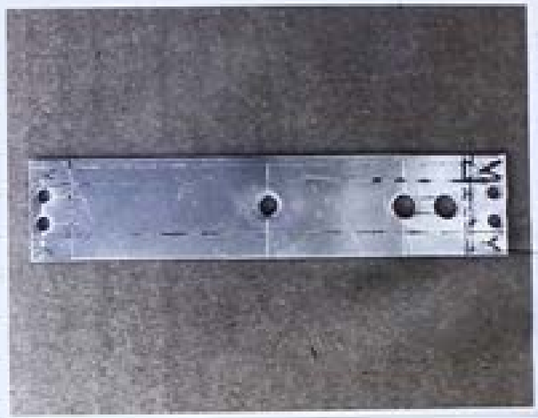
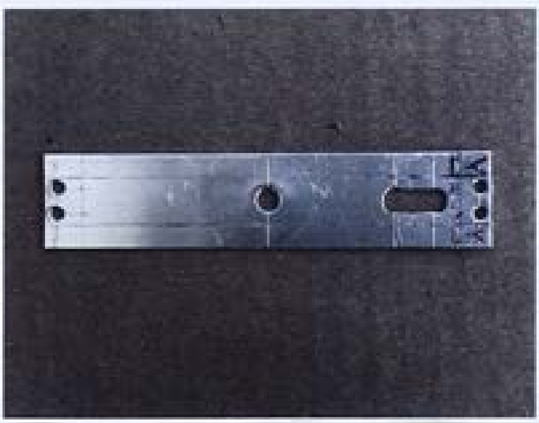
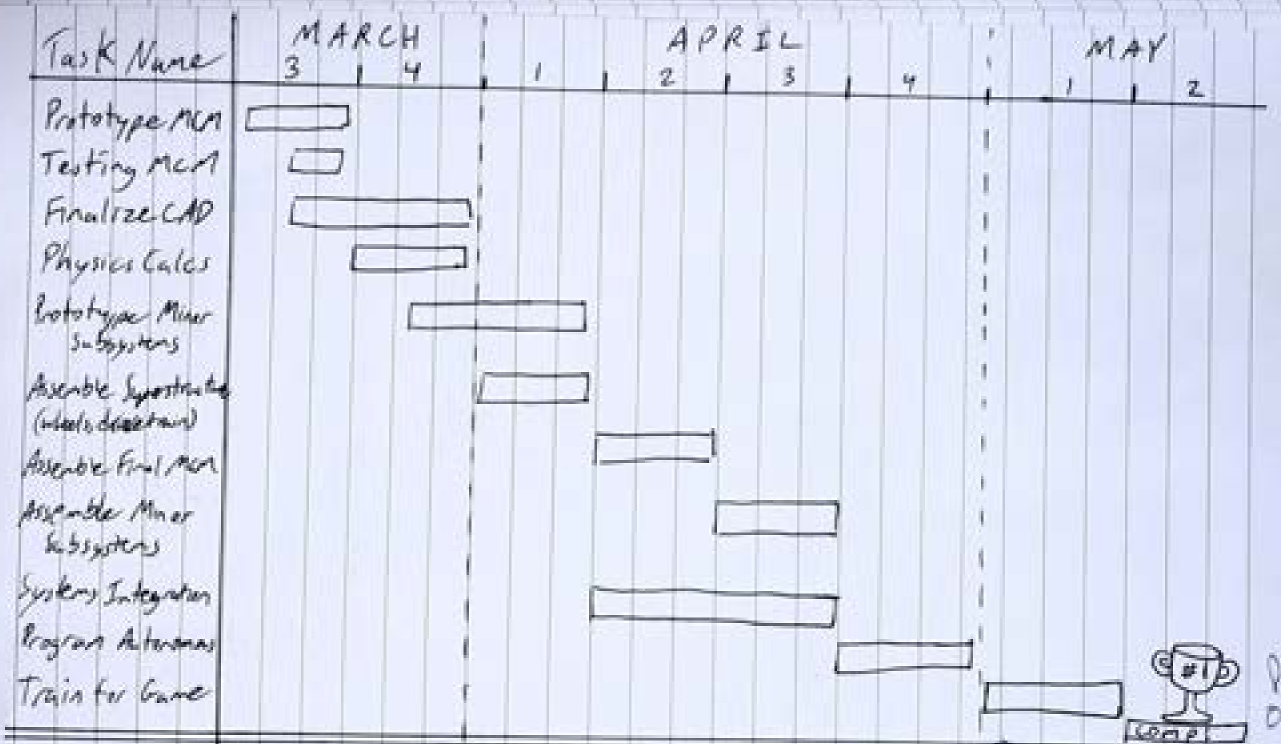
4) Finished Part from Milestone #4 - Progress + Final







5) Detailed Plan



BILL of MATERIALS (preliminary, of course)

Item	Purpose	Quantity
1/4" Bushings	MCM couplings	4x
Timing Pulley	Drivetrain	1x
Builda Stepper (Speed)	MCM power	1x
Builda Stepper (Torque)	Drivetrain	2x
Mecanum Wheels	Drivetrain	12x (6 each side, doubled)
1/4 unthreaded rod	MCM pivot	1x 12" rod
Flat Sheet metal stock	MCM structure	16x16 sheet
POM Square Rod (1/2")	MCM button contact	4x
Square Extrusion (1x1)	Superstructure	unsure, enough to fill 12x12 area
Gear/Pinion Set	MCM motor to linear actuation	1x

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6) Plan to Test MCM

• Procedure

1) Construct wooden rig to act as placeholder superstructure, and place over Gooble Boxes
   ↳ Ground pivot
   ↳ Ground motor for gear/pinion
2) Run ~~xxx~~ manually for 30 seconds
3) Run autonomously for 30 seconds
4) Compare findings

• Performance Expected

1) Wooden rig should be rigid & heavy enough to represent robot-like conditions, and should position ~~xxx~~ MCM over center of button panel

2 & 3) Should press buttons every 500 - 600 ms
Should press buttons down enough to trip limit switches
Should not deflect under load
Should last 10 repeated cycles

(4) Should compare results, see more effective in terms of ease of control and speed

→ Curious to see validation studio to see how my MCM performs!

So am I.

Your plan looks good. You're a bit behind on building the MCM. I expect that you'll catch up. 

9

Milestone #6

MAR 20

1) Summary of MCM

- So, as you know, the last MCM prototype didn't exactly work out.

- This H-pivot idea sounded good in my head and according to all my physics calculations, but there were some staggering issues I failed to consider

→ Where is the pivot mounted
→ Where is the gear/pinion mounted } → what does the chassis look li
→ How does this even be positioned over the gameboard??
↳ In MSS meeting, was given suggestion of the 4-beam arm
↳ * requires massive counterweight for ~~center~~ torque

- I didn't want to deal with these complex issues, and realized I wanted to go back to the drawing board..

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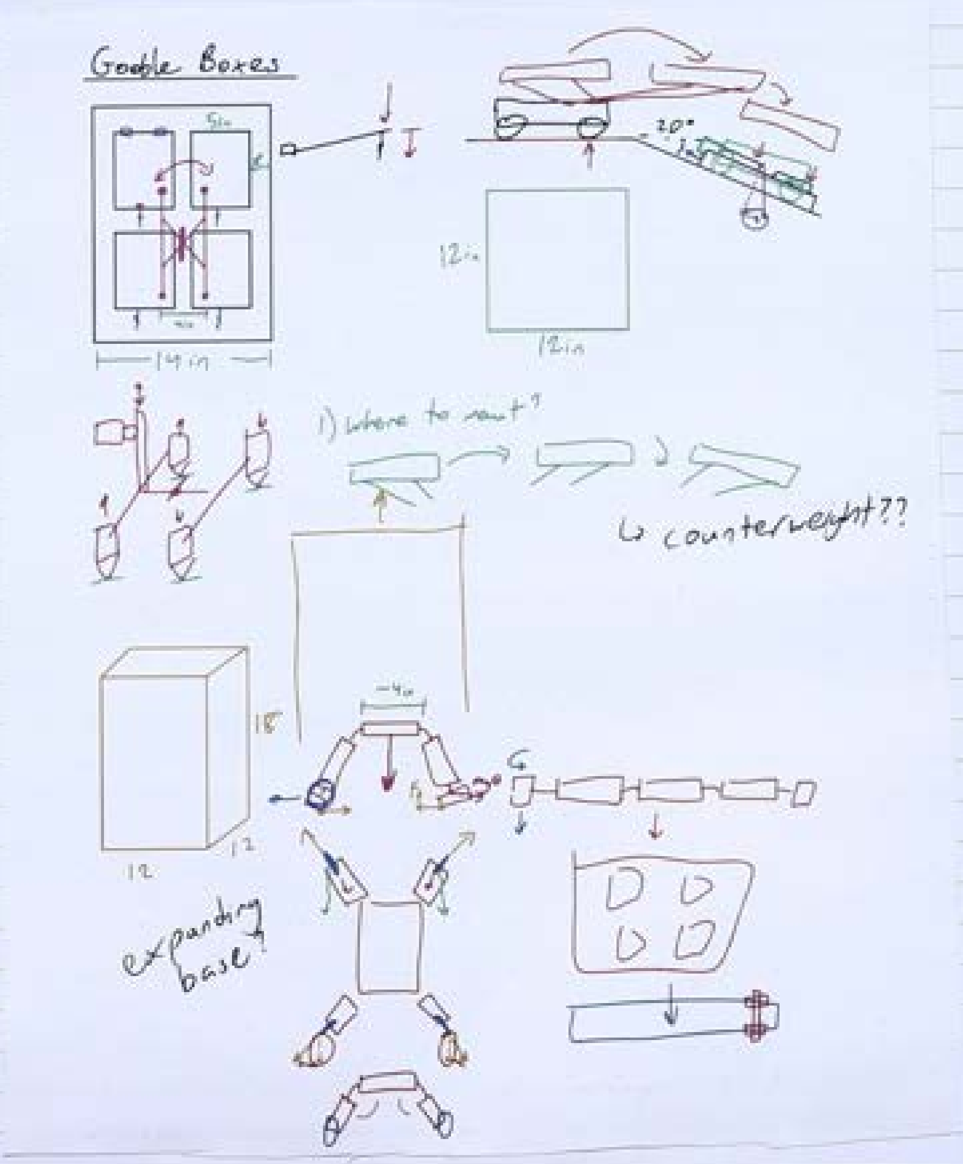
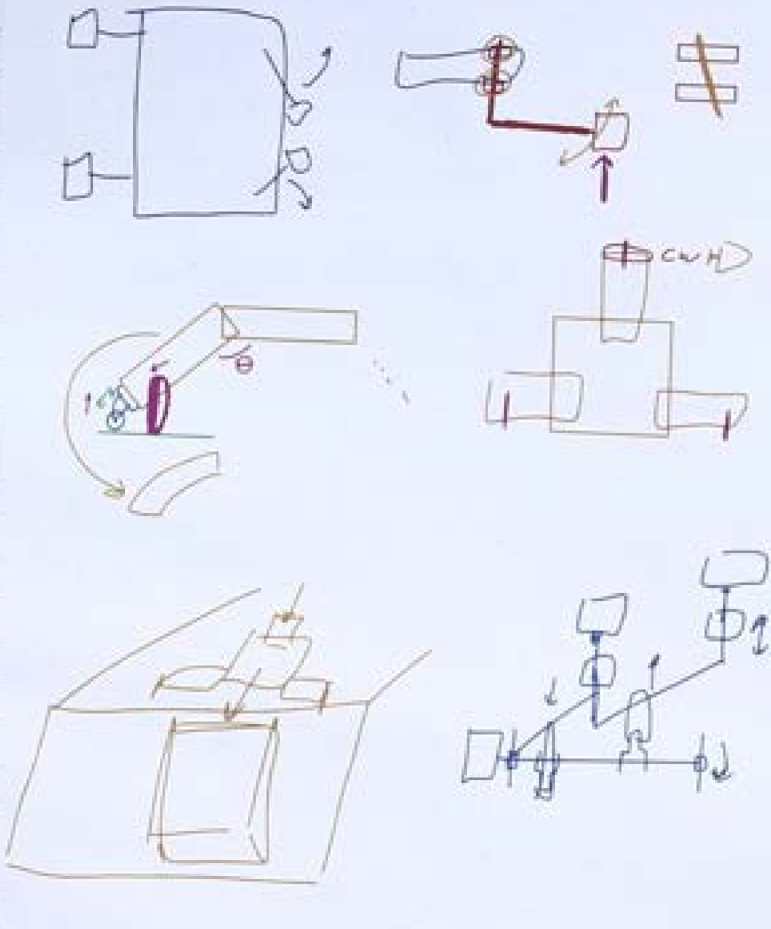
• Attached are some notes I made post-MSS regarding redesign ideas, showing my iterative thought process...





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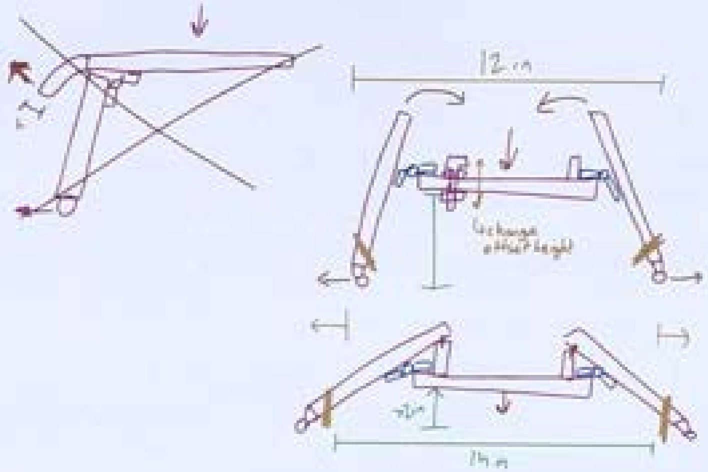
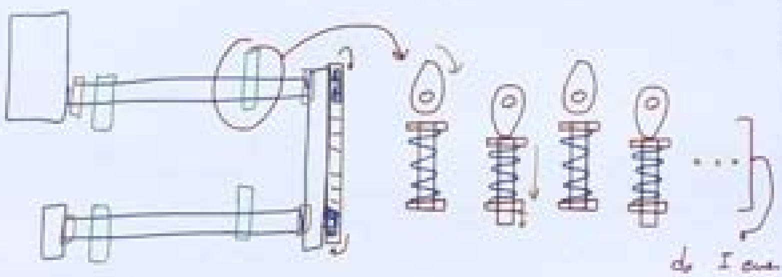
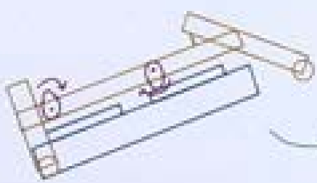


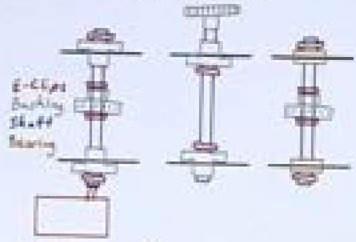


do I even need these springs??
&
directly press buttons with cams??

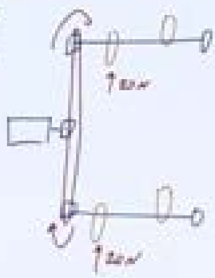


see pictures of Bills Build Demos

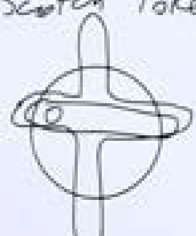
Shaft Coupling Options (from Build Demos)



$k_{smaller} = \frac{k_1 k_2}{k_1 + k_2}$??



Scotch Yoke



→ very nice, but very hard to sychronize... :(

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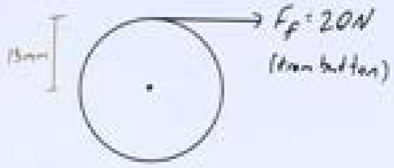


& have to account for parallel spring in CAM pins...

$\tau_{required}$ = 20N · 0.013m = 0.26 Nm (assuming no friction)

↳ even so, Builder Speed can provide 0.77 Nm (3x SF) torque @ 4.8V, so speed servo ok!

→ for speed, 6V required for the 115 RPM
(slightly less than desirable but ok for now...)
(plus will be slower while hitting buttons, but theoretically not by much...!)
↳ have to experimentally see...

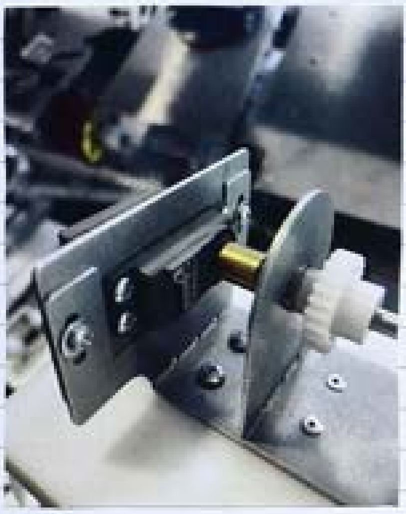
*side note: I would prefer you didn't collect notebooks, so that I could've done this directly in my NB instead of my iPad. However, I do enjoy reading your handwritten comments, too. Maybe having short 3-5 minute 1-on-1 discussions during Lab time to discuss and grade milestones would give the best of both worlds? I'd love to talk about this more.

Very nice notebook entries.
I'm enjoying following your story.

- After (and somewhat during) my redesign, I looked much deeper into some of the Bill's Build Demos

- I feel I didn't utilize them enough before, and fully understanding multiple designs to take the "best of both worlds" was super valuable.

- Here are some I found particularly inspirational..



Motor - Gear Assembly

- Taught me about how to connect motor to shaft

- Showed me the staged alignment features, for motor, bearings, and gears

Shaft Mounting Options

- Showed 4 distinct ways of how to support a shaft at two ends

- Importantly, it showed me that bushings were very practical!

CAM Shaft & Springs

- Demonstrated how I could use CAMs to turn rotation into linear

- Spring stack was super informative!

- A lot of friction due to metal CAM on metal pins

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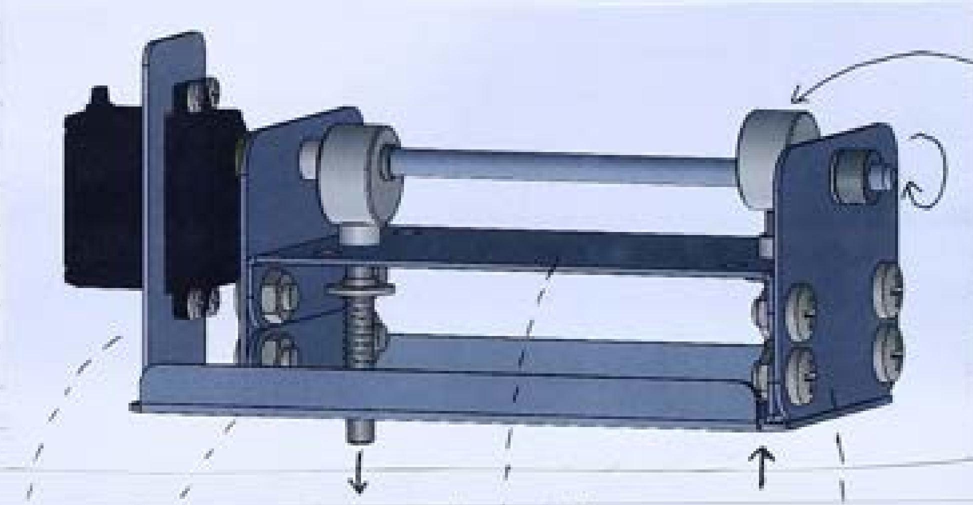
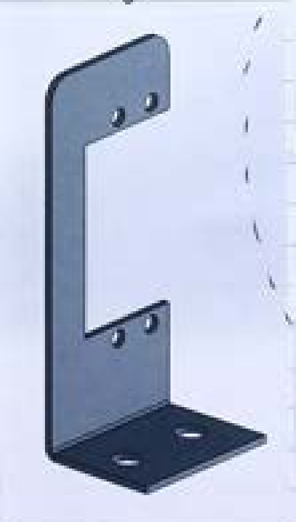
•  (drumroll...) the moment you've been waiting for!

~ the redesigned Google Box presser thing ~ (i need a better name...)



plastic CAMs on metal pins for much lower friction (& no loud screeching sound like the Demo!)

spring panels (2x)



motor mount

base plate

side plates (2x)

... but how does it work?

↳ very similar to CAM shaft Demo, with slight tweaks

→ motor shaft constrained to only have 1 DoF, rotation along x

→ pin shaft constrained to have 2 DoF, rotation about y and translation in y* (though rotation doesn't really matter too much)
*limited by spring

→ as CAM turns, it pushe[s] spring/pin down to a maximum of 0.25", enough to push down button!

→ the spring force from the button imparts a reaction force on the shaft of about 20N at max, which means it generates a torque of about $\tau_b = (20N)(0.[illegible]m) = 0.28N$[m] in the form of friction against the CAM

→ the internal parallel spring and misalignment also add torque to the system but the spring force is very minor (only very small Δx so small spring forced and misalignment is an unknown

↳ at worst, I assume $\tau_{max} = 2 \cdot \tau_b = \underbrace{0.56 Nm}$

↳ In range for Speed[...]

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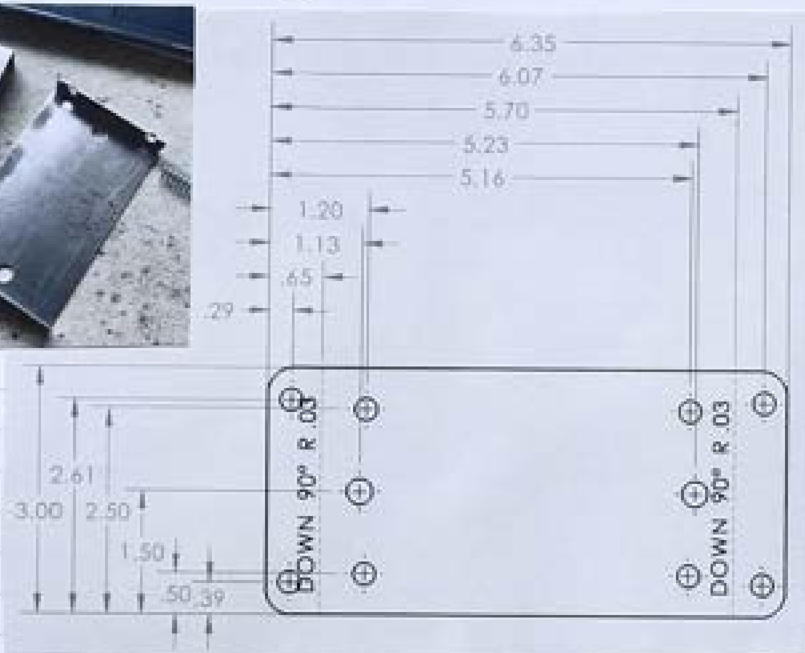
- Manufacturing
  - Initially, I tried manufacturing everything by hand, using my Solidworks drawings like one shown below



*slightly unrelated, but I remembered Amos' lecture about shaft tolerance and how much friction it caused, and I definitely learned that the hard way while making this...

- As you may notice, there are a ~~lot~~ lot of very important locating features on each part, with the additive tolerance mismatches causing disaster. I found manually cutting, drilling, and bending each piece caused way too much ~~imprecision~~ imprecision (*)

(*) → on the right, you can see a noticeable gap on two faces that were supposed to be almost touching

Manual work is good for mock-ups. Not so good for prototypes

• A new way to manufacture... (laser cutting)

• Laser cutting my parts was not only a huge time saver, but also guaranteed way better tolerance/alignment than I could ever achieve by hand

look at them smooth curves!

• Assembly

• Once the parts were machined & CAMs 3D printed, assembly was very simple, just requiring making the spring stacks and bolting everything together!

bottom half of assembly with springs

bushing
spring
nylon washer
O-ring
bushing
1/4 rod

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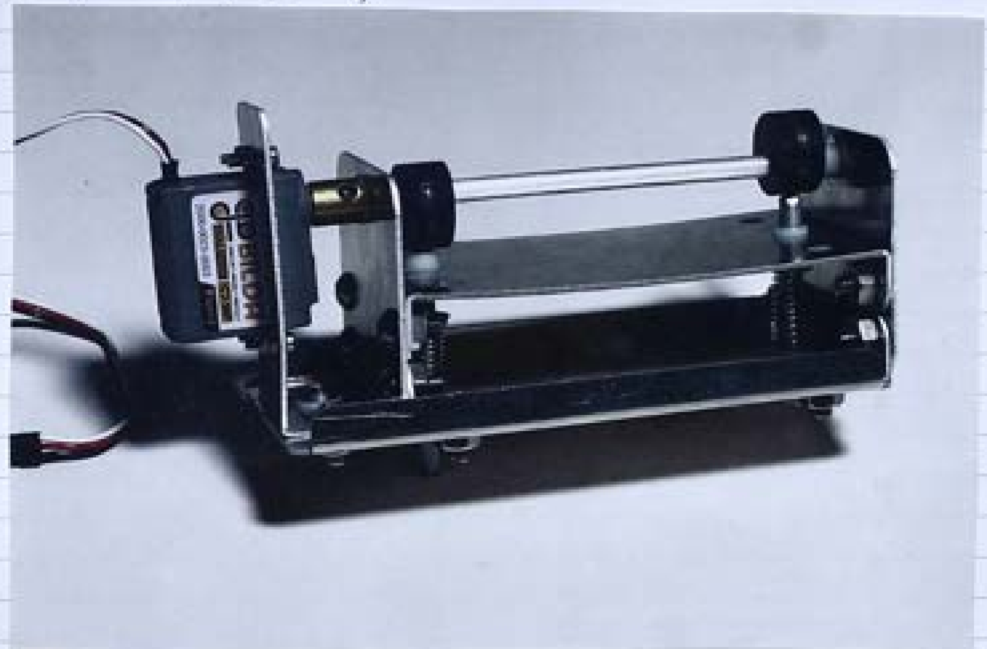
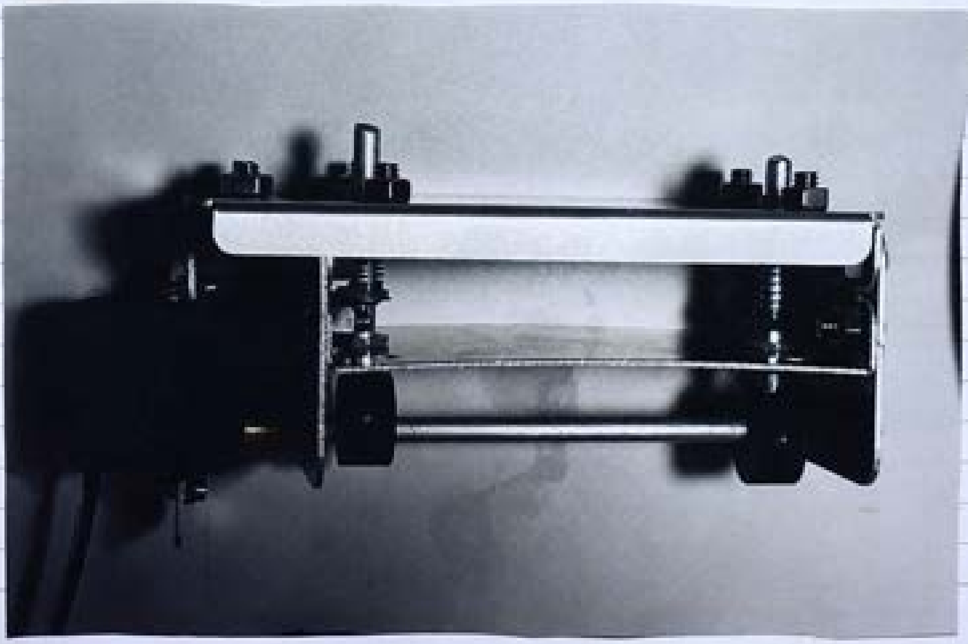
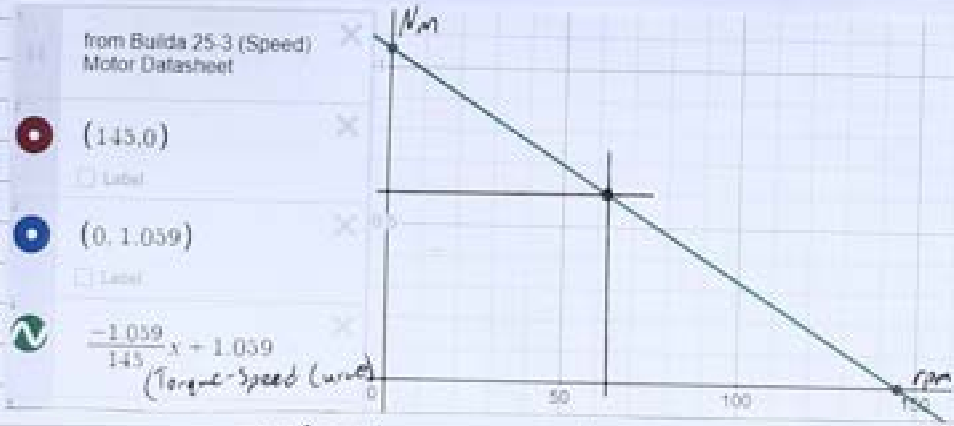
• Final MCM Assembly



Shows that you had a busy week.



2) Merits & Drawbacks



According to experimental testing, I achieved a bit over 60 rpm, which means it undergoes 0.6Nm of torque, very close to my prediction

PROS	CONS
- Has much lower friction compared to Demo	- Had to abandon idea of pressing all four buttons with only one motor, but looking back this is infeasible as two button already stresses the motor
- Will always be perfectly in sync, so button presses will always occur at the same frequency	- Parallel springs add unnecessary torque to system so maybe using CAMs directly on buttons could be a better option? Maybe. Depends on how it's executed.
- Design is Compact & lightweight and super simple to mount onto the underside of many chassis designs	- Only goes half the speed I want, but can redesign CAMs to be oval shaped instead of circular to press twice per rotation

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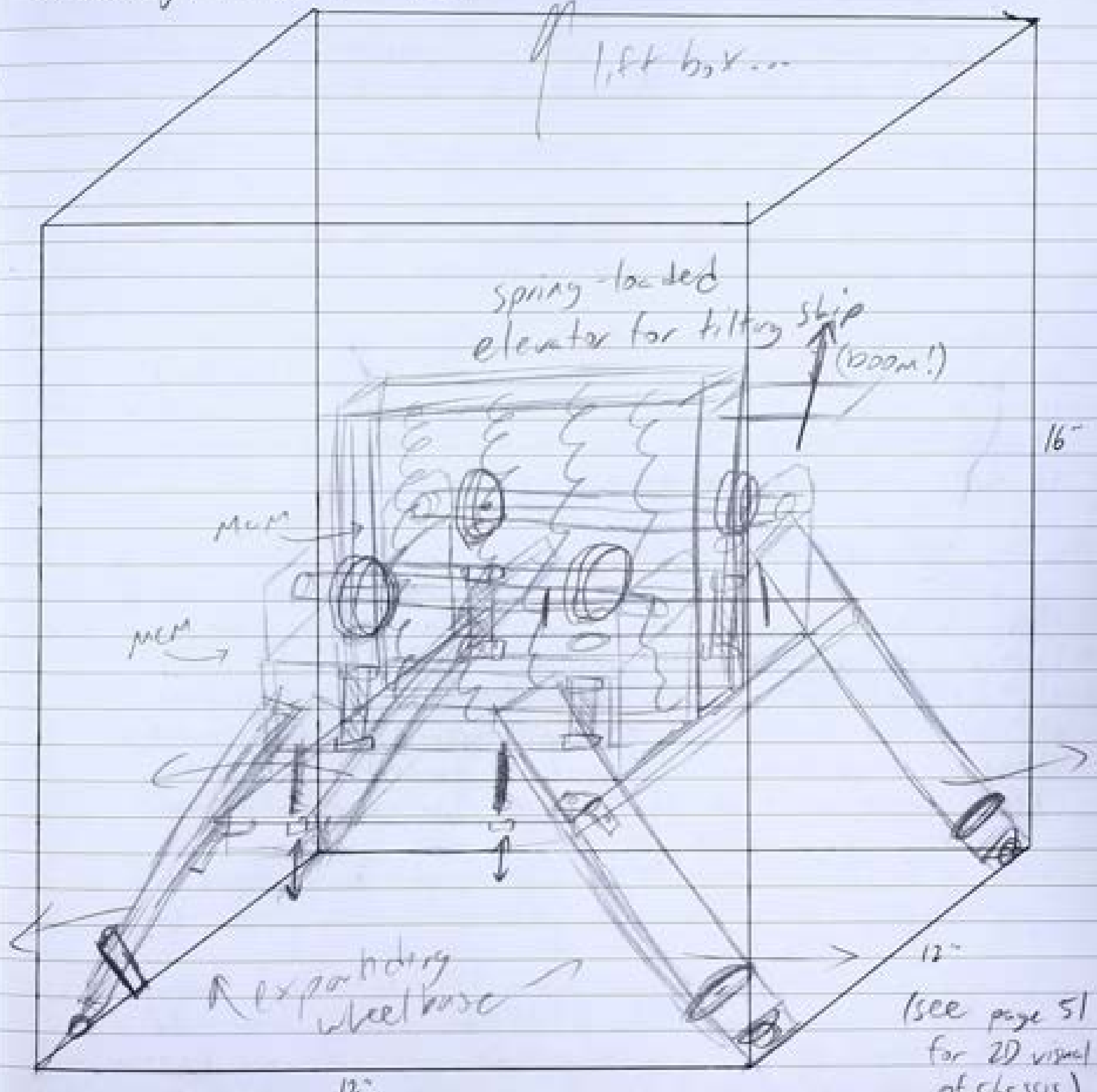
3) Integration into Robot



(see page 51 for 2D visual of chassis)

4) Design Requirements

- Based on the performance of my MCM, I have made a device that alternates button presses

- However, the frequency of the button pressing still needs to be dialed in
  - ↳ this must be done utilizing gear ratios to optimize the power of the motor, as seen in PltW5 transmission

1) Device must press buttons in synchronized pattern
2) Device must press each button every 0.5s (120Hz)
3) Device must not inhibit ground clearance of robot (2.5" min)
4) Device must not "over-press" button & lift robot off ground (10%)
5) Device must minimize friction and misalignment

5) Testing Protocol

1) Rigidly hold device over buttons, with hands or wooden structure
2) Must press buttons in alternating matter
* 3) Must press buttons every second (at least)
4) Must press button all the way down to trip switch
5) Should be repeatable (at least 10 cycles)
6) Play around with different PWM inputs for motor speed

* knowing I will redesign CAM to oval to press twice instead of once per rotation, only ~60rpm ok.

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Thomas, Your MCM worked out well. Nice presentation; you held everyone's attention. These are excellent notebook entries. I'm very curious to learn how your system will work.

Milestone #7

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1) Oral design review topics

- Additional modules
  - ↳ Chassis, Car Multiplier (optional) mind blowers
- Integration
  - ↳ Gooble below frame, multiplier across middle, mind blowers back
- Time required
  - ↳ See later calendar plan...

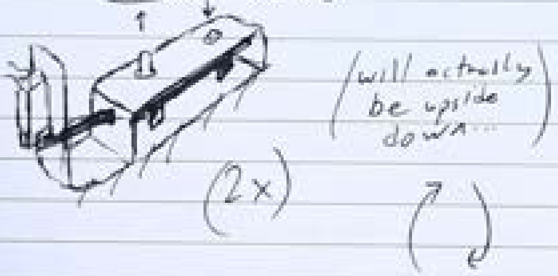
2) Reflective Discussion Re: MCM Demo

↳ Overall, my MCM presentation went very well. My design successfully was able to press the buttons down in an alternating fashion at the correct ~~##~~ RPM. I learned many things about my design during the demonstration phase. Firstly, I observed I designed my CAMs incorrectly, and I need to now develop oval shaped CAMs instead of non-concentric circles. I also realized ~~the~~ from the speed under load output that the friction was nearly doubling the required ~~effect~~ torque when compared to the motor stats for the ideal case with only torque required to press the buttons. I want to experiment with ways to reduce that friction, by maybe adjusting the parallel springs or the material of the rods in contact with ~~a~~ the CAMs, or the material of the CAMs themselves, or the geometry of the contact between the CAM and rod. Also, the layout of the gameboard changed since I last talked to shop staff, so my chassis needs a redesign to now position these boxes over the buttons. Otherwise, I must pivot (pun intended) and switch to a four-bar linkage.

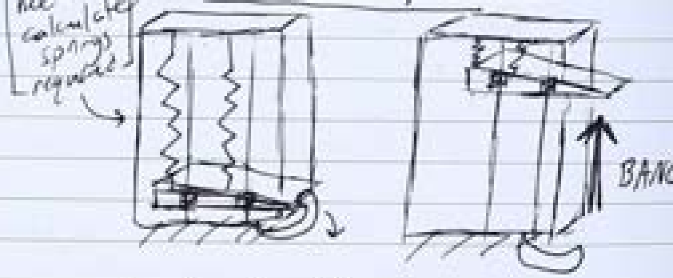
3) Representation of Integrated Systems

↳ I wanted to be able to CAD a mock-up of my robot design, but over spring break I had been in extreme dental pain and needed an emergency root canal & subsequent tooth removals. I was in pain pre- and post surgery, and that pain continued into this week where I also had to study for back-to-back midterms (2.678 & 2.007). Unfortunately I could not finish all the work, and I promise I will work on the robot CAD this coming weekend and show you soon, next lab or in an email. Thank you for your understanding. Regardless, here is a sketch of my implementation idea, covering each module & placement on the chassis.

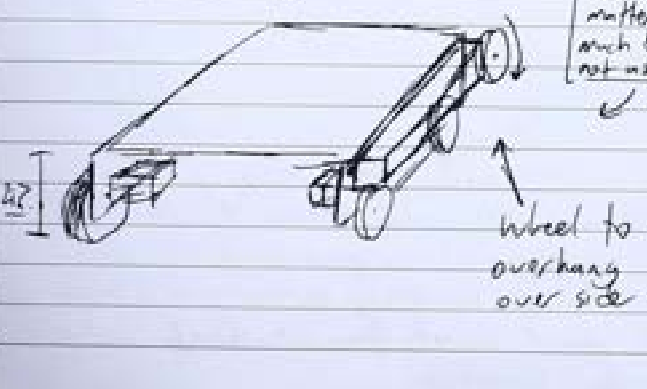
Gobble-Boxes



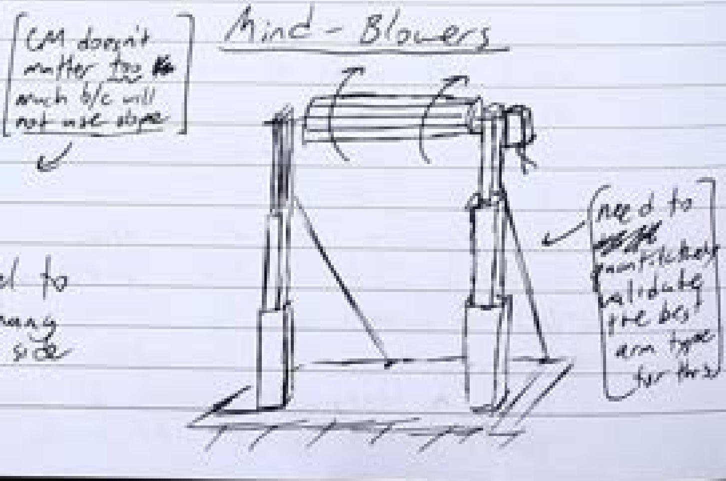
Car - Multiplier



Chassis



Mind - Blowers



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4) Robot Design & Manufacturing Schedule

4 | Experiment with changing material composition of Goble Boxes
5 | Gather Necessary Data for Multiplier
6 | CAD Multiplier
7 | CAD Multiplier
8 | Manufacture Multiplier
9 | "
10 | "

} will determine component distribution after CAD (again, sorry for delay...)

11 | Test Multiplier
12 | Gather necessary data for Mind Blower
13 | CAD Mind Blower
14 | "
15 | Manufacture Mind Blower
16 | "
17 | "
18 | Test Mind Blower
19 | Gather data for chassis
20 | CAD Chassis
21 | "
22 | "
23 | Manufacture Chassis
24 | "
25 | "
26 | Test Chassis Alone
27 | System Integration + Driving Practice
28 | Systems Integration + Driving Practice

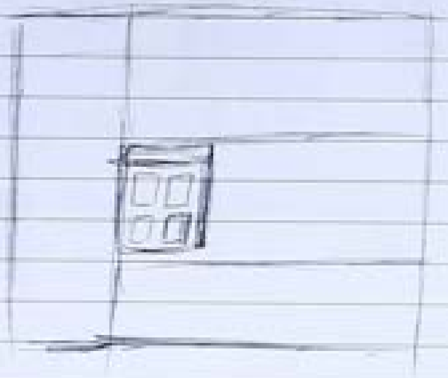
↳ While impounded, I will develop autonomous code and hone in my strategy plan after playing many rounds with my robot

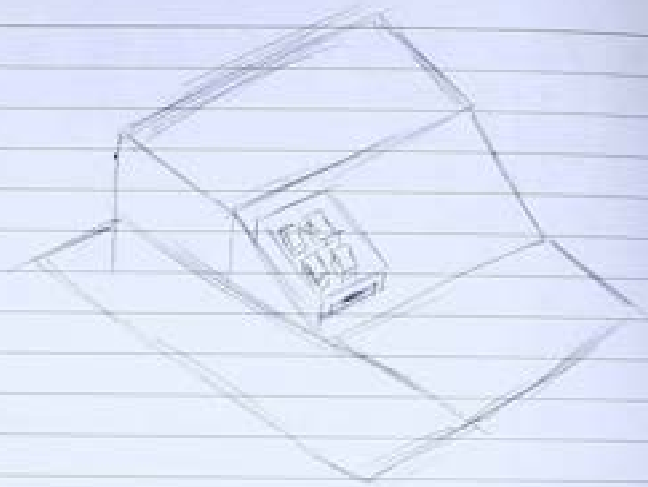
↳ *I'm actually unclear, can I still program it?

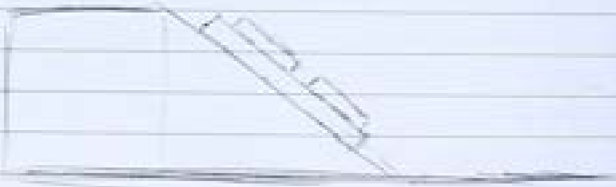
Milestone 8

Apr 18

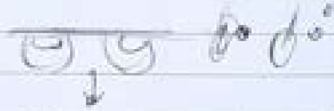
Chassis Development







ideas



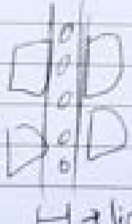
Have unpowered small wheels inside lane to ride along space on the panel

extending wheel arms

↳ very mechanically complex...

↳ how to adjust height?

↳ panel is 14", robot max is 12"



H → lin

→ have wheel/treads along middle path → get data!

update: doesn't fit

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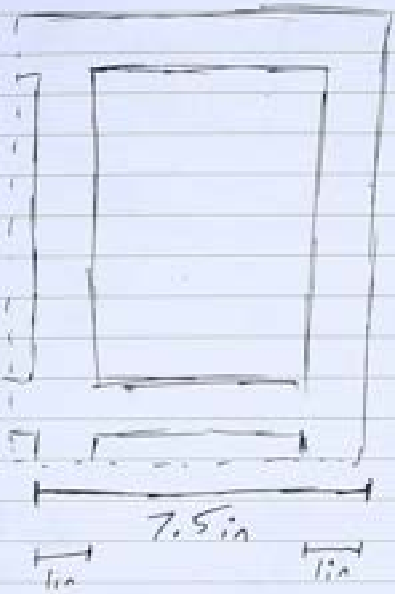
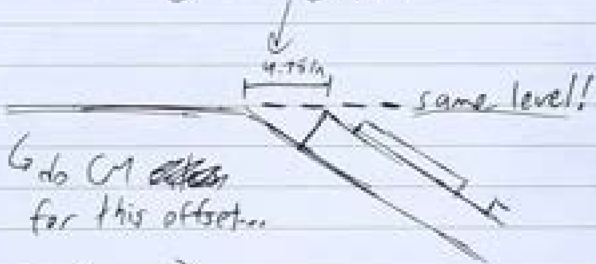
→ what if I just make my wheelbase... small?



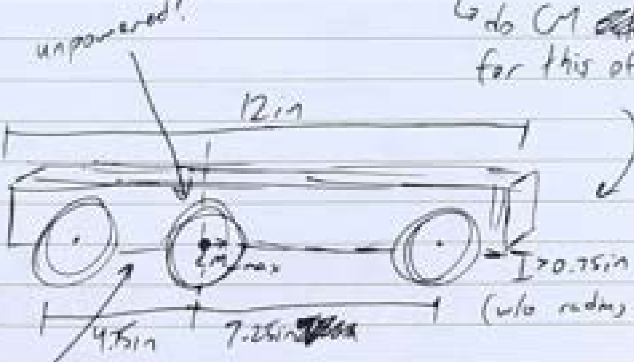
→ avoids many wheelbase problems, like the mirrored button orientation between sides, ~~...~~ having to "retract" one ~~...~~ side of wheels to avoid driving over button, and therefore having some slider or wheels between buttons...

↳ but how to drive up onto platform?

↳ actually, just adjust CM so robot doesn't tip when driving over gap!



↳ do CM ~~...~~ for this offset...



(w/o radius of wheel factored in)

(tank steering)

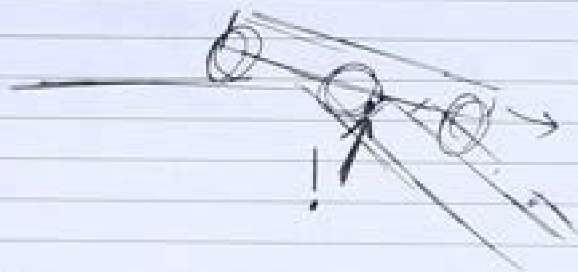
must also not bottom out once front wheel contacts goodie boxes..

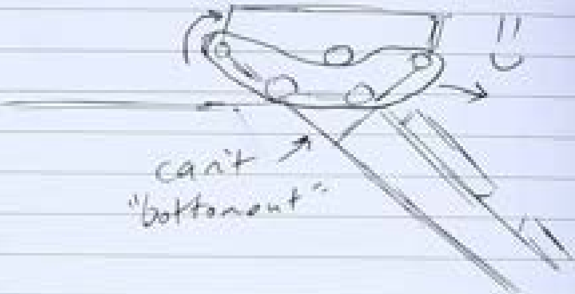
↳ time to make a super simple proof of concept...

↳ make <u>unpowered</u> chassis mockup!

→ Post-Experiment

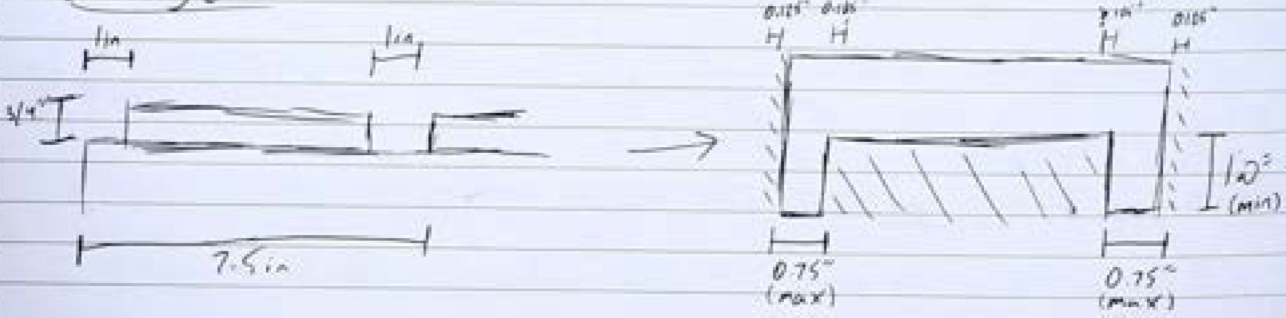
↳ Wheelbase kept bottoming out → need to continuous contact with ground





Idea: Use timing pulleys as tank treads

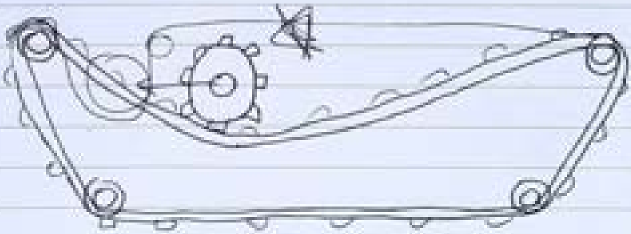
Bounding Box... [front view]



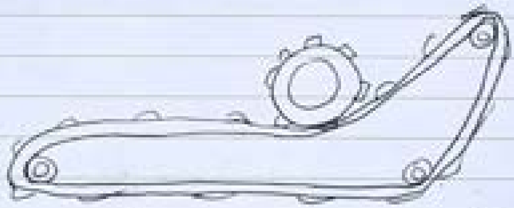
* bushings and not bearings, just because of inventory concerns

** inverted timing belt can help with "grabbing" the ledge to lift onto button panel

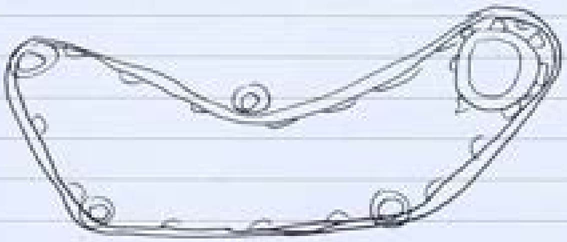
Tread Designs



timing belt tank design
proposed by gerandersen



only lifted on one side
↳ possibly front heavy?



internal tread design

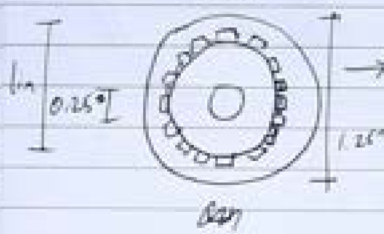
ideally, I want to minimize # of bushings ~~while~~ keeping as much contact with ground as possible, and maximizing contact around timing pulley

↳ while treads on outside is appealing for traction, it is very difficult to get many of the teeth in contact with the gear without extraneous & constraining bushings...
~~however, by the same token, the teeth in contact with~~
↳ shouldn't be an issue if correctly tensioned

★ probably going to go forward with this because
↳ minimizes bushings for maximal contact teeth w/ pulley for external threads
↳ external threads provide much better traction for climbing cliff face

- Contact Area on toothed gear

18" or 24" timing belt



→ 16 teeth timing gear

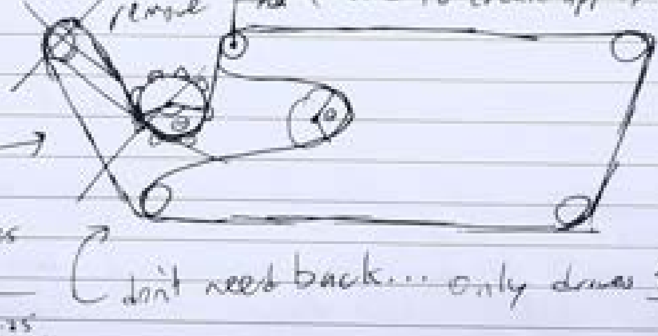
↳ According to belt's datasheet (sdp-si.com) at least six of the teeth must be in mesh to ensure adequate belt tooth shear strength for low-speed application (<0.25 m/s)

↳ for six teeth to be in contact...

$\frac{6}{16} = 0.375 \rightarrow 0.375$ of $2\pi = 0.75\pi$

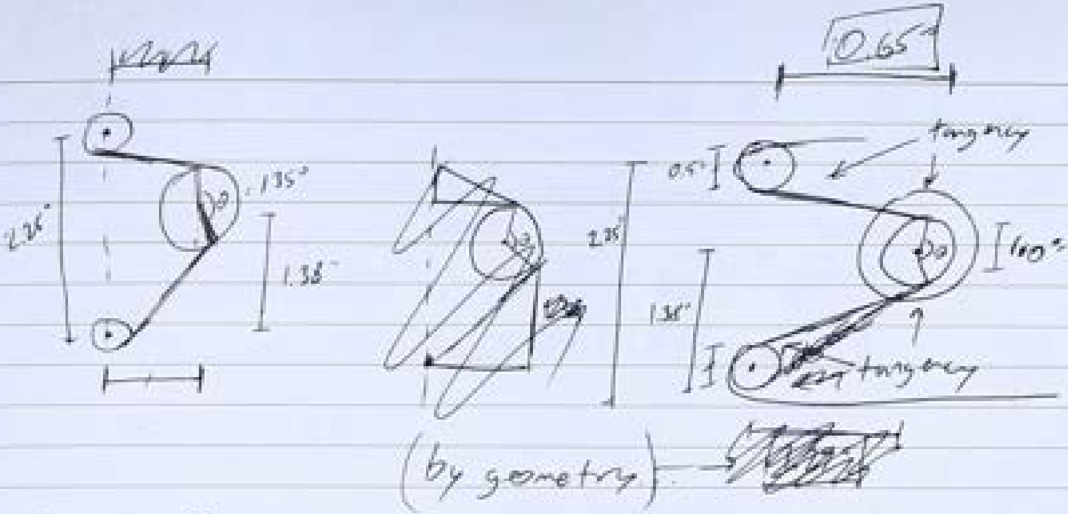
→ $\theta \approx 135°$ (at minimum)

- Tread geometry given minimum angle consideration

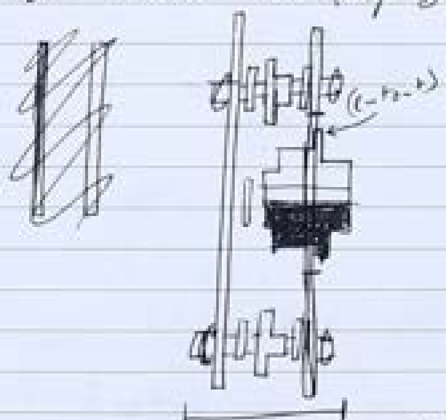


$\sin(45) = \frac{2.25}{h}$

don't need back... only drives forwards



- Front View Stackup of Tank Treads

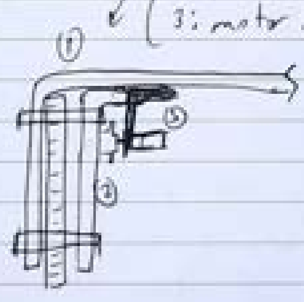


- delrin washer

C - e-ring

- shaft

1: main body
2: track backplate
3: motor holder



• Motor Calcs

↳ Efficiency of Motor & Bushing Assembly

↳ Gearbox • Bushing^4 • Timing • Motor • $Power_{peak}^{48 \checkmark 9R}$

$(95\%) \cdot (90\%)^4 \cdot (95\%) \cdot (80\%) \cdot \underbrace{(48 rpm)(176 mNm)}_{8.45 \cdot 10^{-3}\ kW}$

$= 4.128 \cdot 10^{-3}\ kW$

↳ $\frac{4.128}{8.45} = \boxed{49\%\ \text{efficient}}$

↳ assume μ of tank treads = μ of mintre wheels ($\mu = 0.83$)

1/2 robot (at worst case)

$F_f = \mu N = (0.83)(6\ lbs) = (0.83)(27N) = 22.4N$

↳ $\tau_{max} = (0.5 in)(22.4N) = (0.0127 m)(22.4N) = \underline{0.285\ Nm}$

↳ @ 49% efficiency $= 0.285 \cdot \frac{1}{.49} = \boxed{0.58\ Nm}$

↳ @ 9 lb robot weight (more reasonable, given small wheelbase), new $\tau_{accurate} = \boxed{0.43 Nm}$ (w/ efficiency)

↳ Based on this, I select the $\boxed{\text{98 Gear Ratio LDO motor}}$ as $\tau_{accurate}$ is at peak ~~\$~~ power ~~...~~ (@ 30.1 rpm) and worst case τ_{max} is @ ~~1~~19.5 rpm.

[L = 23mm]

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→ this can just be an "L" from sheet metal on a servo. nothing fancy.

→ Now, how about holding on to the box?

↳ could we potentially use the same "arm" for both box and lifting space ship??

↳ honestly, no, it just overcomplicates it

1) "wc" motion of button holder not compatible w/ car multiplier

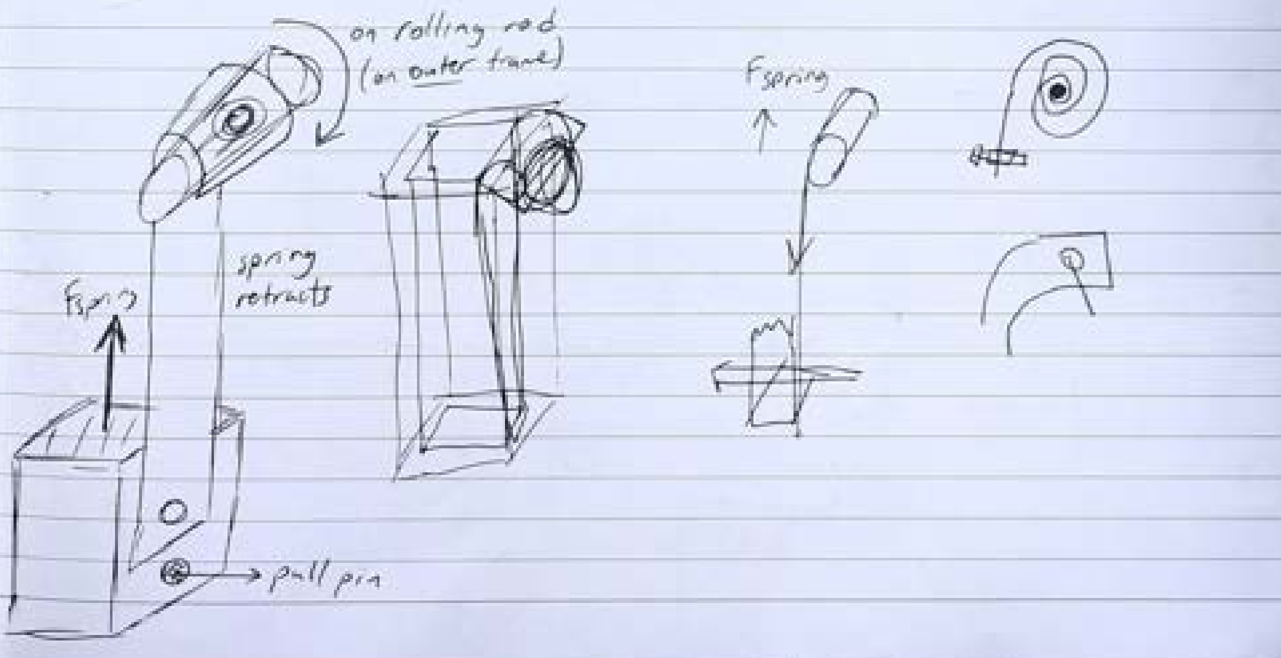
2) will be very slow, I can get away with

(I know this from first run)

• Ship Multiplier Options

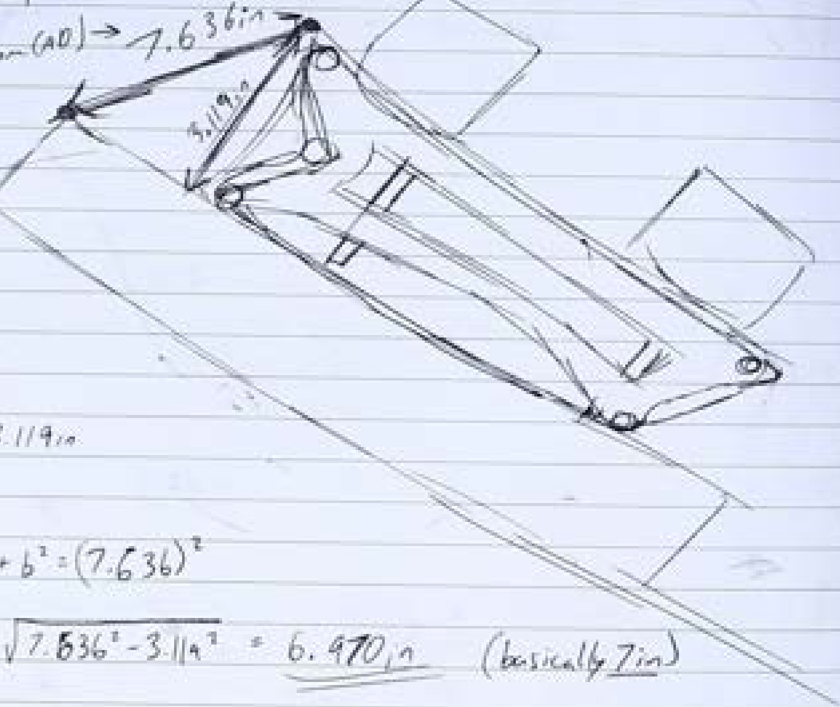
1) Gear Pinion	Fast but hard to manufacture right
2) Ball Screw/Lead Screw	Very slow but reliable
★ 3) Mainspring	Very fast, easy to manufacture, friction?
4) Pulley/Winch	Very high friction, unreliable

↳ Going forward with (3), ~~mainspring~~. "Constant force spring"



→ okay, let's back up a bit lol...

↳ we need the arm to balance CM & hold robot on button panel



↳ $(3.119)^2 + b^2 = (7.636)^2$

↳ $b = \sqrt{7.636^2 - 3.119^2} = \underline{6.970\,in}$ (basically 7in)

Milestone #9

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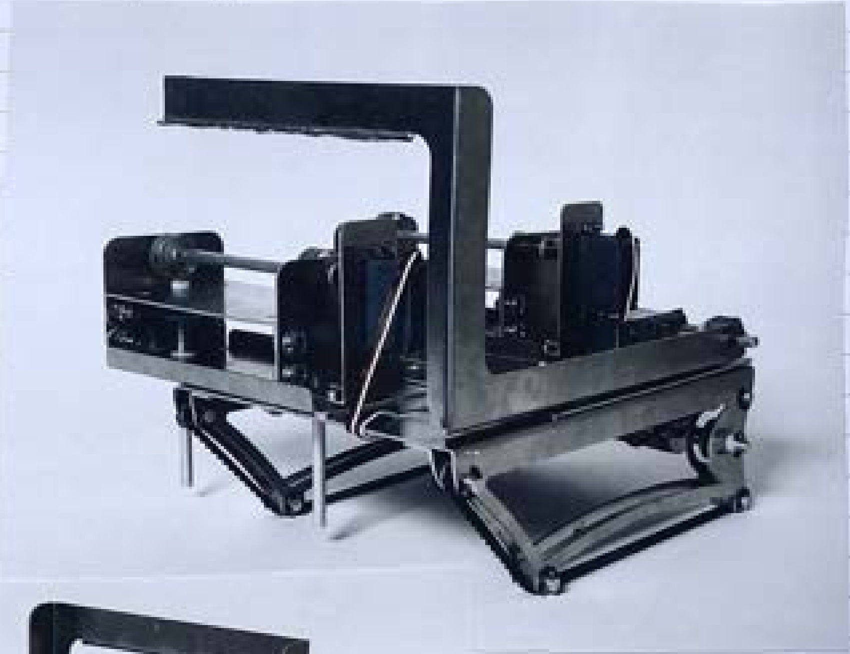
1) Complete Robot in Current State

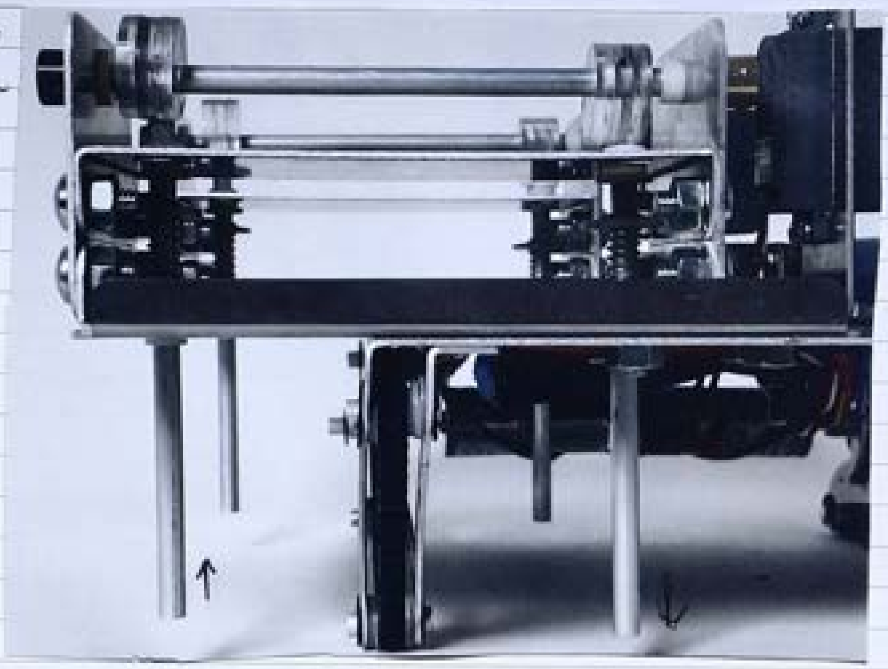
Full Robot
(Front Isometric)



Full Robot
(Back Isometric)

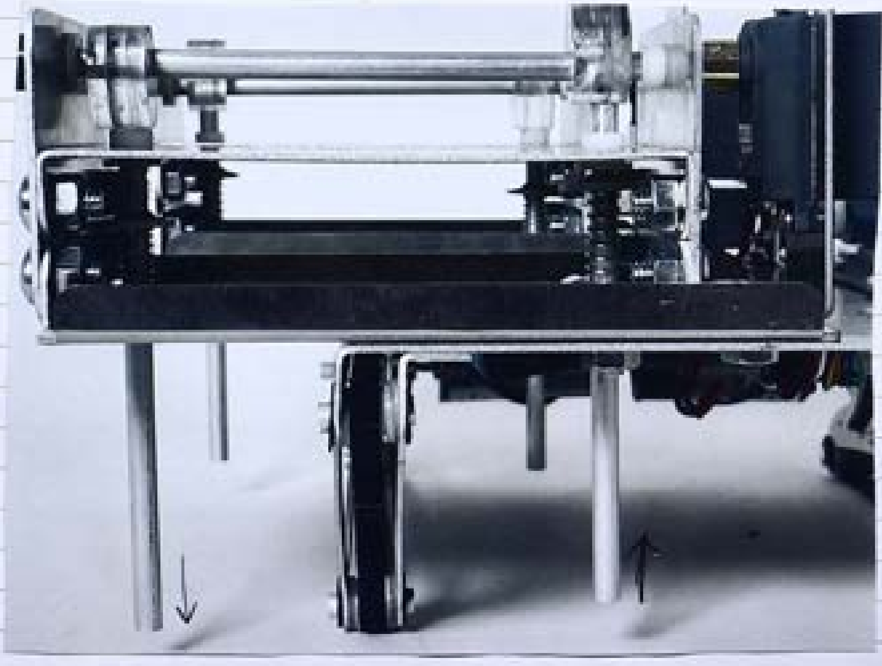
MCM
state 1

(press right
button)



MCM
state 2

(press
left button)



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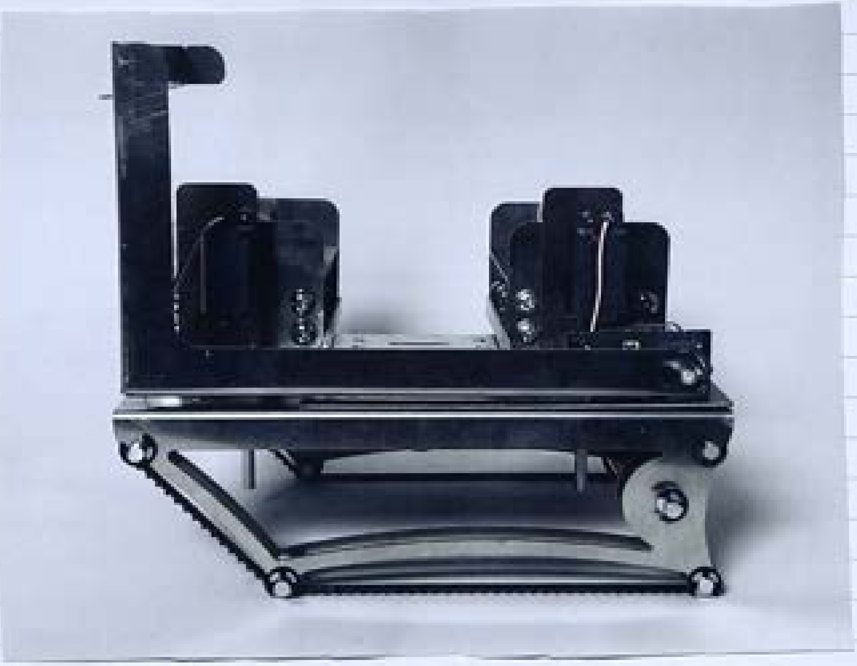
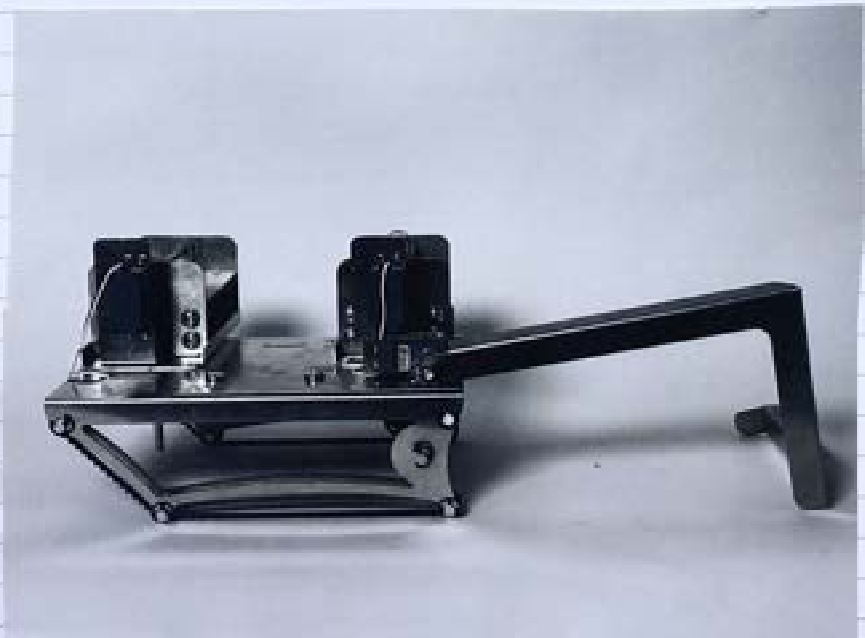


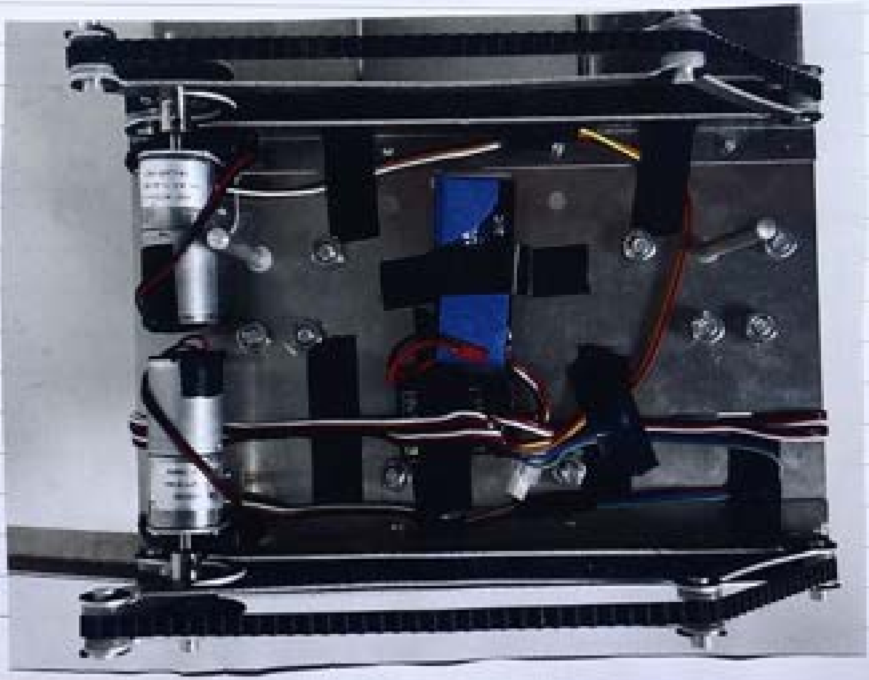
Gooble Arm (retracted)



Gooble Arm (extended

Tank
Treads

Electronics
Panel



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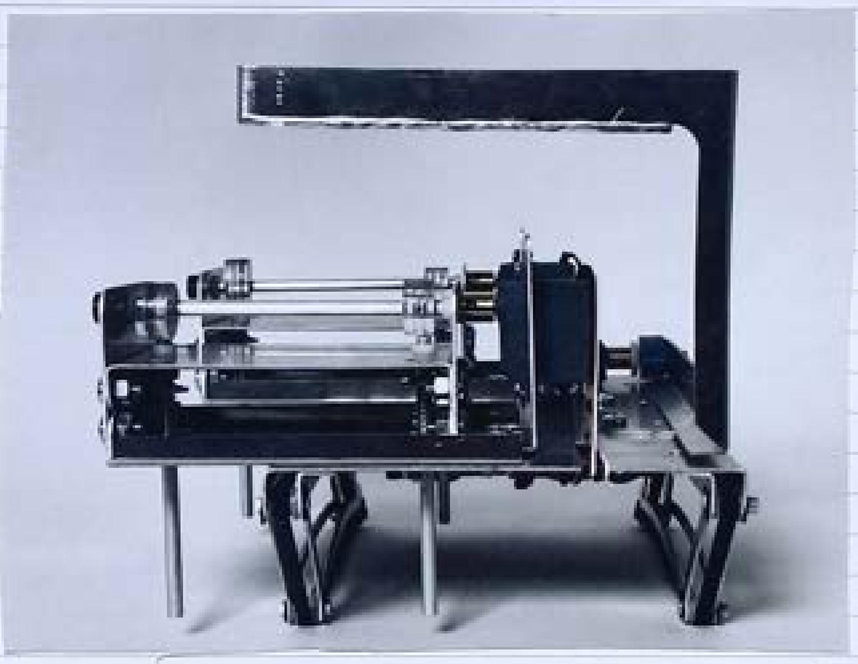
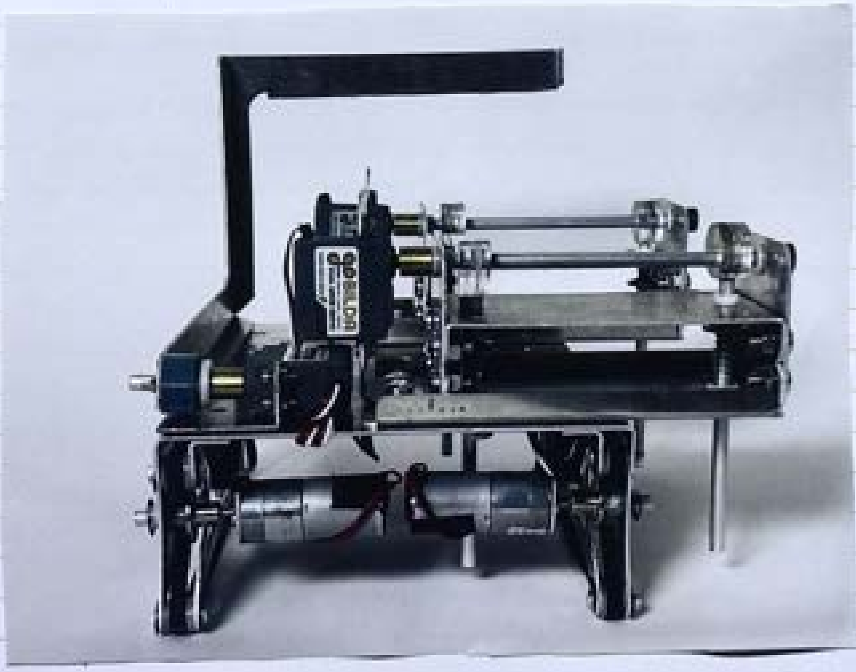


Front View



Back View

Very nicely documented.

2) Fabrication Details

↳ What has been done?

- Most parts were plasma cut 1/16" aluminum sheetmetal and bent into shapes and attached with bolts
- Notable exceptions are the CAMs and Gears, both of which were made using laser cut acrylic
- Three Buildin Speed motors were used (CAMs, L-Arm)
- Two L~~...~~ 98 gearhead motors were used (treads)
- Timing pulley was used as treads and was tensioned by adjusting radius of laser cut acrylic gear experimentally
- Super Glue was used rarely, only to hold acrylic CAMs on ~~...~~ rod and to hold a stubborn bolt in place
- The hardest part was by far the MCM (goobl boxes) as they require very fine measurements for pressing e-clips to correctly calibrate the parallel springs, as well as the fact that it has the most ~~...~~ assembly steps

↳ What still must be done?

- I would still like to CAD & manufacture a mechanism to lift the UFO. I have a design in my head & some preliminary sketches, but I still have to calculate force of springs required, ~~...~~ the telescoping arm, and finally manufacture it
- To manufacture it, I will need to mill a 1x1 aluminum bar and a delrin square rod as the basis for the arm, and cut them to length of course
- Then I must drill press holes to attach the constant force springs, and attach with bolts
- Finally, I will laser cut a mount and attach it to the open holes I left on my chassis

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3) Stored energy calculation

↳ Sources...

1) Battery — $E = \text{mAh} \cdot V = 1200\,\text{mAh} \cdot 7.4V = 8.88\,kJ$

2) Parallel Springs (Small) — $E = \frac{1}{2}kx^2 = \frac{1}{2}(k)(0.25\,in)^2 = 2 \cdot 10^{-5} \cdot k$ ← (negligible...)

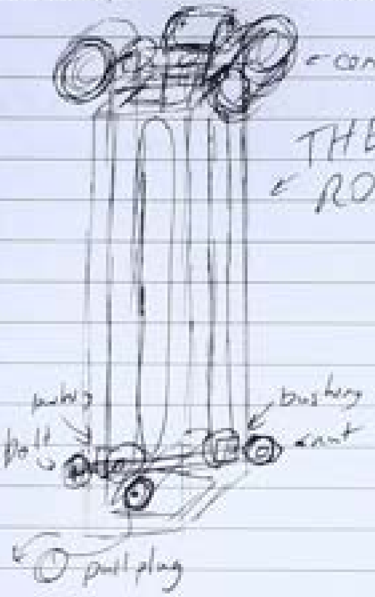
4) Pre-Flight Checklist

- Ensure battery is > 75% charged
- Plug in battery, and ensure all motors/drives plugged into receiver
- Try all controls (steering, forwards, CAMs, L-Arm) necessary
- Ensure CAMs are in neutral position to clear panel
- Ensure L-Arm starts in retracted position
- Ensure belt motors properly trimmed on controller
- Ensure controller adequately charged
- Ensure belts properly tensioned to avoid slippage
- Ensure belts are clean and free from dust / debris
- Brush off game board to remove dust or debris
- Check all set screws on motors properly tightened

10

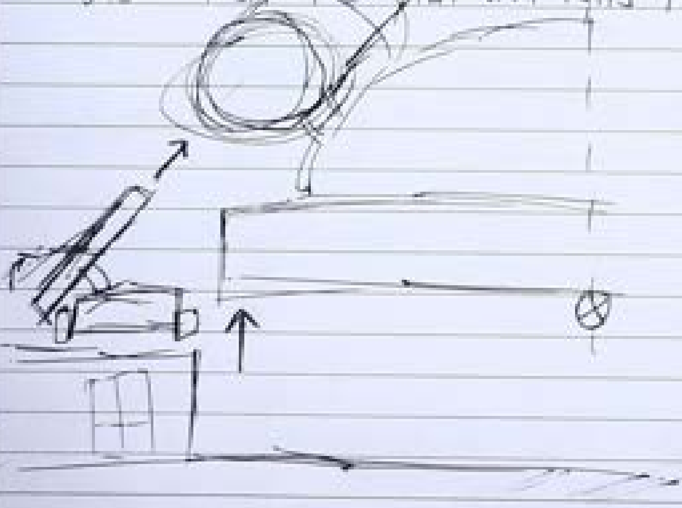
Thomas,
At this point, your robot is well engineered. Your work shows your effective use of lessons learned. Also a good job with the checklist.

→ finally the car multiplier



falling platform? (to get under ship)

both pull plugs on ~~[illegible]~~ seperate winches w/ different length strings such that the platform falls first & the rocket fires second



Milestone #10

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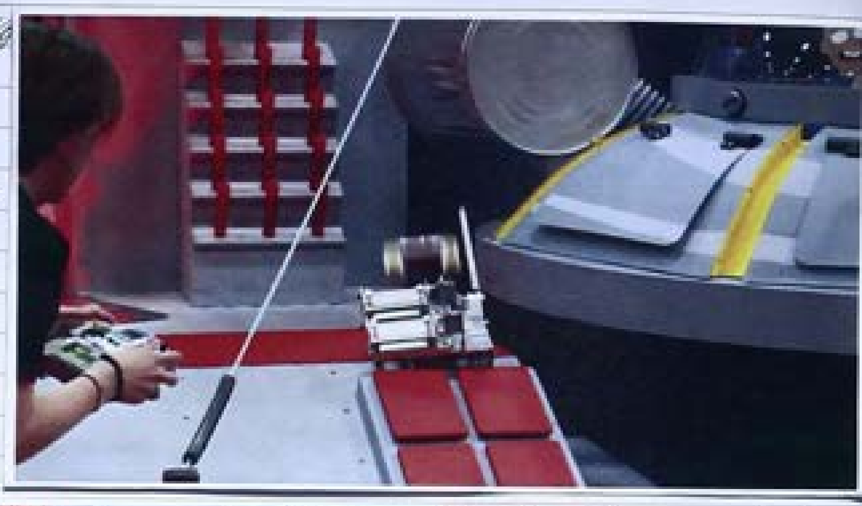
1) Final Machine

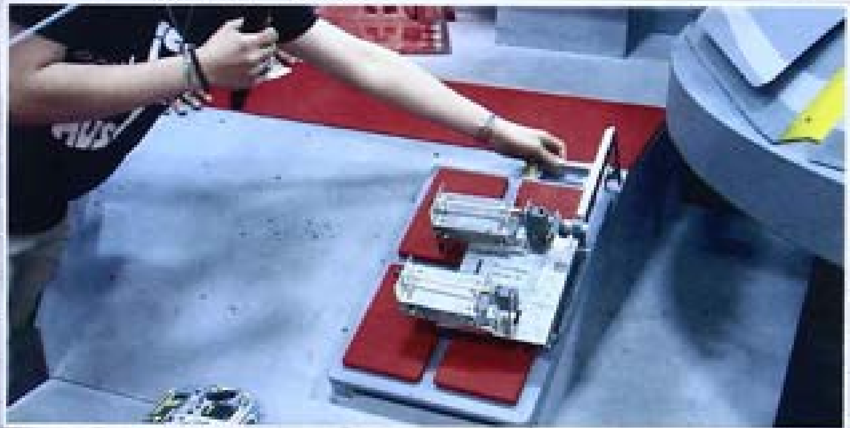
↳ My machine was designed to do one thing very well. I decided that I would rather have a very safe and robust design rather than some risky design that could score a lot of points.

↳ My strategy begins with a calibration step to ensure that all of my end effectors are flush with the gooble boxes when the CAMs are in the neutral position. This way when the CAMs spin they accurately press down

↳ Unfortunately, right before my round, my belt tensioner loosened and the belt slipped off my timing pulley. There was nothing I could do in time to put the belt back onto the gear, so I started the round knowing I could not move. !!

↳ Knowing I couldn't move, I attempted to propel myself forward using my arm to slam against the table and tilt myself over the edge of the ramp. This did not work, but created a lot of noise!





↳ After the round, Amos let me demo how my machine could've worked if the belts had not slipped off. I placed it on top of the boxes and showed how the arm was designed to grab the ba of the box and hold the robot firmly in place.

↳ After I turned on my dual CAM system, I showed how consistently I was able to score points on buttons. Amos seemed very impressed, and I was happy to see the points go up and get recognized for my design.

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2) As for other people attempts at gooble boxes, I saw a few people with similar and different approaches. Almost all of the ~~[illegible]~~ autonomous button pressers I saw did not function ~~[illegible]~~ as intended as the gooble boxes are a challenge that requires a lot of precision in alignment and control. As for pressing the buttons I only saw one other person attempt a CAM mechanism, but they made the CAMs directly in contact with the buttons, without the adjustable rods I had. This made their system much less reliable and could not score on both rows of buttons. Most people used large cantilevered shafts to press buttons, which created many mechanical complications, such as rack/pinions not deploying from the large ~~[illegible]~~ load.

~~[illegible]~~ ↳(the pen I've been using all semester just ran out of ink, so sad! I used ~~[illegible]~~ it for every milestone haha.) RIP

3) +5 I used CAD extensively at the beginning of the design process to create detailed mechanisms so I knew what to manufacture. One of my biggest takeaways from 2.007 is that CAD is not holy, and the real world does not care about how perfect your models are. Manufacturing, assembly, misalignment, super glue accidents, and overlooking attention to disassembly was a huge learning experience for me. (!!! especially this one)

I also utilized tools like Python ~~[illegible]~~ to run scripts to calculate thickness of parts like cantilevers, and ~~[illegible]~~ Desmos to calculate ~~[illegible]~~ which LDO~~[illegible]~~ motors to use given my desired torque and speed at 7.4 V.

4) I used the metal shear and metal hole puncher
15 extensively in the beginning of the semester.
I was very unsatisfied by their performance
for making precision machines. I learned that while
they're very good at prototyping, they fail at providing
enough resolution for final implementations. For my
final robot, I used primarily the plasma cutter
in N52, the bandsaw, the press fit machine, 3D printers
(very minorly), hand tools like saws and screwdrivers,
and the sheet metal bender (I found out I could
lock the angle wayyy too late!). I feel I
definitely have improved in working with prototyping
and designing in sheet metal, and some parts that
took me days to manufacture and assemble (such
as my first MCM final) ended up taking me only a
few hours by the end of semester.

6) In retrospect, now I have a better understanding of how
long assembly & manufacturing take, so my ambitious
plans for developing a new MCM every week seem
wildly impractical. Perfection is the enemy of progress.
I should have experimented more by quickly designing
and manufacturing many physical prototypes, because I
discarded many ideas early on due to a poor understanding
and preconceived notions about how motors functioned. I have
learned to be more experimentalist and more realistic
when planning tasks. I also could've developed a better
strategy to gain more points, possibly by experimenting more
with other modules rather than depth-first searching goodie boxes

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7) I adored the shop staff (I ♡ you Scott) and they made the class way more worth it. I don't really understand why impounding a week early is that important, though. I also would've liked to see a starter design challenge a bit more complicated than the mini-me, perhaps something that integrated what was being taught in lecture. Also the pop quizzes for attendance do not encourage attendance, but rather for people to send the link to friends, as I saw people near me doing. There's got to be a better way.

Overall, this has been one of the best classes I've taken here. The support from you, Professor Seering, has been invaluable and has made a tremendous difference in my life and my confidence as a mechanical engineer. Thank you for inspiring me every step of the way and always being there to talk to. You're amazing.

→ 2.007 complete ✓

Thomas,

I've really enjoyed having you in lab. From the beginning, you've had good clarity with regard to your goals, and you've adjusted well as you've learned. Your building skills got progressively stronger. I'm quite sure that your portfolio of designs will become a record of more and more good systems with time. You're on track to be an excellent designer with an attitude that will enable you to achieve this status. I wish you the best with your ongoing design experiences.

Warren