DESIGN HIGHLIGHTS

846

THE FUNKY MONKEYS

LYNBROOK ROBOTICS

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THE FUNKY MONKEYS

TEAM 846

-INTRODUCING OUR 2018 ROBOT-

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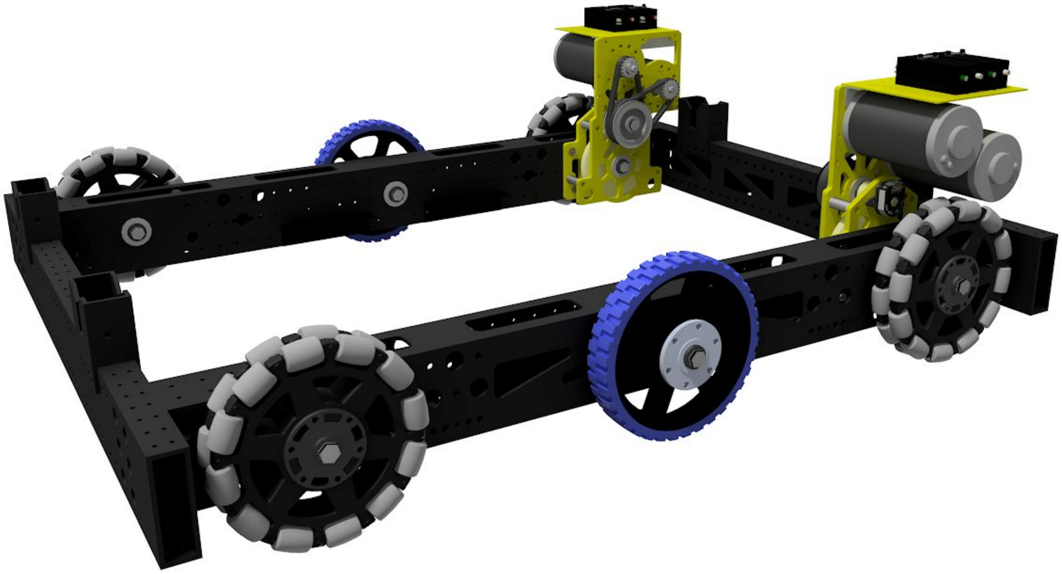
Drivetrain

Eesha Deepak (Junior), Anna Shaposhnik (Sophomore)

With Zhonghe Zheng (Freshman), Anika Singh (Senior), Shannon Heh (Junior), Patricia Huang (Freshman), Laasya Chukka (Freshman), Ivie Xue (Freshman)



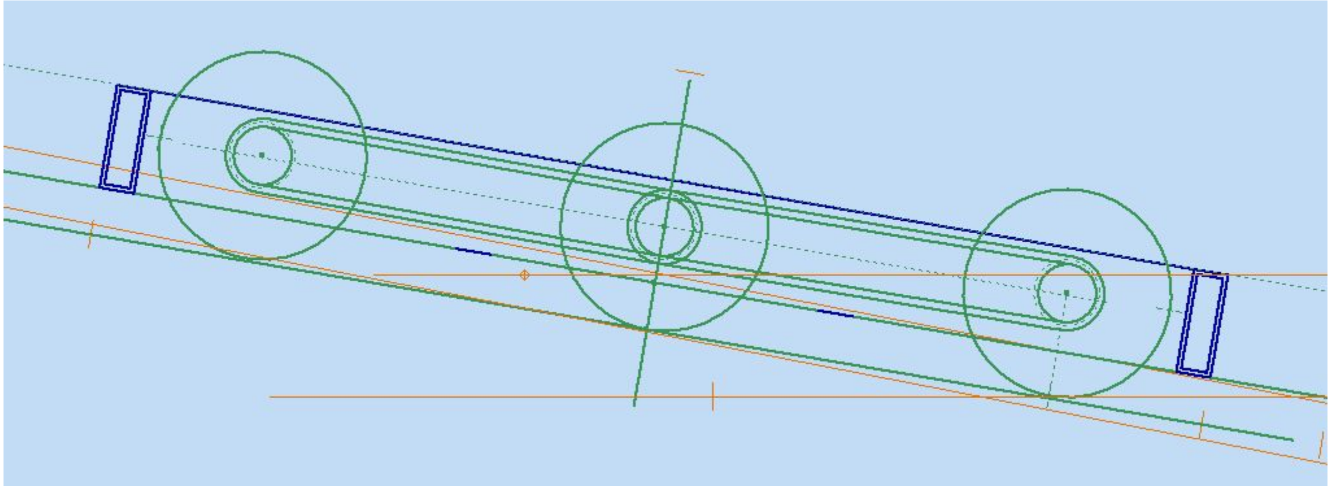
Design Requirements:

1. Clear the cable protectors and platform ramp
2. Drive quickly around the field
3. Turn quickly
4. Minimize rocking

Drivetrain Frame

When trying to choose an orientation for our robot based off of the maximum robot volume, we realized that three narrow robots would barely fit on the platform. With there being points for having robots stationed on the platform, we decided to proceed with a narrow robot design.

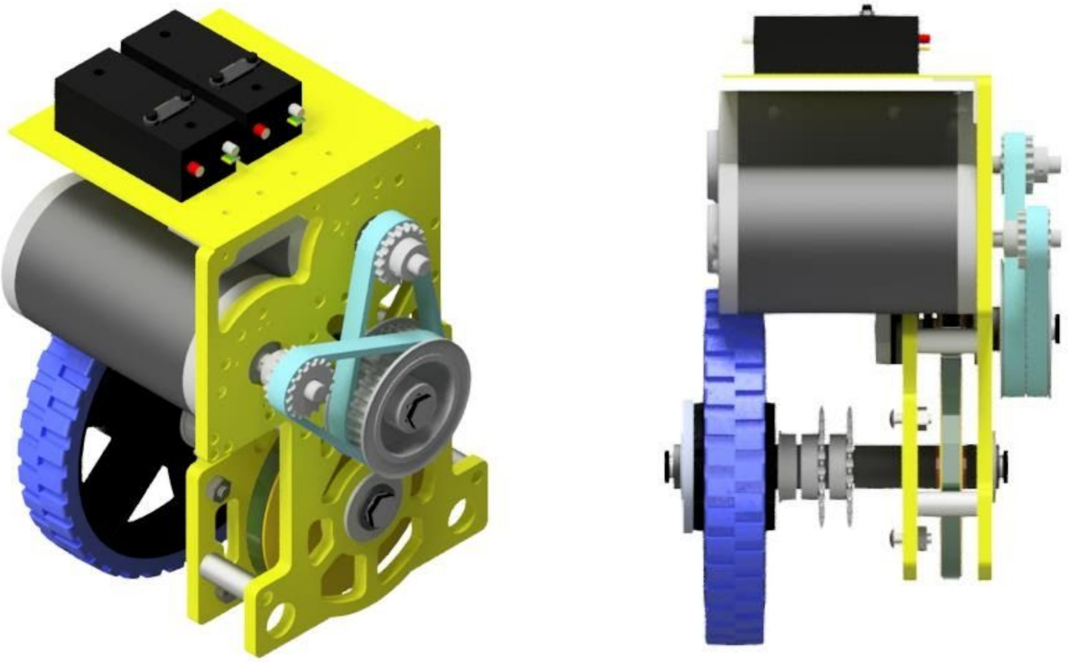
We also did some tests to see if we would be able to clear the platform and cable protectors. With these simulations, we came to the conclusion that 6 inch wheels were the best option to balance chain slop and clearing these barriers.



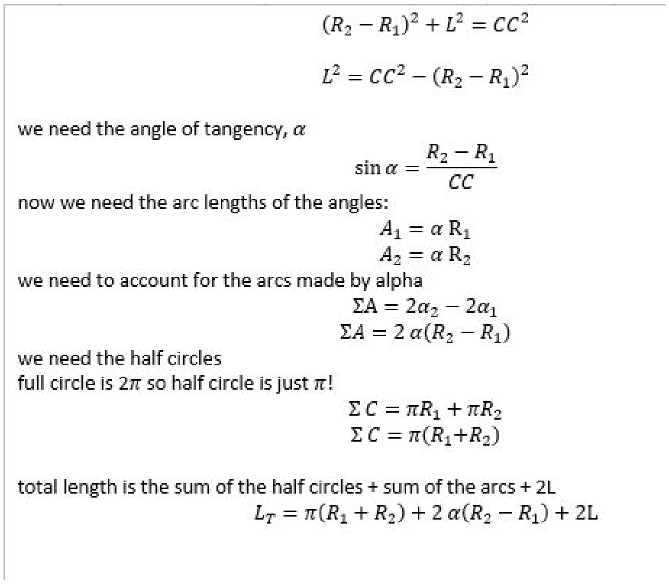
Using CAD to check that our drivetrain can climb the platform.

Additionally, we wanted our robot to be able to turn quickly, but not tip over. Therefore, we used a 6-wheel layout, with omni wheels on the front and back, and traction wheels in the center, with a slight center drop. This arrangement allows us to make our robot agile and quick to turn while keeping the pushing power of traction wheels.

Gearbox



The motors hang over the wheels to give more space for electronics and the climbing gearbox inside, and we placed the speed controllers over the gearbox for better system management



$$(R_2 - R_1)^2 + L^2 = CC^2$$

$$L^2 = CC^2 - (R_2 - R_1)^2$$

we need the angle of tangency, α

$$\sin\alpha = \frac{R_2 - R_1}{CC}$$

now we need the arc lengths of the angles:

$$A_1 = \alpha \, \mathrm{R}_1$$

$$A_2 = \alpha \, \mathrm{R}_2$$

we need to account for the arcs made by alpha

$$\Sigma\mathrm{A} = 2\alpha_2 - 2\alpha_1$$

$$\Sigma A = 2\,\alpha(R_2 - R_1)$$

we need the half circles

full circle is 2π so half circle is just π!

$$\Sigma\, C = \pi R_1 + \pi R_2$$

$$\Sigma\, C = \pi(R_1 + R_2)$$

total length is the sum of the half circles + sum of the arcs + 2L

$$L_T = \pi(R_1 + R_2) + 2\,\alpha(R_2 - R_1) + 2\mathrm{L}$$

The amount of teeth on the belt drive is determined by the center to center distance between the pulley and the motor, and we used goal seek to make sure the amount of teeth was a whole number.

Adjustability in tensioning is provided by an array of mounting holes, each pair placing the center of the motor further away from the pulley.

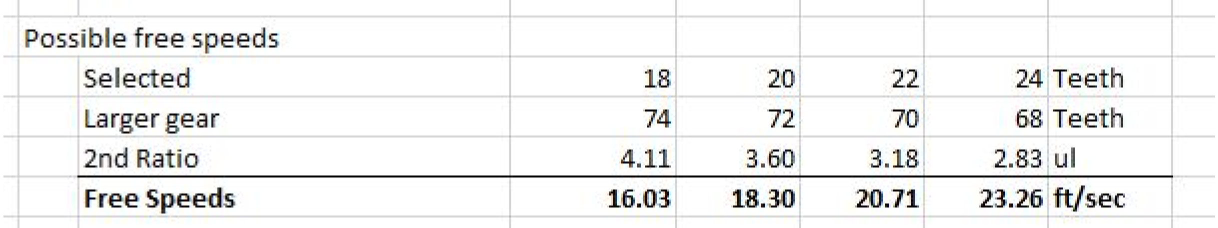
Belt Variation (in Belt Length)	CC	Belt Length		Percent Change	Belt Variation in CC	
0	2.74	275.00		0.00%	0.00	0 '.5 -.5 +1
0.500	2.75	275.5	mm	0.18%	0.01	
-0.500	2.73	274.5	mm	-0.18%	-0.01	
1.000	2.76	276.0	mm	0.36%	0.02	

After arbitrarily determining our goal to increase the belt length by 0, 0.5, -0.5 and 1 mm, we found the belt variation in CC needed to change by 0.01.

Possible Gear Ratios and Final Free Speeds			
Free Speed Wheel Velocity (on wh	139.5	ft/s	no gear reduction
First stage Reduction	2.1176	ul	selected first stage reduction
Free speed with G.Ratio=1	65.9	ft/set	
Slowest target speed	16	ft/sec	
Target gear ratio	4.12		
Smallest pinion available	18	Teeth	
Larger gear	74.130	Teeth	
SumTeeth	90	Teeth	
Adjustment to Sum of teeth	2	Teeth	manual override to get better ranges.
Sum Teeth	**92**	**Teeth**	

Looking at some notes on other team's robot weights and their top speeds, we estimated the target speed to be around 16 ft per sec for a 120 pound bot.

We also made sure that we could have possibility of variation for adjustability in gear ratio.



Possible free speeds					
Selected	18	20	22	24	Teeth
Larger gear	74	72	70	68	Teeth
2nd Ratio	4.11	3.60	3.18	2.83	ul
Free Speeds	**16.03**	**18.30**	**20.71**	**23.26**	**ft/sec**

The design includes a parameterized gear model that changes to check that all 4 gear ratios do not interfere with anything.

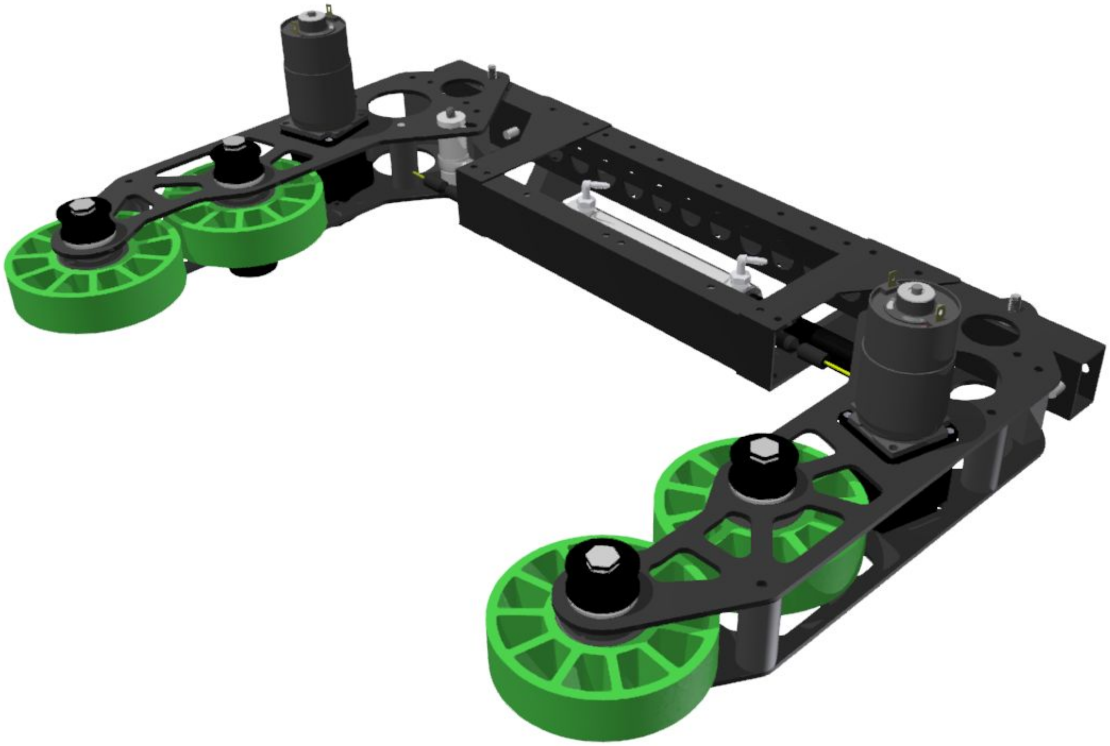
As such, we designed the gearbox to be able to account for the biggest possible gear: the 74 tooth one.

In addition to the gearbox, we machined a talon mounting plate directly over the motors to provide additional space for electrical components.

Cube Manipulator

James Jiao (Junior)

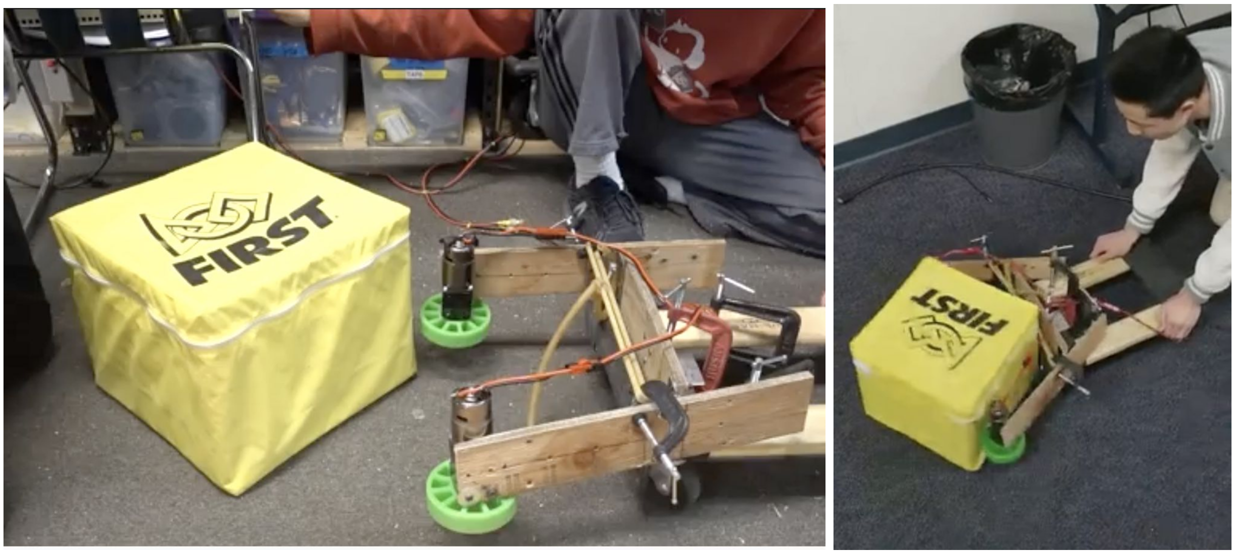
With Atul Nair (Junior), Jonah Soong (Sophomore), Shaunak Bhandarkar (Junior)



Design Requirements:

1. "You touch it, you own it" - collects cube once intake touches it
2. Collect power cube in any resting orientation from the ground
3. Securely hold block as robot traverses field and lifts cube
4. Fast active deploy and easy for operator to control
5. Prevent arms from banging around—smoothly open and close

Prototyping

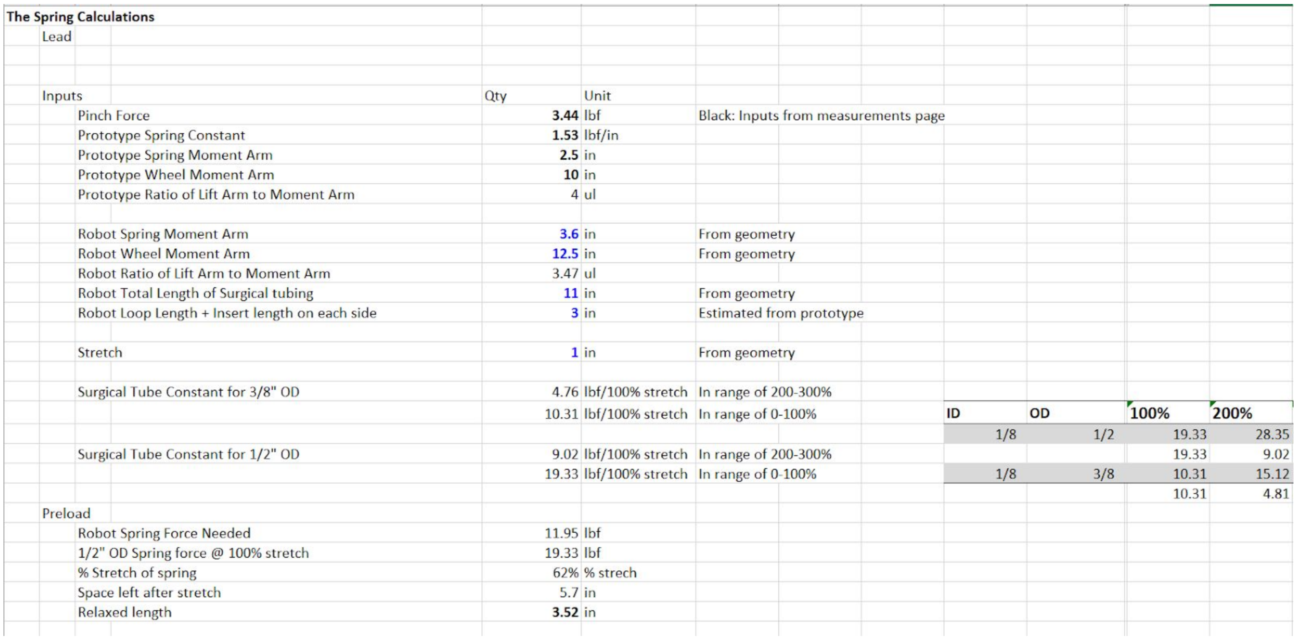


Testing our prototype that involved the 4” extra compliant wheels mounted to wooden boards on hinges. This prototype manipulator was able to effectively collect cubes.

Our first approach involved a clamp design, which we prototyped with two wooden boards on hinges. Although the clamp grabbed the cube tightly, especially with nubs to grab onto the sides, it was not a continuous intake of cubes.

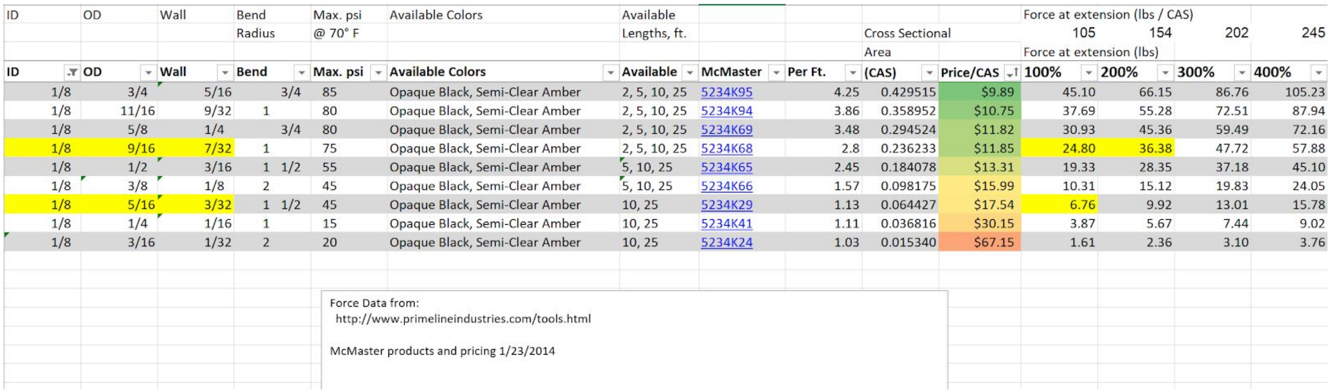
Then, we created a prototype collector using the 4” diameter extra compliant wheels from AndyMark. Although it was simple, our prototype could collect cubes from any orientation, so we decided to pursue this design. The key takeaway was that surgical tubing springs allowed the arms to open up to collect the cube from different angles.

Surgical Spring Calculations



The Spring Calculations							
Lead							
Inputs	Qty	Unit					
Pinch Force	**3.44**	lbf	Black: Inputs from measurements page				
Prototype Spring Constant	**1.53**	lbf/in					
Prototype Spring Moment Arm	**2.5**	in					
Prototype Wheel Moment Arm	**10**	in					
Prototype Ratio of Lift Arm to Moment Arm	4	ul					
Robot Spring Moment Arm	**3.6**	in	From geometry				
Robot Wheel Moment Arm	**12.5**	in	From geometry				
Robot Ratio of Lift Arm to Moment Arm	3.47	ul					
Robot Total Length of Surgical tubing	**11**	in	From geometry				
Robot Loop Length + Insert length on each side	**3**	in	Estimated from prototype				
Stretch	**1**	in	From geometry				
Surgical Tube Constant for 3/8" OD	4.76	lbf/100% stretch	In range of 200-300%				
	10.31	lbf/100% stretch	In range of 0-100%	**ID**	**OD**	**100%**	**200%**
				1/8	1/2	19.33	28.35
Surgical Tube Constant for 1/2" OD	9.02	lbf/100% stretch	In range of 200-300%			19.33	9.02
	19.33	lbf/100% stretch	In range of 0-100%	1/8	3/8	10.31	15.12
						10.31	4.81
Preload							
Robot Spring Force Needed	11.95	lbf					
1/2" OD Spring force @ 100% stretch	19.33	lbf					
% Stretch of spring	62%	% strech					
Space left after stretch	5.7	in					
Relaxed length	**3.52**	in					

Calculations for replicating spring force from prototype onto final design



ID	OD	Wall	Bend Radius	Max. psi @ 70° F	Available Colors	Available Lengths, ft.			Cross Sectional Area		Force at extension (lbs / CAS)			
											105	154	202	245
											Force at extension (lbs)			
ID	**OD**	**Wall**	**Bend**	**Max. psi**	**Available Colors**	**Available**	**McMaster**	**Per Ft.**	**(CAS)**	**Price/CAS**	**100%**	**200%**	**300%**	**400%**
1/8	3/4	5/16	3/4	85	Opaque Black, Semi-Clear Amber	2, 5, 10, 25	5234K95	4.25	0.429515	$9.89	45.10	66.15	86.76	105.23
1/8	11/16	9/32	1	80	Opaque Black, Semi-Clear Amber	2, 5, 10, 25	5234K94	3.86	0.358952	$10.75	37.69	55.28	72.51	87.94
1/8	5/8	1/4	3/4	80	Opaque Black, Semi-Clear Amber	2, 5, 10, 25	5234K69	3.48	0.294524	$11.82	30.93	45.36	59.49	72.16
1/8	9/16	7/32	1	75	Opaque Black, Semi-Clear Amber	2, 5, 10, 25	5234K68	2.8	0.236233	$11.85	24.80	36.38	47.72	57.88
1/8	1/2	3/16	1 1/2	55	Opaque Black, Semi-Clear Amber	5, 10, 25	5234K65	2.45	0.184078	$13.31	19.33	28.35	37.18	45.10
1/8	3/8	1/8	2	45	Opaque Black, Semi-Clear Amber	5, 10, 25	5234K66	1.57	0.098175	$15.99	10.31	15.12	19.83	24.05
1/8	5/16	3/32	1 1/2	45	Opaque Black, Semi-Clear Amber	10, 25	5234K29	1.13	0.064427	$17.54	6.76	9.92	13.01	15.78
1/8	1/4	1/16	1	15	Opaque Black, Semi-Clear Amber	10, 25	5234K41	1.11	0.036816	$30.15	3.87	5.67	7.44	9.02
1/8	3/16	1/32	2	20	Opaque Black, Semi-Clear Amber	10, 25	5234K24	1.03	0.015340	$67.15	1.61	2.36	3.10	3.76

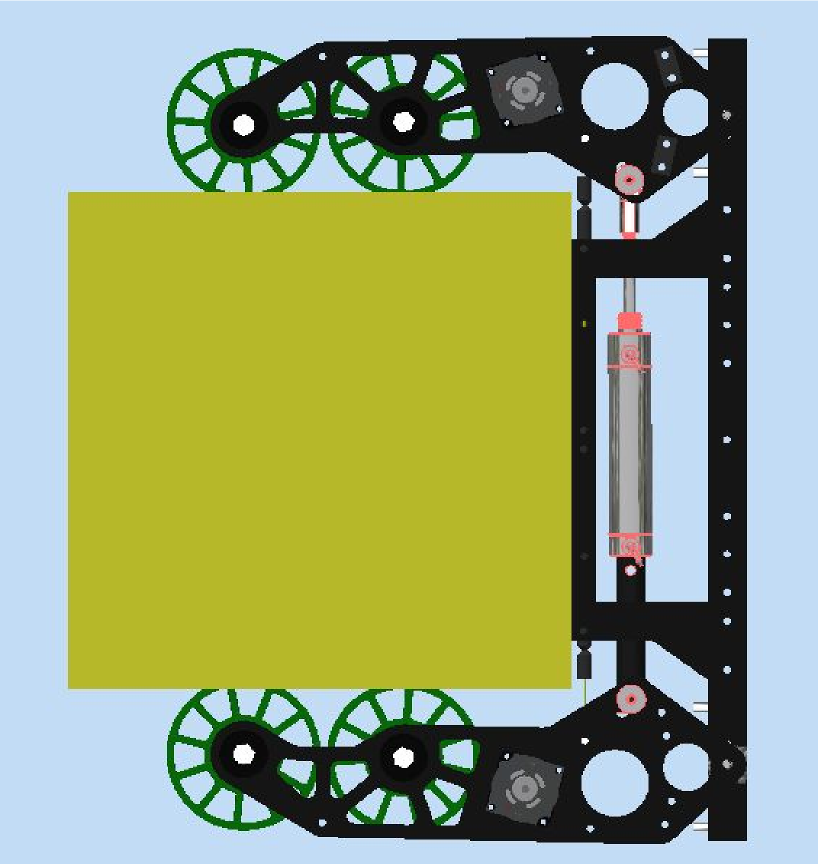
Force Data from:
http://www.primelineindustries.com/tools.html

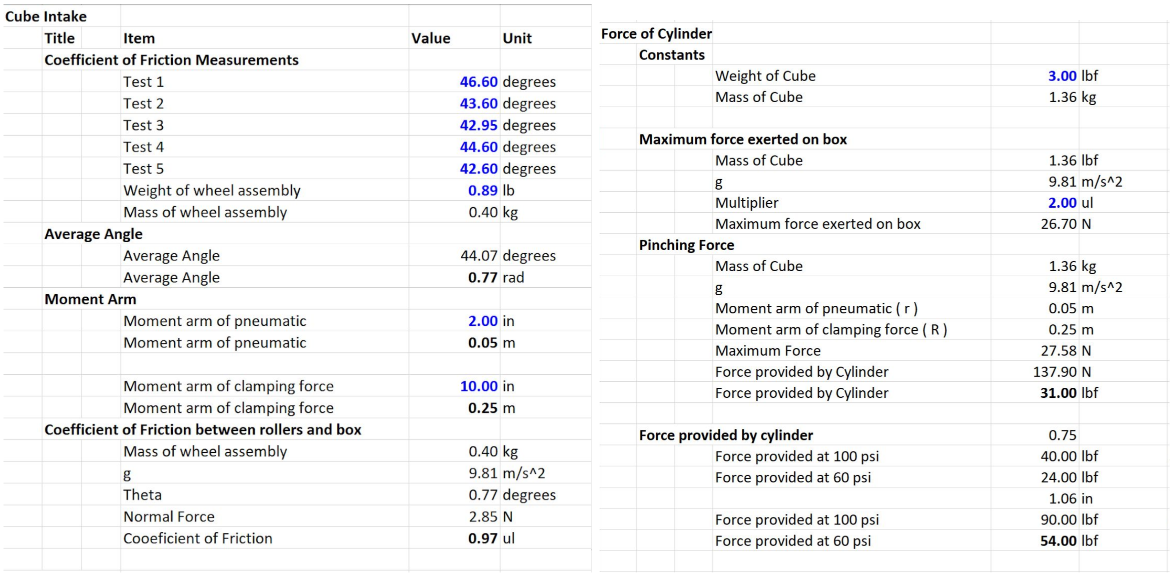
McMaster products and pricing 1/23/2014

List of different sized surgical tubing from McMaster and their spring forces, part numbers, prices, etc.

To replicate the results of our prototype on our final design, we needed to calculate the correct spring force and select surgical tubing to provide it. To do so, we compiled a list of different sized surgical tubing and the stretch force they provided at different extensions. We also measured and matched the spring force of the spring on our prototype on our final design.

Gripping the cube





Cube Intake					
	Title		**Item**	**Value**	**Unit**
	Coefficient of Friction Measurements				
			Test 1	**46.60**	degrees
			Test 2	**43.60**	degrees
			Test 3	**42.95**	degrees
			Test 4	**44.60**	degrees
			Test 5	**42.60**	degrees
			Weight of wheel assembly	**0.89**	lb
			Mass of wheel assembly	0.40	kg
	Average Angle				
			Average Angle	44.07	degrees
			Average Angle	**0.77**	rad
	Moment Arm				
			Moment arm of pneumatic	**2.00**	in
			Moment arm of pneumatic	**0.05**	m
			Moment arm of clamping force	**10.00**	in
			Moment arm of clamping force	**0.25**	m
	Coefficient of Friction between rollers and box				
			Mass of wheel assembly	0.40	kg
			g	9.81	m/s^2
			Theta	0.77	degrees
			Normal Force	2.85	N
			Cooeficient of Friction	**0.97**	ul

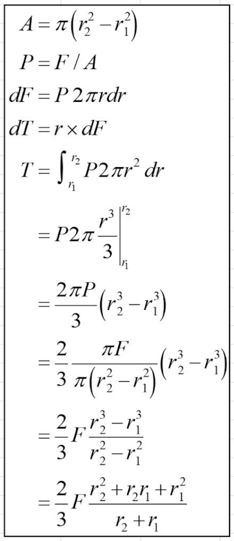
Force of Cylinder					
	Constants				
			Weight of Cube	**3.00**	lbf
			Mass of Cube	1.36	kg
	Maximum force exerted on box				
			Mass of Cube	1.36	lbf
			g	9.81	m/s^2
			Multiplier	**2.00**	ul
			Maximum force exerted on box	26.70	N
	Pinching Force				
			Mass of Cube	1.36	kg
			g	9.81	m/s^2
			Moment arm of pneumatic (r)	0.05	m
			Moment arm of clamping force (R)	0.25	m
			Maximum Force	27.58	N
			Force provided by Cylinder	137.90	N
			Force provided by Cylinder	**31.00**	lbf
	Force provided by cylinder			0.75	
			Force provided at 100 psi	40.00	lbf
			Force provided at 60 psi	24.00	lbf
				1.06	in
			Force provided at 100 psi	90.00	lbf
			Force provided at 60 psi	**54.00**	lbf

Calculations of measuring coefficient of friction between wheels and cube and selecting optimal cylinder for gripping the cube

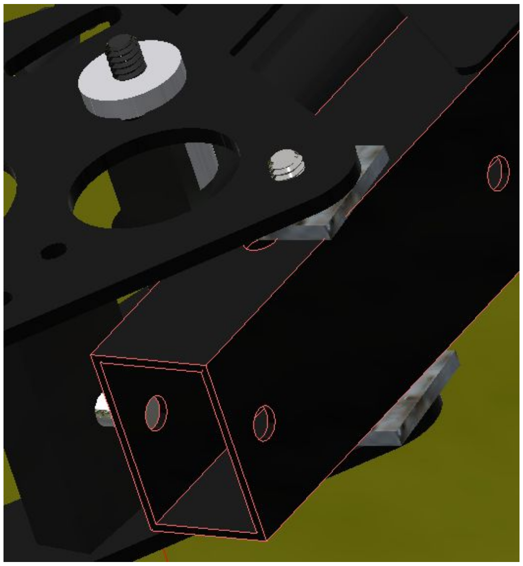
The next challenge was holding the cube securely as the robot traverses the field. We chose to use the 4” diameter extra compliant wheels from AndyMark to collect and deploy the cubes, as the compliance helped secure the cube. In addition, we measured the coefficient of friction between the wheels and the cube, with the result being very high (close to 1). However, the springs on the collector were not enough to securely hold the cube, so we added a pneumatic clamping cylinder that would actuate when the cube has been collected.

Friction Damping

Friction damper			
dia	1	in	
hole dia	0.25	in^2	
Area			
area outside	0.79	in^2	
area hole	0.049	in^2	
area	0.736	in^2	
max pressure	200	psi	
Force	147.26	lb	
rotational friction			
Torque (using pressure)	51.54	in-lb	
Torque (using force)	51.54	in-lb	1



$$A = \pi\left(r_2^2 - r_1^2\right)$$
$$P = F / A$$
$$dF = P\,2\pi r dr$$
$$dT = r \times dF$$
$$T = \int_{r_1}^{r_2} P 2\pi r^2\,dr$$
$$= P2\pi \left.\frac{r^3}{3}\right|_{r_1}^{r_2}$$
$$= \frac{2\pi P}{3}\left(r_2^3 - r_1^3\right)$$
$$= \frac{2}{3}\frac{\pi F}{\pi\left(r_2^2 - r_1^2\right)}\left(r_2^3 - r_1^3\right)$$
$$= \frac{2}{3}F\frac{r_2^3 - r_1^3}{r_2^2 - r_1^2}$$
$$= \frac{2}{3}F\frac{r_2^2 + r_2 r_1 + r_1^2}{r_2 + r_1}$$



Calculations of friction damping material and frictional torque it would provide with a spring washer

To further improve the intake ability of our cube manipulator, we purchased friction material and used spring washers to add damping to the manipulator arms. During our testing the arms would whack around, so by adding friction the arms could better grab and secure the cube. This is one of the first times we explored adding damping to a joint, with the spring washers allowing for easy adjustment. The calculations from the previous page measure the friction force/torque that a tightened-down spring washer can provide.

Lift

Andrew Ng (Junior),

With Jing-Chen Peng (Senior), Arthur Zhang (Senior), Jonathan Huang (Freshman)

Our robot uses a linear lift and pivoting arm to raise the cube.

Design Requirements:

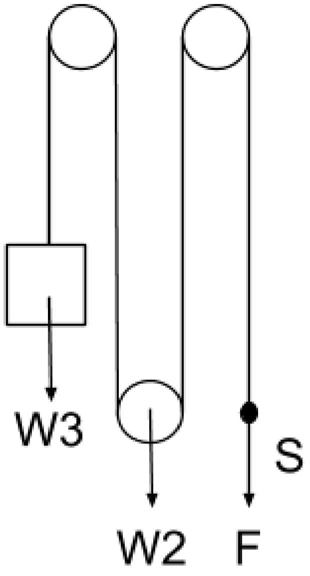
1. Raise cube to height of scale at any position in 2 seconds
    a. on top of one layer of cubes in the high position of the scale
2. Move cube to height of switch or exchange in 1 second

Lift Elevator

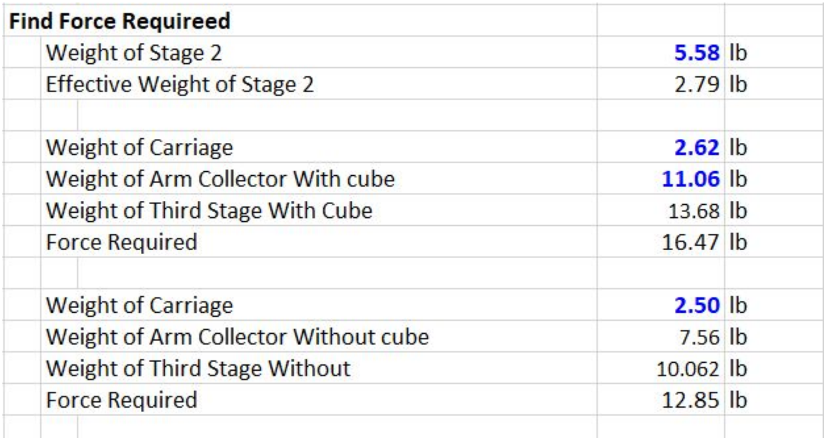
In order to raise the cube intake high enough to reach the scale, we designed a cascading lift with seven feet of travel.

Counterbalancing

In order to move the lift up and down quickly, we used a custom Neg'ator spring motor to balance the weight of the lift. Since we directly attach to the carriage, we need a spring motor that only pulls with half the weight of the second stage plus the weight of the carriage assembly.

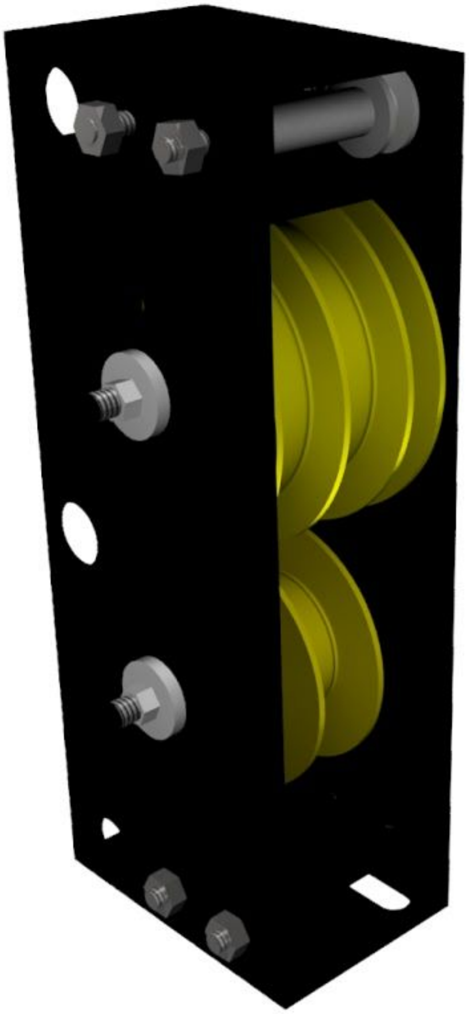


$$
\begin{gathered}
Fs = U_2 + U_3 \\
Fs = W_2 h_2 + W_3 h_3 \\
s = 2h_2 \\
h_3 = 2h_2 \\
F(2h_2) = W_2 h_2 + W_3 (2h_2) \\
F = \frac{W_2}{2} + W_3
\end{gathered}
$$



Find Force Requireed		
Weight of Stage 2	**5.58**	lb
Effective Weight of Stage 2	2.79	lb
Weight of Carriage	**2.62**	lb
Weight of Arm Collector With cube	**11.06**	lb
Weight of Third Stage With Cube	13.68	lb
Force Required	16.47	lb
Weight of Carriage	**2.50**	lb
Weight of Arm Collector Without cube	7.56	lb
Weight of Third Stage Without	10.062	lb
Force Required	12.85	lb

We calculated how much force we needed to perfectly counterbalance the lift



Our Custom Neg’ator spring motor

This year, we decided to create our machine our own Neg'ator spring motor, which saves us weight and offers more adjustability. We 3D printed custom ABS spools to wind two constant torque springs on. By adjusting the radius of the spool that the counterbalancing cable winds on, we can tune the motor to provide the exact amount of force needed to counterbalance the lift.

Lift Carriage

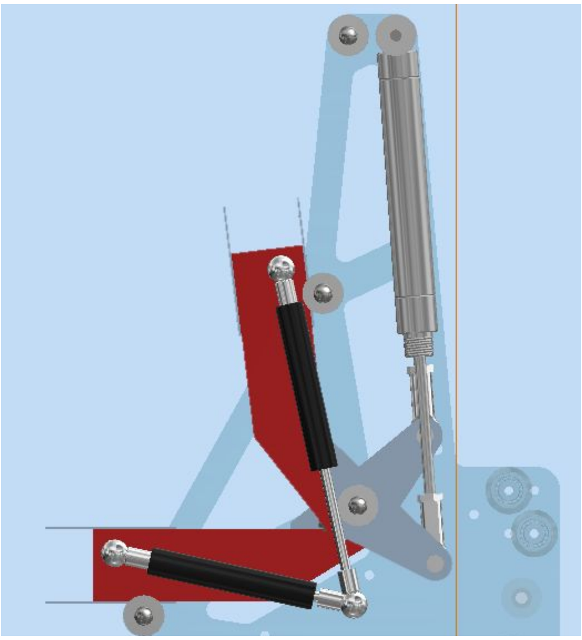
Our lift carriage slides up and down the elevator and mounts the cube manipulator. In addition, it pivots to raise and lower our collector, providing us with additional vertical travel and helping us collect and place cubes.

Lifting the arm

When designing our carriage, we decided that we would only need two positions: straight up, in the robot's starting configuration, and straight sideways, for collecting and deploying the cube. Because of this, we chose to use pneumatic cylinders to raise and lower the arm, saving weight and reducing the complexity of both the mechanical system and the software required to control it.

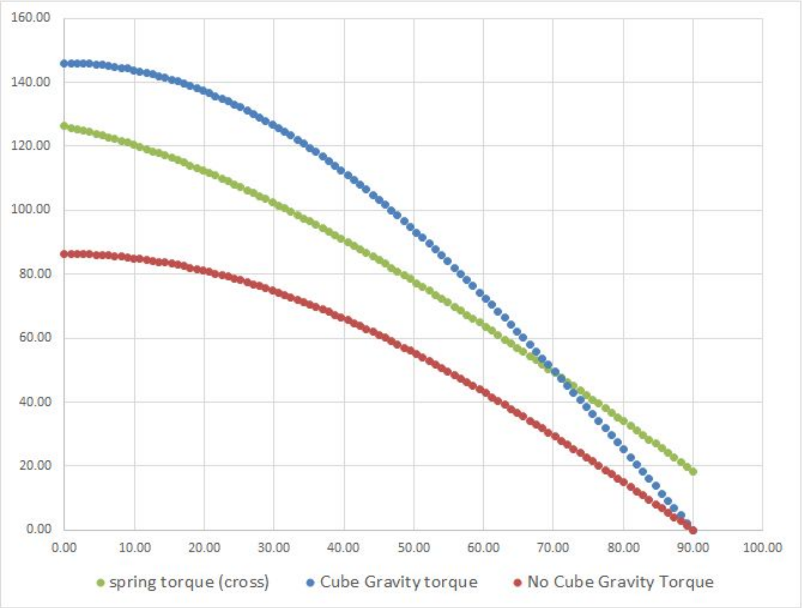
Counterbalancing

Since we have to lift the collector and the cube on a long lever arm, we decided to counterbalance the carriage arm. Gas springs provided us with a compact, simple solution to this problem.



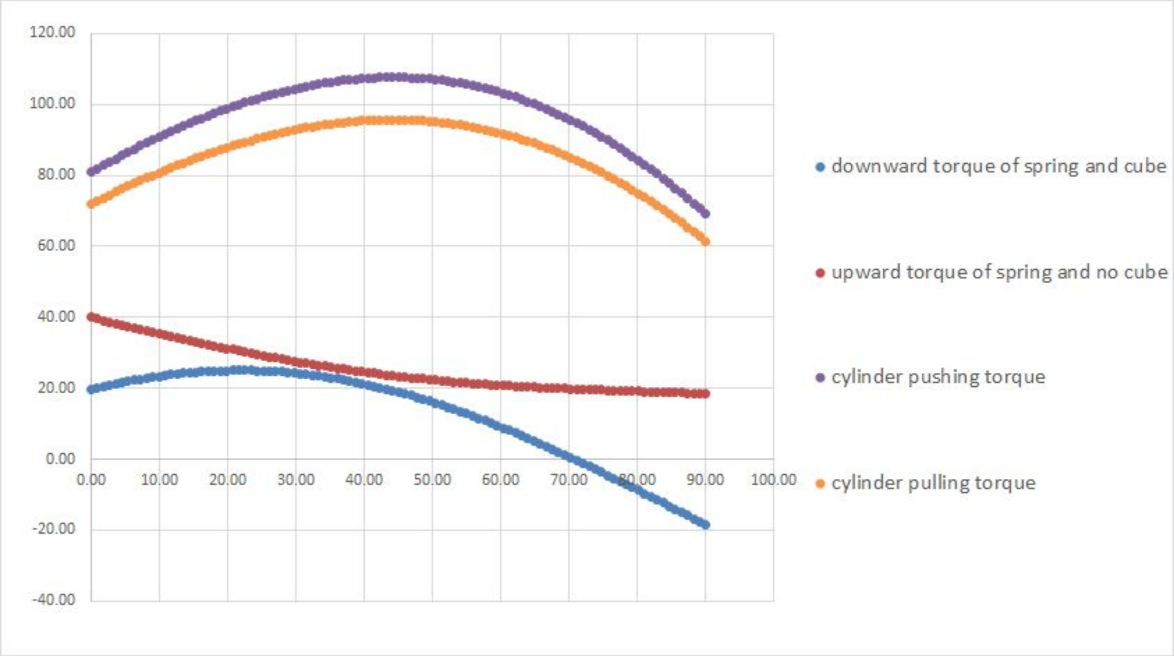
A pair of gas springs counteracts the torque due to gravity.
Air cylinders work to move the arm up and down.

Our goal was to have the gas spring counteract the torque from gravity, so that the air cylinder would not have to do the work of lifting the arm itself, only providing force to hold the arm in the up or down positions.



Torque of counterbalance (green), compared to the load and with respect to angle. The cube changes the load on the end of the arm significantly, accounting for a third of the loaded arm's effective weight. We chose a cylinder so that the arm with a cube (blue line) is underbalanced, and tends to fall, while the arm without a cube (red line) is overbalanced, and tends to rise.

Our arm can't be balanced perfectly because the weight of the cube changes the amount of torque we have to balance by a significant amount. We chose a cylinder arrangement that produced torque somewhere between that required to balance an empty arm and that required for a cube-loaded arm, minimizing the amount of additional torque our pneumatics had to provide.

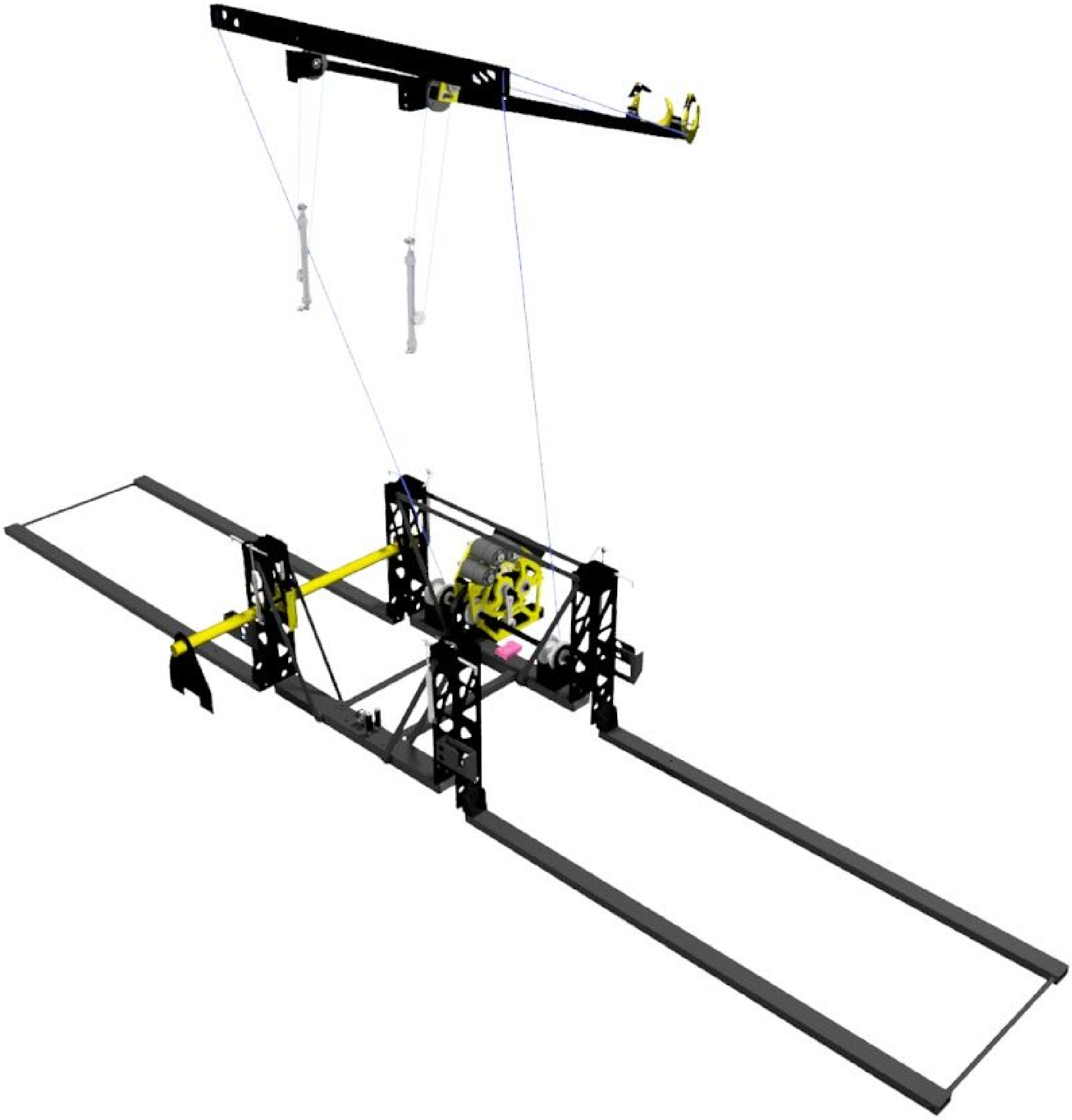


Torque from pneumatic cylinders, compared to load after counterbalancing.

Because our pneumatic cylinders did not have to do as much work lifting our cube manipulator, we were able to use relatively small cylinders to move the arm up and down. We chose for the cylinders to provide similar force on both the top and bottom of travel

Climber

Arthur Zhang (Senior), Garrett Peake (Junior), Sam Pickholtz (Freshman)

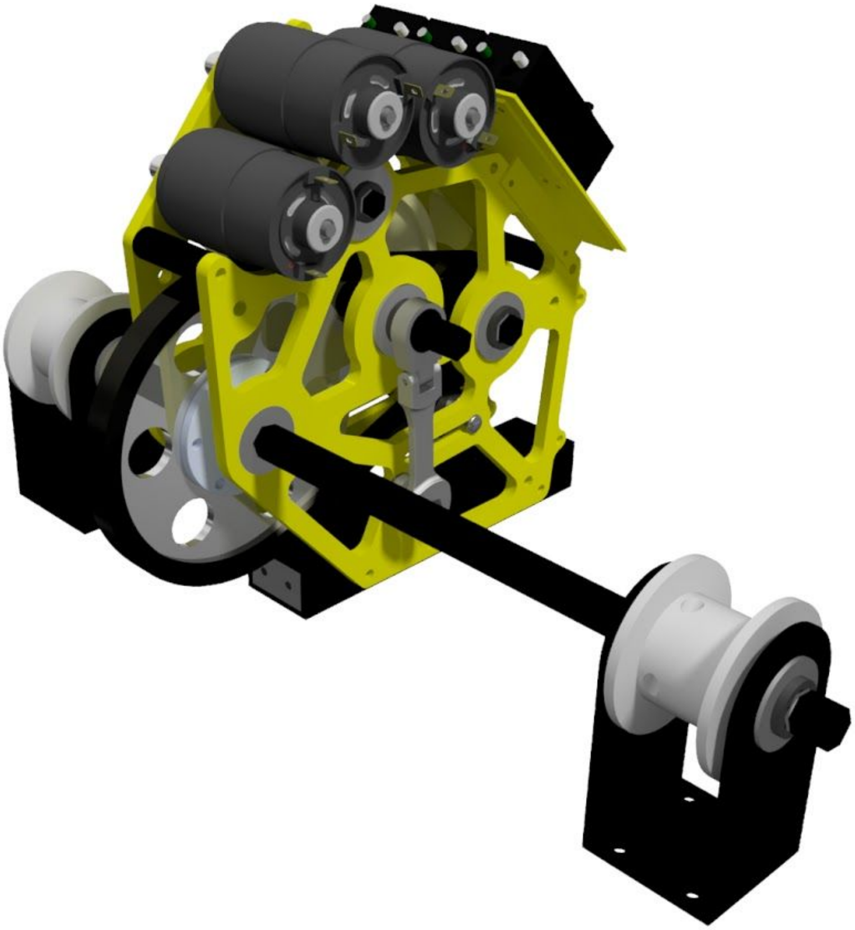


The climber is a highly adjustable system capable of lifting three robots within five seconds or climbing one robot in under one second. It is comprised of three distinct mechanical assemblies: the gearbox, swing arm, and lifting forks.

Overall Design Requirements:

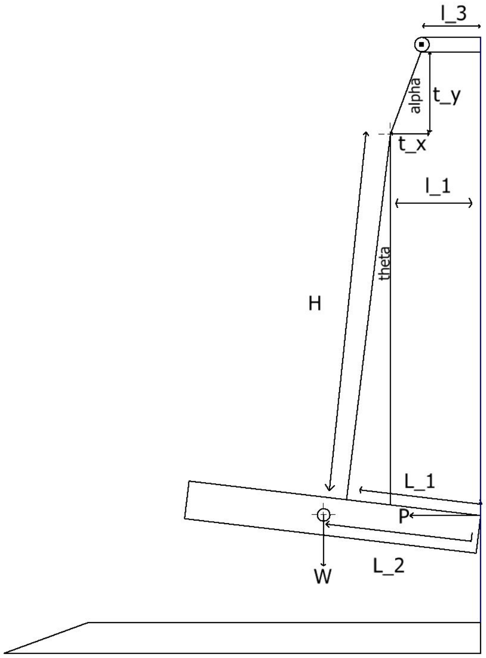
1. Be able to assist or directly lift three robot
2. Finish robot alignment and climb within ten seconds
3. Allow wide margin of error for alignment and hook deployment

Gearbox/Winch System



Robot Tilt Calculations

We calculated how much the robot would tilt in three dimensions before we decided to do a three robot climb. Assuming we were lifting three robots, we determined that if the center of mass remains between our two lifting hooks, our robot would stay level. Furthermore, we simulated all possible weight distribution scenarios and determined that we could tolerate up to a 50 lb weight difference between two alliance robots before tipping.



System of equations for calculating optimal eyehook position

$$F(\theta) = W\,L_2 - T_y\left(L_1 - Ht_y\right) - T_x(H + L_1\tan(\theta))$$

$$T_y = W + \mu T_x$$

$$T_x = \frac{\mathrm{W}\tan(\alpha)}{1 - \mu\tan(\alpha)}$$

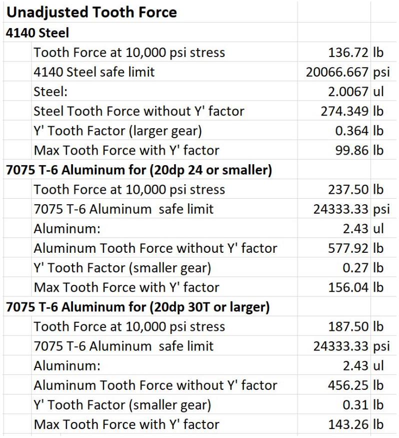
$$\tan(\alpha) = l_1 - L_3$$

$$l_1 = (L_1 - H\tan(\theta)) \times \cos(\theta)$$

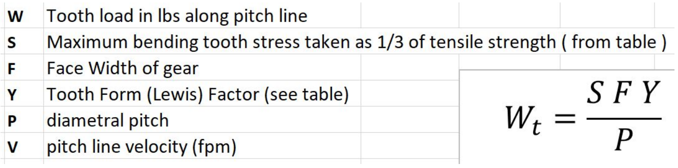
Force diagram and system of equations we used to calculate the optimal eyehook location

Next, we determined through calculations and prototyping that if we routed the climbing ropes through an eye hook, we could reduce the amount our robot tilts forward or backwards while climbing. To evaluate the eye hook mount location, we solved a system of equations to balance the torque of the system. This gave us range of angles our robot tilts at various eye hook locations and demonstrated the optimal eye hook location is 53 inches from the ground.

Material Strength Calculations



Unadjusted Tooth Force		
4140 Steel		
Tooth Force at 10,000 psi stress	136.72	lb
4140 Steel safe limit	20066.667	psi
Steel:	2.0067	ul
Steel Tooth Force without Y' factor	274.349	lb
Y' Tooth Factor (larger gear)	0.364	lb
Max Tooth Force with Y' factor	99.86	lb
7075 T-6 Aluminum for (20dp 24 or smaller)		
Tooth Force at 10,000 psi stress	237.50	lb
7075 T-6 Aluminum safe limit	24333.33	psi
Aluminum:	2.43	ul
Aluminum Tooth Force without Y' factor	577.92	lb
Y' Tooth Factor (smaller gear)	0.27	lb
Max Tooth Force with Y' factor	156.04	lb
7075 T-6 Aluminum for (20dp 30T or larger)		
Tooth Force at 10,000 psi stress	187.50	lb
7075 T-6 Aluminum safe limit	24333.33	psi
Aluminum:	2.43	ul
Aluminum Tooth Force without Y' factor	456.25	lb
Y' Tooth Factor (smaller gear)	0.31	lb
Max Tooth Force with Y' factor	143.26	lb

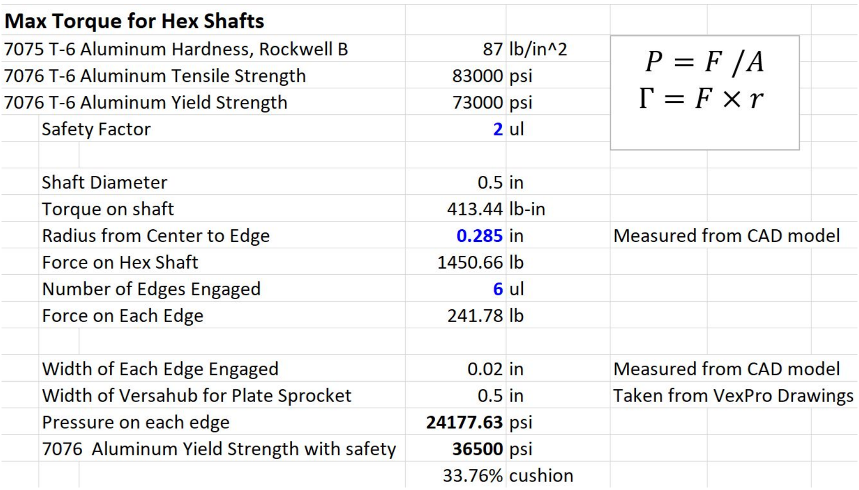


W	Tooth load in lbs along pitch line
S	Maximum bending tooth stress taken as 1/3 of tensile strength (from table)
F	Face Width of gear
Y	Tooth Form (Lewis) Factor (see table)
P	diametral pitch
V	pitch line velocity (fpm)

$$W_t = \frac{S\ F\ Y}{P}$$

Equation for determining the max force our gears' teeth can withstand (Reference: http://www.bostongear.com/products/open/theory.html)

Using Y’ tooth form factor and gear dimensions, we found the max allowable force of each gear we planned on using. We found that while the force each gear experiences on the first three stages of our gearbox was tolerable, the force on the output stage of the gearbox could break teeth on our gears. Therefore, we decided to use #35 chain on the output stage instead for its strength.



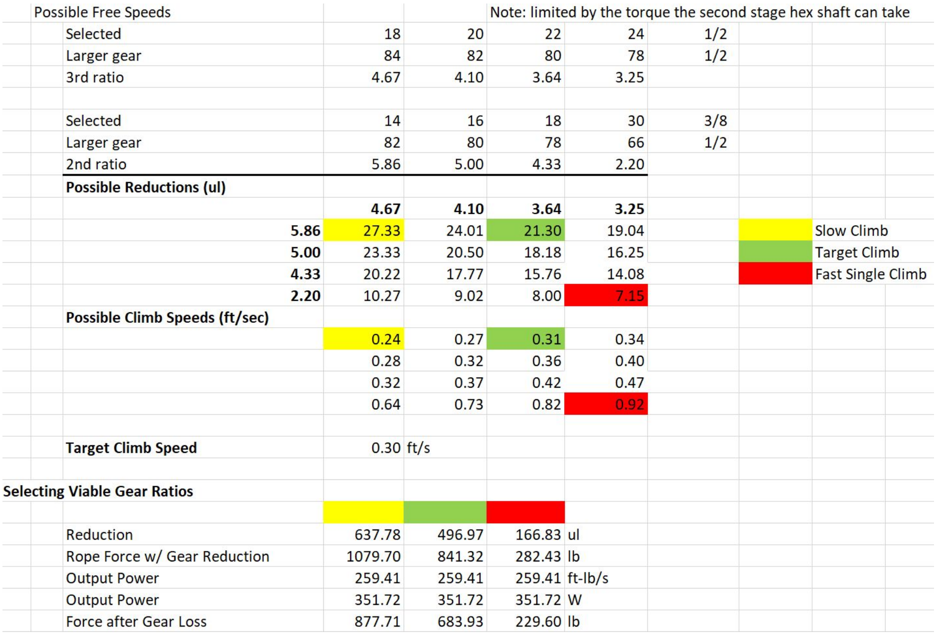
Max Torque for Hex Shafts			
7075 T-6 Aluminum Hardness, Rockwell B	87	lb/in^2	
7076 T-6 Aluminum Tensile Strength	83000	psi	
7076 T-6 Aluminum Yield Strength	73000	psi	
Safety Factor	**2**	ul	
Shaft Diameter	0.5	in	
Torque on shaft	413.44	lb-in	
Radius from Center to Edge	**0.285**	in	Measured from CAD model
Force on Hex Shaft	1450.66	lb	
Number of Edges Engaged	**6**	ul	
Force on Each Edge	241.78	lb	
Width of Each Edge Engaged	0.02	in	Measured from CAD model
Width of Versahub for Plate Sprocket	0.5	in	Taken from VexPro Drawings
Pressure on each edge	**24177.63**	psi	
7076 Aluminum Yield Strength with safety	**36500**	psi	
	33.76%	cushion	

$$P = F / A$$
$$\Gamma = F \times r$$

Calculations for making sure we don’t risk stripping the hex shafts used on the climber gearbox

We also wanted to make sure we weren’t at risk of stripping our hex shafts, so we calculated the maximum torque each shaft would experience and the max torque each hex shaft would allow.

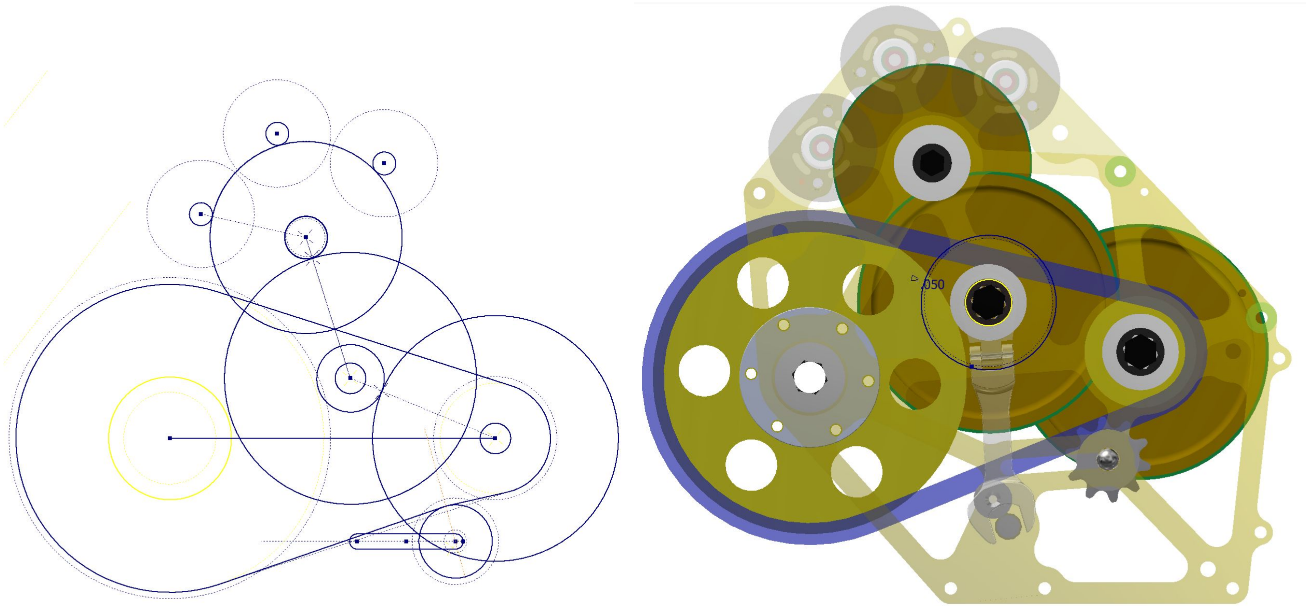
Gearbox Calculations



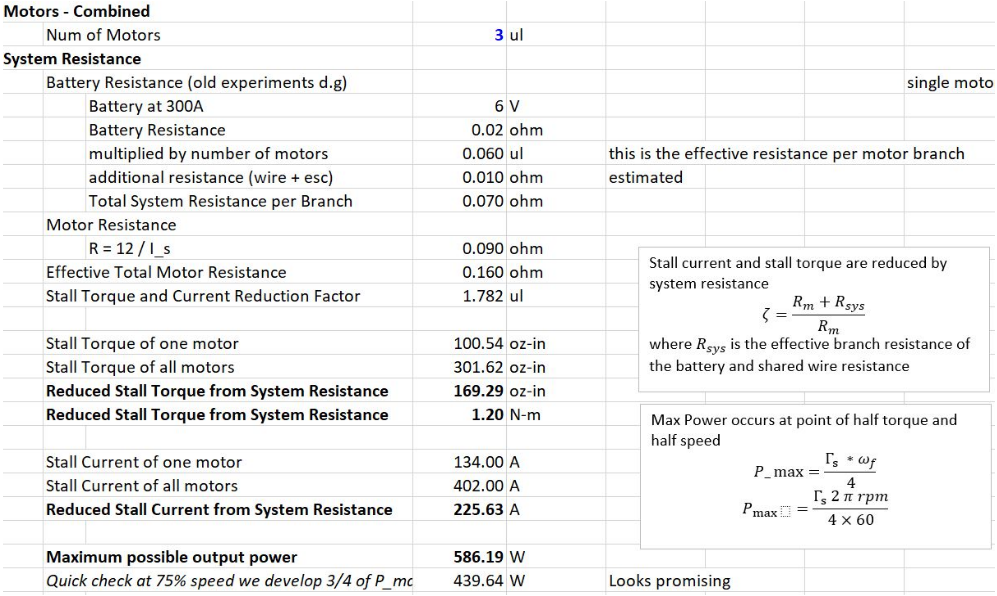
Possible Free Speeds			Note: limited by the torque the second stage hex shaft can take				
Selected	18	20	22	24	1/2		
Larger gear	84	82	80	78	1/2		
3rd ratio	4.67	4.10	3.64	3.25			
Selected	14	16	18	30	3/8		
Larger gear	82	80	78	66	1/2		
2nd ratio	5.86	5.00	4.33	2.20			
Possible Reductions (ul)							
	4.67	**4.10**	**3.64**	**3.25**			
5.86	27.33	24.01	21.30	19.04		🟨	Slow Climb
5.00	23.33	20.50	18.18	16.25		🟩	Target Climb
4.33	20.22	17.77	15.76	14.08		🟥	Fast Single Climb
2.20	10.27	9.02	8.00	7.15			
Possible Climb Speeds (ft/sec)							
	0.24	0.27	0.31	0.34			
	0.28	0.32	0.36	0.40			
	0.32	0.37	0.42	0.47			
	0.64	0.73	0.82	0.92			
Target Climb Speed	0.30	ft/s					
Selecting Viable Gear Ratios							
	🟨	🟩	🟥				
Reduction	637.78	496.97	166.83	ul			
Rope Force w/ Gear Reduction	1079.70	841.32	282.43	lb			
Output Power	259.41	259.41	259.41	ft-lb/s			
Output Power	351.72	351.72	351.72	W			
Force after Gear Loss	877.71	683.93	229.60	lb			

The gearbox's design lets us adjust the gears used to best fit the force needed

We designed the gearbox to be highly adjustable, allowing us to switch the gear reduction of the gearbox from 640:1, producing 878 lbs of force, to 167:1, producing 230 lbs of force. This allows us to optimize the climb time before matches depending on the weight we need to lift each match.



We used CAD to design the gearbox as compactly as possible and check for interferences.



Motors - Combined			
Num of Motors	3	ul	
System Resistance			
Battery Resistance (old experiments d.g)			single moto
Battery at 300A	6	V	
Battery Resistance	0.02	ohm	
multiplied by number of motors	0.060	ul	this is the effective resistance per motor branch
additional resistance (wire + esc)	0.010	ohm	estimated
Total System Resistance per Branch	0.070	ohm	
Motor Resistance			
R = 12 / I_s	0.090	ohm	
Effective Total Motor Resistance	0.160	ohm	
Stall Torque and Current Reduction Factor	1.782	ul	
Stall Torque of one motor	100.54	oz-in	
Stall Torque of all motors	301.62	oz-in	
Reduced Stall Torque from System Resistance	**169.29**	oz-in	
Reduced Stall Torque from System Resistance	**1.20**	N-m	
Stall Current of one motor	134.00	A	
Stall Current of all motors	402.00	A	
Reduced Stall Current from System Resistance	**225.63**	A	
Maximum possible output power	**586.19**	W	
Quick check at 75% speed we develop 3/4 of P_mc	439.64	W	Looks promising

Stall current and stall torque are reduced by system resistance

$$\zeta = \frac{R_m + R_{sys}}{R_m}$$

where R_{sys} is the effective branch resistance of the battery and shared wire resistance

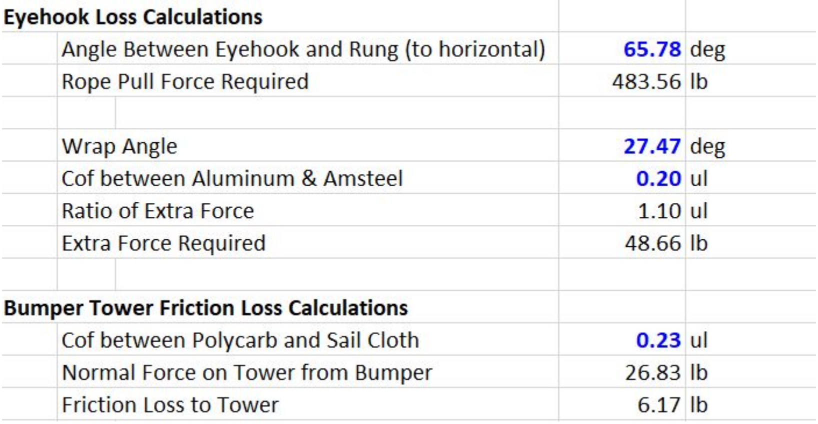
Max Power occurs at point of half torque and half speed

$$P\_\max = \frac{\Gamma_s \ * \omega_f}{4}$$

$$P_{\max} = \frac{\Gamma_s \, 2\,\pi\, rpm}{4 \times 60}$$

We accounted for the system resistance on each 775pro motor, which actually significantly impacted each motor's operating efficiency.

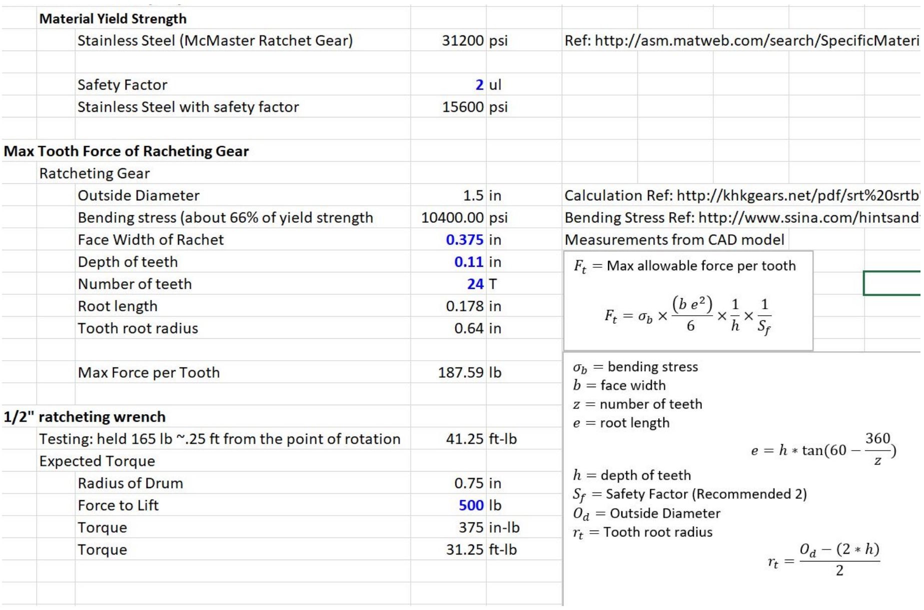
In addition, we felt it was important to consider the system resistance, which significantly reduces the maximum stall torque and current of our 775pro motors. By considering these factors, we can more accurately determine if our maximum power output is enough to meet our lifting requirements.



Eyehook Loss Calculations		
Angle Between Eyehook and Rung (to horizontal)	65.78	deg
Rope Pull Force Required	483.56	lb
Wrap Angle	27.47	deg
Cof between Aluminum & Amsteel	0.20	ul
Ratio of Extra Force	1.10	ul
Extra Force Required	48.66	lb
Bumper Tower Friction Loss Calculations		
Cof between Polycarb and Sail Cloth	0.23	ul
Normal Force on Tower from Bumper	26.83	lb
Friction Loss to Tower	6.17	lb

Using the capstan equation, we found exactly how much extra force we needed.

To calculate how much force we needed to lift three robots, we determined the force loss to the eye hook using the capstan equation, friction loss from our bumpers against the tower, and force loss due to the angle we pulling from. Combining these factors, we calculated that the maximum force our gearbox should be capable of pulling with is 550 lbs.



Material Yield Strength			
Stainless Steel (McMaster Ratchet Gear)	31200	psi	Ref: http://asm.matweb.com/search/SpecificMateri
Safety Factor	**2**	ul	
Stainless Steel with safety factor	15600	psi	
Max Tooth Force of Racheting Gear			
Ratcheting Gear			
Outside Diameter	1.5	in	Calculation Ref: http://khkgears.net/pdf/srt%20srtb
Bending stress (about 66% of yield strength	10400.00	psi	Bending Stress Ref: http://www.ssina.com/hintsand
Face Width of Rachet	**0.375**	in	Measurements from CAD model
Depth of teeth	**0.11**	in	
Number of teeth	**24**	T	
Root length	0.178	in	
Tooth root radius	0.64	in	
Max Force per Tooth	187.59	lb	
1/2" ratcheting wrench			
Testing: held 165 lb ~.25 ft from the point of rotation	41.25	ft-lb	
Expected Torque			
Radius of Drum	0.75	in	
Force to Lift	**500**	lb	
Torque	375	in-lb	
Torque	31.25	ft-lb	

F_t = Max allowable force per tooth

$$F_t = \sigma_b \times \frac{(b\,e^2)}{6} \times \frac{1}{h} \times \frac{1}{S_f}$$

σ_b = bending stress
b = face width
z = number of teeth
e = root length

$$e = h * \tan(60 - \frac{360}{z})$$

h = depth of teeth
S_f = Safety Factor (Recommended 2)
O_d = Outside Diameter
r_t = Tooth root radius

$$r_t = \frac{O_d - (2 * h)}{2}$$

We calculated how much force a pawl could withstand before breaking and compared it to a ½” ratcheting wrench.

To keep our robot from falling down after climbing, we used a ratcheting wrench. We decided on this solution by calculating the max force a ratcheting wrench or ratchet and pawl mechanism could take before breaking. From this, we found that a ½” ratcheting wrench was much stronger than needed while a single ratchet and pawl would likely break if it supported the weight of three robots.

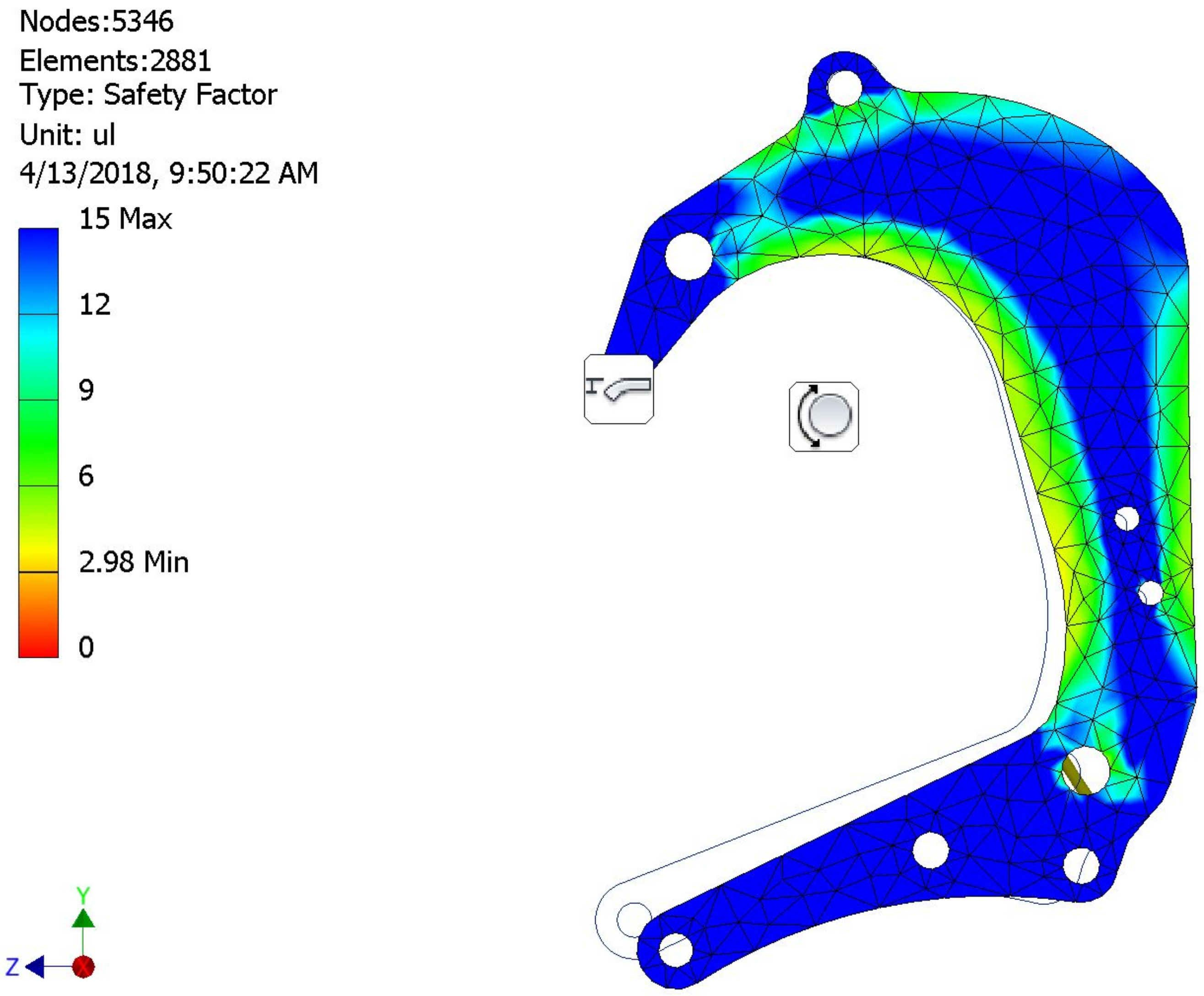
Swing Arm Hook Deployment System

Overall Design Requirements:

1. Be capable of deploying hooks in under two seconds
2. Give drivers a large margin of error for aligning

We designed a swing arm connected to the lift that deploys hooks for climbing. The final iteration of the design consists of counterbalancing the arm over it’s 180 degree motion while powering it with a pneumatic attached to a pulley.

The counterbalancing of the arm consists of calculating the torque of the arms at a specific location and then stretching a piece of surgical tubing to act as a spring to counterbalance the arm. When done perfectly the surgical tubing will nullify the torque of the arm at all positions as well as reduce power requirements to lift the arm.

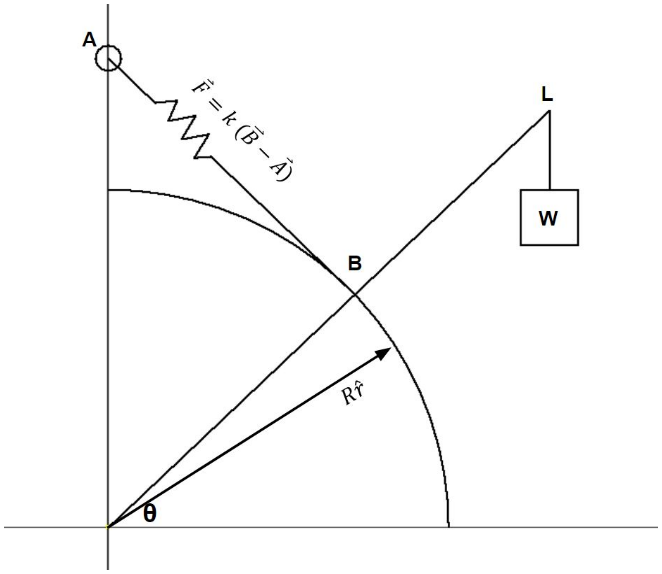


We used FEA stress analysis to optimize the hook's design.

There are two important aspects for our hook design: the load the hook can withstand when climbing and the ability of the hook to stay on the bar. Using Inventor's stress analysis feature, we optimised the hook design to withstand 700-800 lbf of load. Given that three robots total weigh around 450 pounds and with two hooks that force will be split in half, each hook has to withstand at least 225 lb of load. To ensure the hook stays on the bar, we designed a one way gate latch mechanism that allows the rung to enter the hook and act as a hardstop to keep the hook from coming off the bar. Using 3D printing prototype hooks, we were able to optimize the effectiveness of this mechanism.

Perfect Spring Balancing for Gravity Arm

Equation for calculating required spring constant K given the spring attachment point on arm of B, with center of gravity of that arm at L and another spring attachment point at A. The equation assumes a perfect spring that has zero force at zero distance. Since this is impossible, the work around is placing a pulley at A and having the spring above and then connect to a rope that routes through A to B.



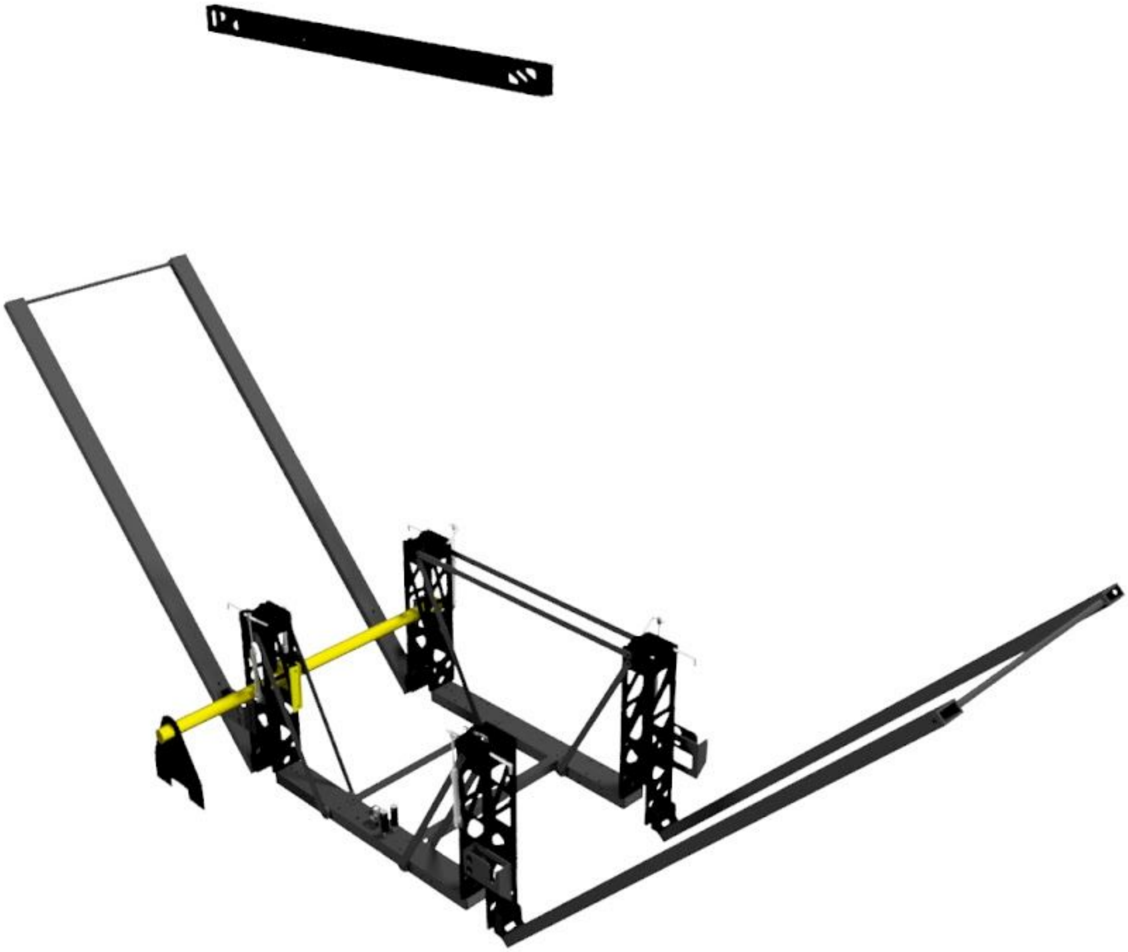
$$\vec{A} = H\hat{y}$$
$$\vec{B} = \mathrm{R}\hat{r}$$
$$T_L = L\hat{r} \text{ x } \mathrm{W}\hat{y}$$
$$= LW\ (\hat{r}\ x\ \hat{y})$$
$$= LW \sin\theta$$
$$F_S = k\ (\vec{B}\ -\ \vec{A})$$
$$T_S = R\hat{r}\ x\ k(\vec{B}\ -\ \vec{A})$$
$$= RK\ \hat{r}\ (R\hat{r}\ - H\hat{y})$$
$$= -RKH\ (\hat{r} \text{ x } \hat{y})$$
$$= -RKH \sin\theta$$

When Force of Spring equals torque of arm:

$$RKH = LW$$
$$HK = \frac{L}{R}W$$

Thus, the weight is perfectly balanced at all angles from -90° to +90°, provided HK = W ✕ L/R!

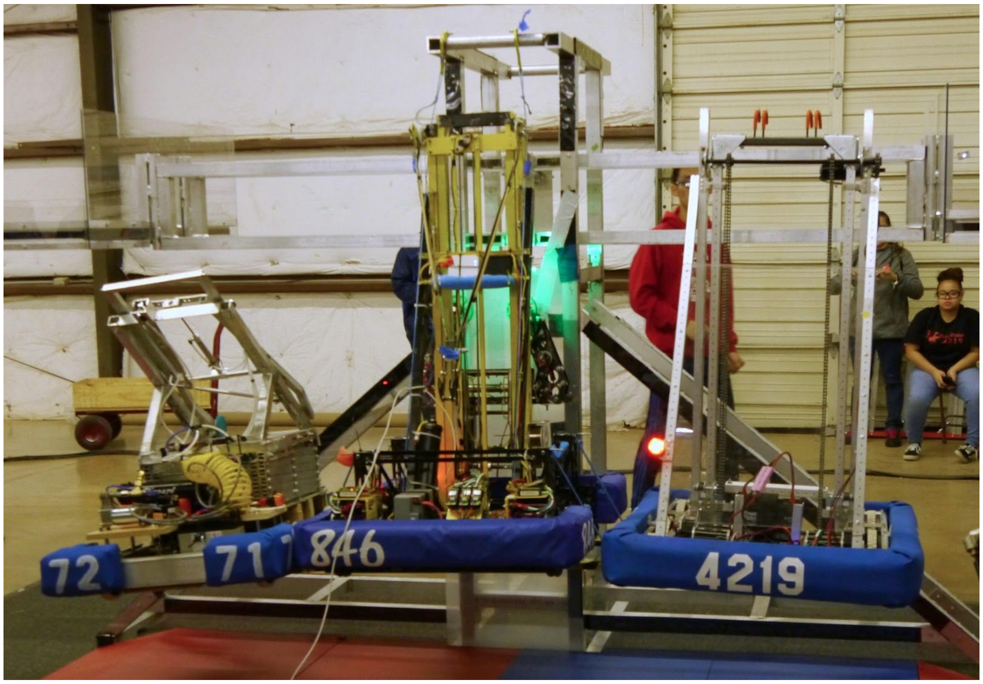
Fork System



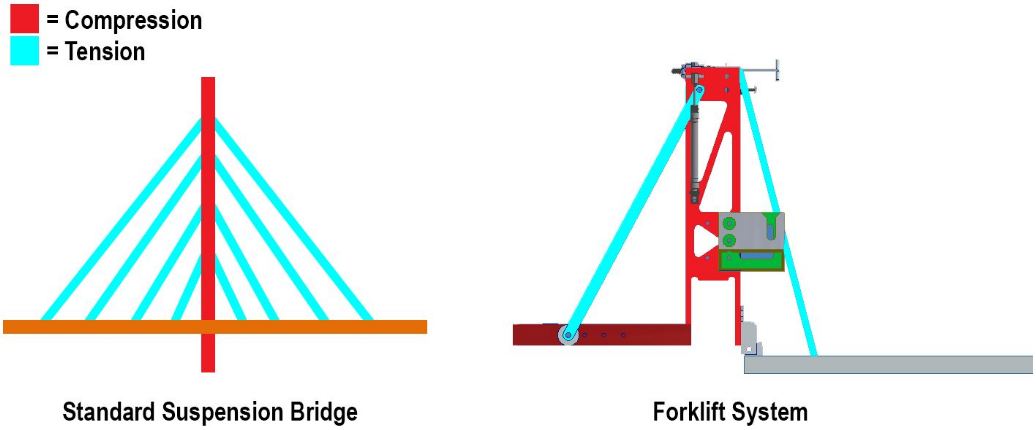
Overall Design Requirements:

1. Be capable of tolerating forces of a levered robot while retaining a good safety margin
2. Be capable of starting in a compact state and being quickly deployable
3. Fit within leftover space and weight from other systems
4. Retain forks in the case of power or pressure loss

After determining that a three-robot lift was possible, we looked at different methods to accomplish this. We decided on a forklift design and explored the common method of a single folding fork assembly braced by the drivetrain and a suspension bridge design. We found that a suspension bridge type design would allow a lower weight requirement while taking up less lateral volume on the robot.



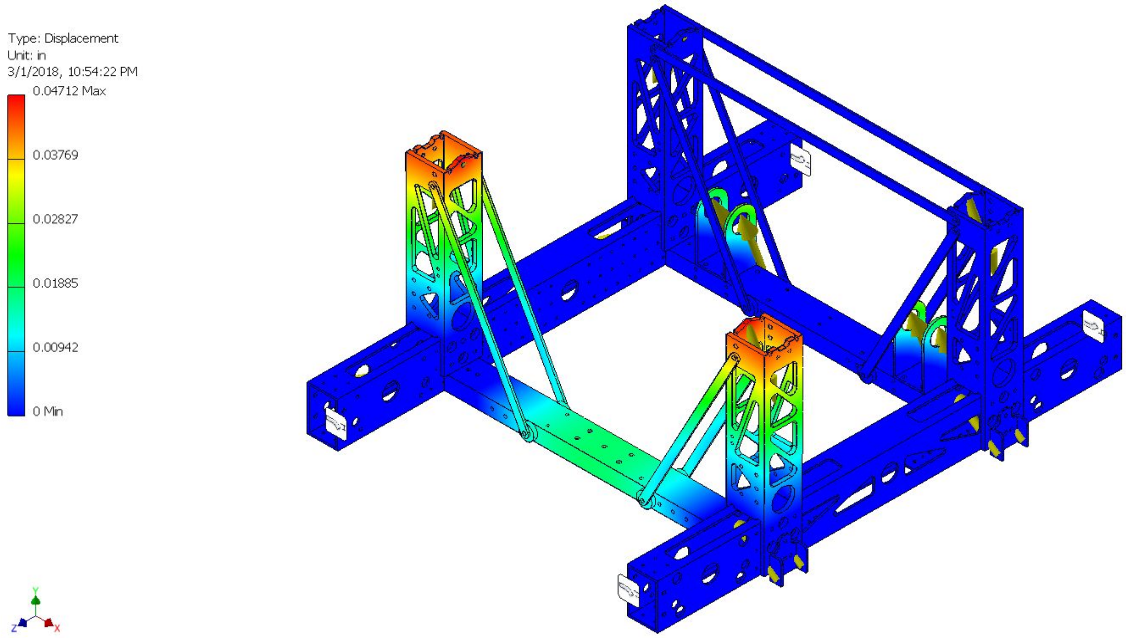
Real life lifting versus controlled force analysis



Comparison between our forks and a suspension bridge

Material Strength Calculation

The materials required to withstand the forces on this system needed to be very rigid with a high modulus of elasticity. After considering different metal options, we chose to use 6061 alloy aluminum for its superior strength and relatively low cost. Simulations showed a much more favorable safety margin of 1.75 and in real life testing, our forks survived a load of more than double the expected worst-case load.



Using stress analysis to check the design

The material for the attachment from the fork to the tower was also of major concern. For each material, we had to consider strength, stretch, weight, compactness, shape memory. The options we considered were high strength rope, steel cable, roller chain, and linked metal plates. Rope seemed the most suitable for our needs due its high strength and compactness along with low stretch, weight, and shape memory. After looking at different ropes, we decided to use ⅛” diameter Amsteel-Blue rope, with a yield strength of 2500 lbs and low stretch factor.

Testing

Before assembling the final forks, we tested each component of the subsystem to make sure it stood up to the loads involved. The first tests began with the bolts we would use to attach the ropes to the towers. After assembling a large lever, we used a luggage scale and human strength to gain an accurate measurement of the yield strength of the bolts. The ¼” bolts would tend to break apart at 1300-1500 lbs, more than strong enough for our design.

We next tested different methods of terminating the rope. Our options were knotting, capturing, and splicing. After exploring different types of knots, the stretch of each knot and the inconsistency with which they were able to be tied ruled out that option. A mentor with a background in sailing recommended splicing the rope and provided the tools required to do so. After much trial and error we were able to achieve a consistent splice with predictable elongation.

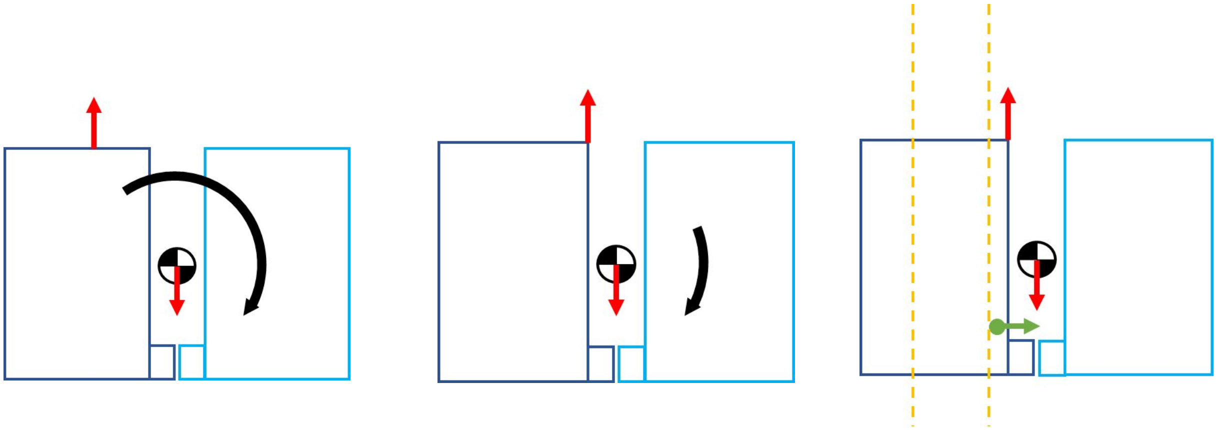
Garrett Peake (Junior) measures how much force the forks can take

In order to account for the most rigorous scenarios on our robot, we assumed each ally would weigh 150 lbs and be as far outwards while sitting on the forks as possible. A bend test on 6063 aluminum stock showed us the necessity for a material upgrade; after testing 6061 aluminum we determined that 6061 alloy would be more than substantial for our purposes. We applied double the expected load to the system and, with some deflection, the material withstood the force and returned to its original shape without fail.

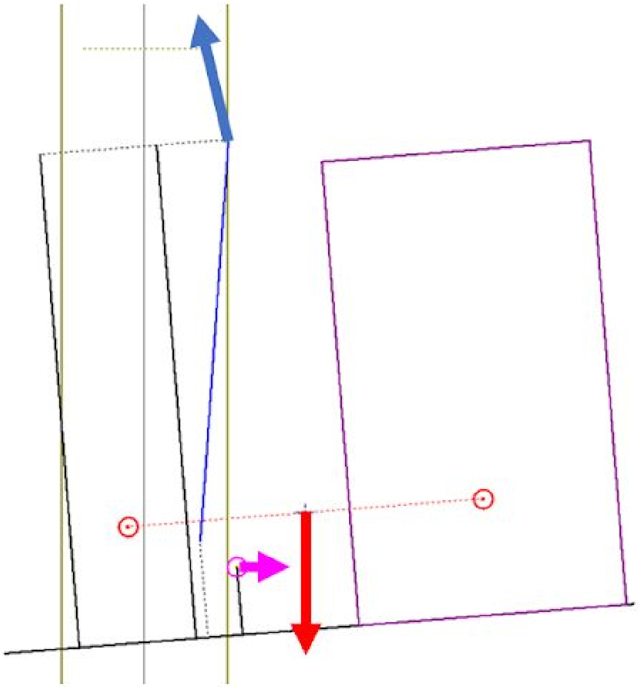
Two-robot climb redesign

"Wes" lifts a retired robot, with weights added to make it 145 pounds.

We decided that being able to “buddy climb”, lifting one other robot, is an important functionality. To accomplish this, we moved the eyehooks for our climbing ropes as far to the edges of the robot volume as possible. This shifted the pivot point between us and an alliance bot as close to the predicted CG of the system, which reduces the torque imbalance between our two robots. We also designed what we dub “the finger”, which is a spring loaded tube released by a pneumatic cylinder. This butts up against the 2 inch wall protrusion on the side of the tower and keeps our robots level as we climb.



Moving the rope attachment point closer to the edge of the robot reduces tipping torque. The finger (green) braces against the side of the tower, producing a reacting torque to stop us from tipping.



During the design process, we used carefully constrained sketches in Inventor to simulate a side climb and make sure the robots were not tilting too far.

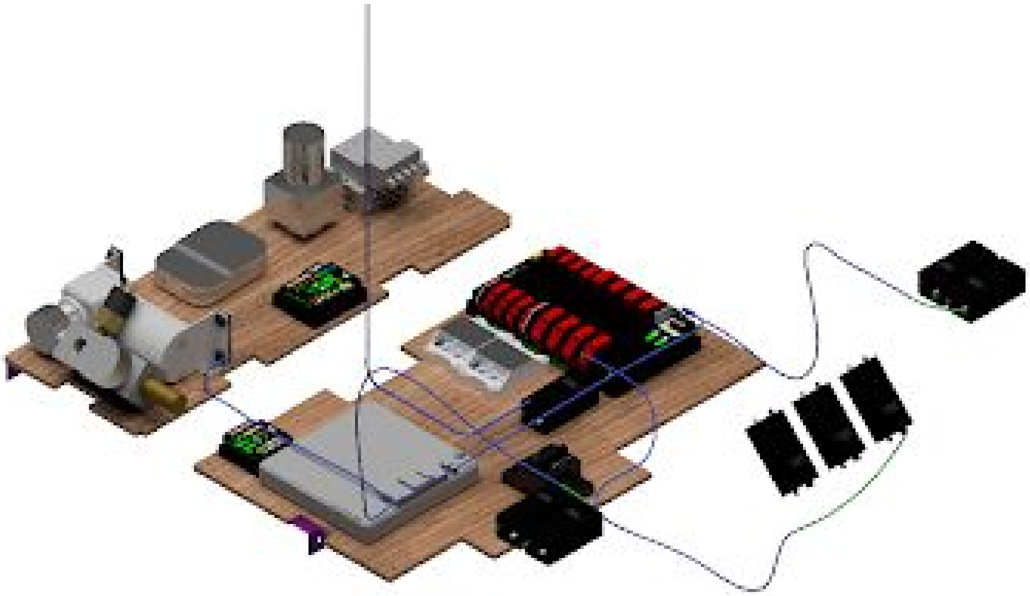
Electrical

Ravi Varma (Senior), Sean Chen (Senior)

With Zachary Wu (Sophomore), Timothy Yang (Senior), Kunal Sheth (Sophomore), Isha Venkatesh (Freshman)

Planning

As soon as the CAD model for the drivetrain was done, our subsystem started to CAD the baseboard. After making the pieces of the baseboard in Autodesk Inventor to align with the other subsystem, we proceeded with adding wires to our model with the Cables and Harnesses feature in Inventor AutoCAD.



This year we decided to add wires to our CAD model. This not only allowed us to plan out the wiring paths far in advance, but also allowed us to get rough estimates for how long the each wire would have to be.

1	Item	Part Number	BOM Structure	Length	QTY	Description	Percent	With Added	Rounded Up	Plus %
2	1	12AWG-RED/BLK.Left Talons To PDP	Normal	24.621	24.621 in	12AWG-RED/BLK	0.2	29.5452	30	35
3	2	12AWG-RED/BLK.Climber To PDP	Normal	29.623	29.623 in	12AWG-RED/BLK	0.2	35.5476	36	41
4	3	12AWG-RED/BLK.Lift To PDP	Normal	33.028	33.028 in	12AWG-RED/BLK	0.2	39.6336	40	45
5	4	.Default Library Splice	Normal	1	1	Default Library Splice	0.2	N/A	N/A	N/A
6	5	12AWG-RED/BLK.Right Talon To PDP	Normal	20.28	20.280 in	12AWG-RED/BLK	0.2	24.336	24.5	29.5
7	6	12AWG-RED/BLK.Pentiometer Talon to PDP	Normal	55.776	55.776 in	12AWG-RED/BLK	0.2	66.9312	67	72

This year, we also planned out our baseboard manufacturing process by printing out paper at 100% size relative to the board and pasting it on the board for increased accuracy. This enabled us to have all our cuts and holes exactly where we wanted them to go. As a result, this year we were able to have all the pieces of the electrical subsystem go directly where we intended them to go, and we were able to put together the electrical subsystem within hours.

Wiring

Using the Bill of Materials from our electrical subsystem model, we knew ahead of time exactly what lengths each wire can be. Before putting together the baseboard, we cut and crimp the wires before putting it together.

After we finished laying the wires out in the Autodesk Inventor as part of the Cables and Harnesses feature, we cut them and put them on the robot as according to the model. This process went smoothly as planned.

CAD in Robot Design

CAD Training for Members

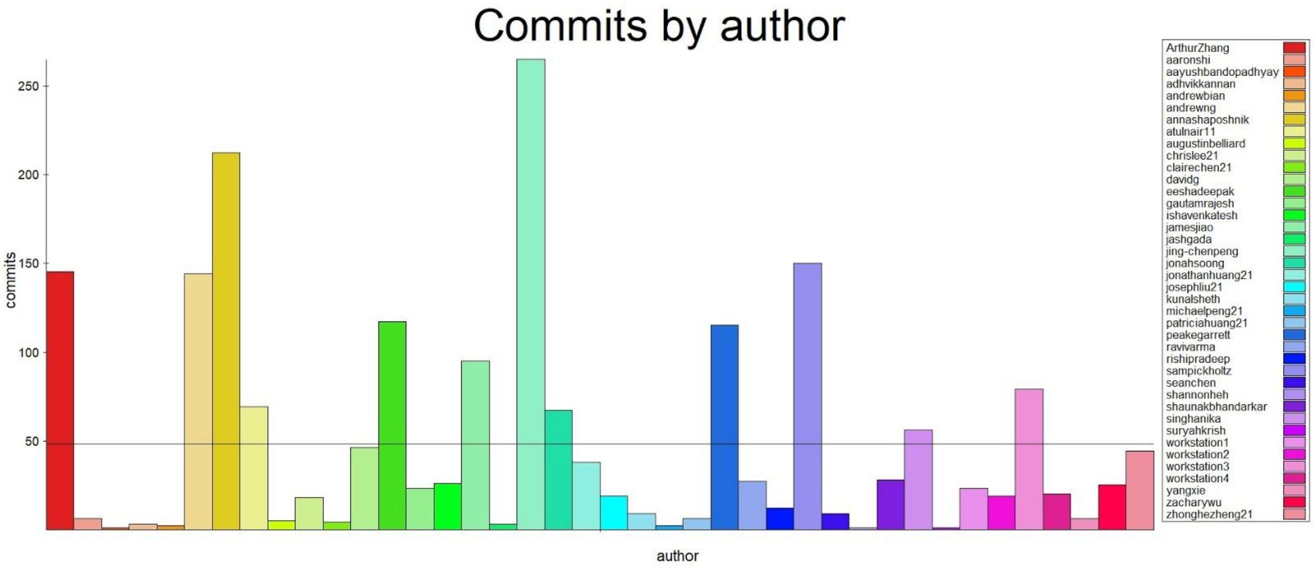
A primary tenet of Lynbrook Robotics is to teach CAD to new members to increase the number of people involved in the robot design process during build season. Over the past several years, we have trained over 50 members each year in using the Autodesk Inventor CAD software. Our training includes both classroom-like instruction through a series of lectures and presentations as well as personalized teaching before and during build season. Students can gain comprehensive knowledge of Autodesk Inventor through individual designs that the students work on and smaller in-class design competitions. The students then use their new CAD skills to contribute during build season. In fact, this year we were even able to get four of our rookie members deeply involved in the complex design work.

Division of Responsibilities and Workload

Lynbrook Robotics uses a “top-down” approach to split up the design workload amongst multiple members. We analyze the necessary functionalities of our robot and then split up the design responsibilities amongst different subsystem leads, who collaborate to put together their CAD assemblies into one final robot model. Through a use of sub-assemblies and modular robot components, we can create a robot model that can be easily modified when necessary. Our robot’s four primary subsystems this year were the drivetrain, lift, cube manipulator, and the climber. Our climber system was further split into three parts: the winch, the hook deployment mechanism, and the forks. All of these subsystems were student-led and student-designed.

File Management and Collaboration through Subversion

Since 2009, Lynbrook Robotics has used the Subversion version control software to manage and share our robot design files among the entire team. Using Subversion, a third of our membership is involved in the robot design, creating CAD models, making drawings for machining, maintaining bills of materials, and recording their design calculations on worksheets. We currently have 1942 revisions to our Subversion repository with contributions from 34 students.



Statistics for repository commits per author.