Cyber Blue – 234 Winch Design 2014

This short paper describes the mechanical design of Cyber Blue's 2014 "winch" to play the Aerial Assist game. We are publishing this paper in an effort to help teams that may be struggling with this part of their robot design.

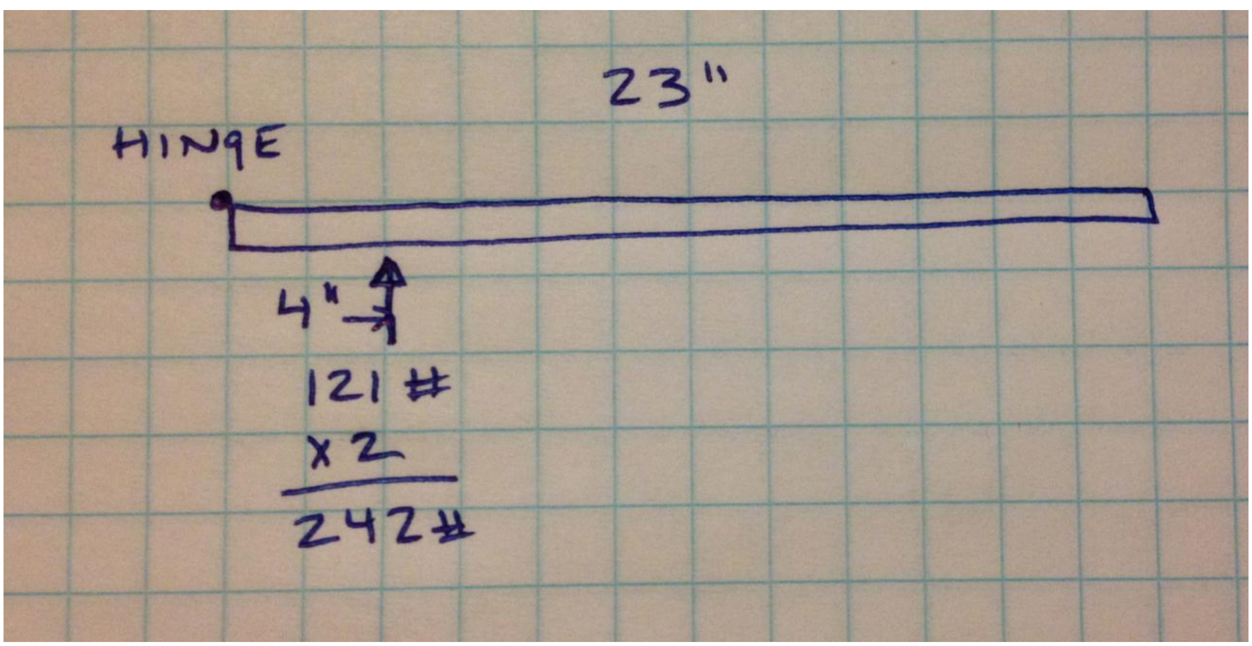
Many teams use winches for robot functions, and we have used a winch in previous years. For our 2014 robot, we had some specific performance requirements to achieve. The winch design needed to meet these requirements:

1. Retract the launcher in less than 2 seconds.
2. Allow a rapid release of the launcher.
3. No backdrive.

When we started the design steps for the winch, we already had our launcher designed and functional, so we knew the forces we would be working with.

FORCES

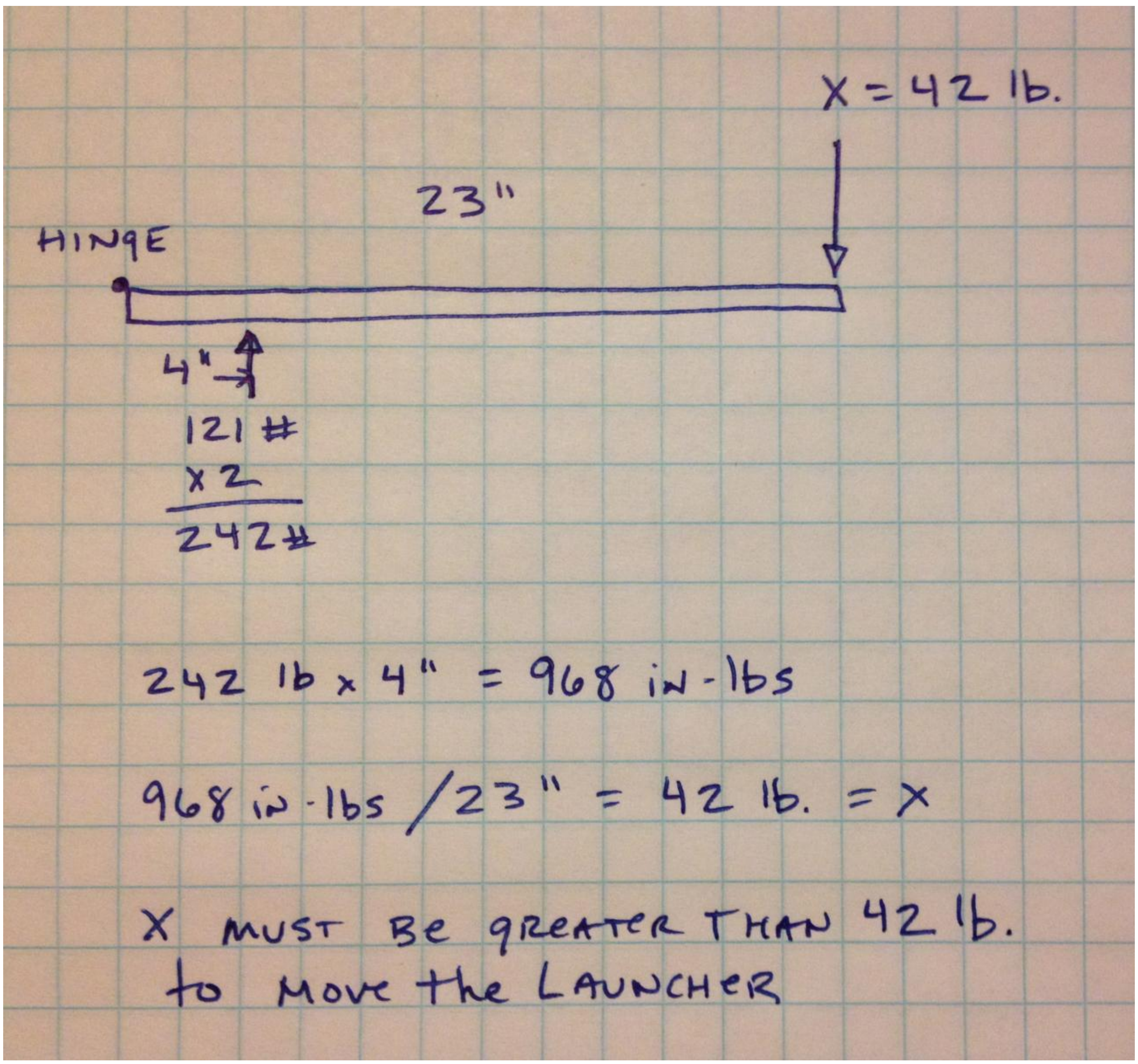
The diagram below shows the forces on the launcher that we need to overcome with the winch.



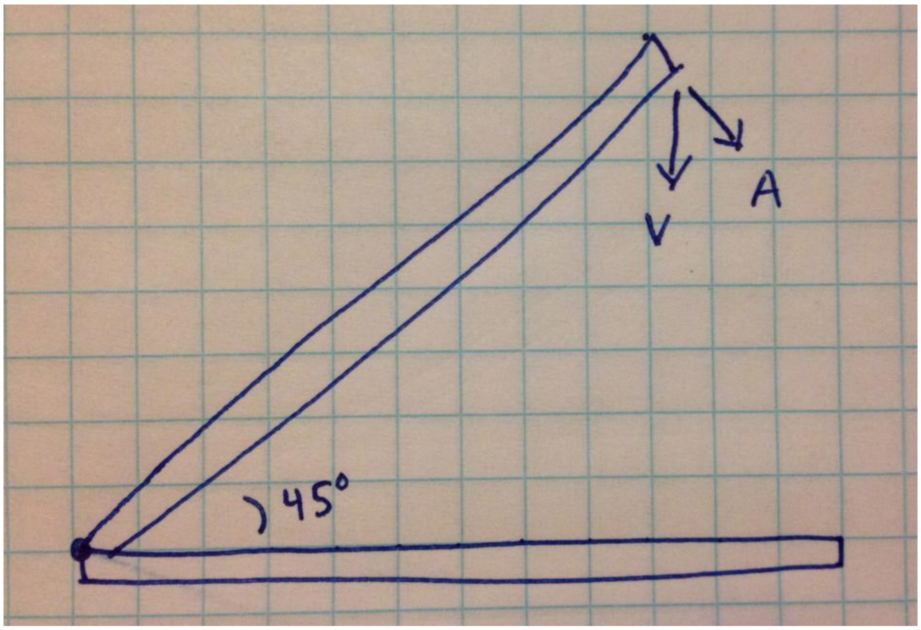
The springs we are using provide 121 pounds of force each and they are placed at 4 inches from the center of the hinge. To calculate the moment (torque), we multiply the Force times the Distance. There are two springs, so the Force is (2 x 121) lbs = 242 lbs. Multiplying by 4 inches gives 968 in-lbs. The torque we need to overcome is 968 in-lbs.

With our robot design, the winch will need to pull down a strap at the back end of the launcher. The launcher arm is 23 inches long. The "pull down" force multiplied by the arm length will need to exceed the torque generated by the springs of 968 in-lbs. To solve the equation, we will set the two to be equal.

The moment (torque) created by the force at the end of the arm will be F x 23 inches. From above, we want the two moments to be equal, we can solve for the force by dividing 968 in-lbs by 23 inches. This solution is 42 pounds. We will need more than 42 pounds of force to lower the launcher.



Before we determine the work required, we need to take another design factor into consideration. If we could pull the launcher straight down, it would take 42 pounds of force. But we will mount our winch near the back of the robot, so we will be pulling at an angle. This means that the vertical component of our pulling force must be 42 pounds, but the actual force from the winch must be higher than that.



As noted in the sketch above, the launcher is at an angle after launching the ball and that angle point is the starting point for the pull. When the launcher is "up", it is at an angle of approximately 45 degrees. We will call the vertical component of this force V, and it is 42 pounds. We will be pulling at an angle, and this force is designated by A.

If you think of a right triangle, V would be one side and A would be the hypotenuse. The angle formed by V and A is 45 degrees, so to find the side A (which is the same as the force A), so we can use the sine function. Sine 45 is .7071, so we can divide V by .7071 to determine A. 45 / .7071 is 59. Therefore, to get a vertical force of 42 pounds, we will need to pull 59 pounds at a 45 degree angle. As we pull, the angle will get smaller, so this starting force is our highest force required.

FORCE = 59 Pounds

WORK

The launcher arm needs to move 18 inches from the launch position to the ready position. To determine the work load and power required, we use W (work) = F (force) x D (distance).

W = F x D = 59 pounds x 18 inches = 1062 in-lbs.

Since we want to do this work in 2 seconds, we use P (Power) = W/ T (time).

P = W/T = 1062 in-lbs. / 2 seconds = 531 in-lbs/sec. To convert this to ft-lbs / sec, we divide by 12 and have 531 in-lbs/sec / 12 inches per foot 44.25 ft-lbs/sec.

We can convert this to Watts using 1.36 W = 1 ft-lb/sec.

Power = 44.25 ft-lbs/sec x 1.36 W/1 (ft-lb/sec) = 60 Watts.

Power required = 60 Watts

SPEED

Based on space limits and some spare parts we had for our initial design we plan to use a 2" sprocket to wind up the pull strap to move our launcher 18". Using 2πr to determine our circumference, we have a 6.28 in circumference on our sprocket.

$2\pi r = 2\pi*1=6.28$ inches.

So for every revolution of our winch, we will move the launcher 6.28 inches. Since we need to move it 18 inches, we will need to turn 18 inches / 6.28 inches per revolution = 2.87 revolutions.

If our goal is under 2 seconds, we require 2.87 revolutions / 2 seconds = 1.4 revolutions per second, which is 86 revolutions per minute (1.4 x 60).

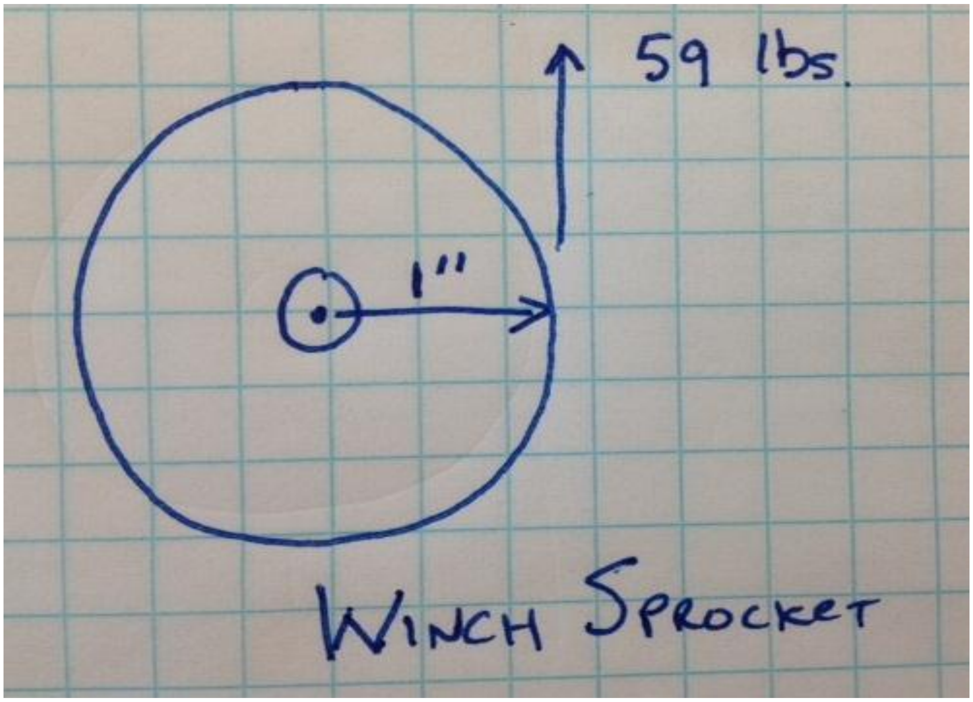
We have a spare 40:1 speed reducer that we would like to use. It is a worm drive reducer and cannot be back driven, so it will be good for this application.

Our target speed is 86 rpm, so with a 40:1 reduction we will need a gearbox input speed of 3439 rpm (86 x 40). So we need a motor with an output speed of 3439 rpm or higher to meet our time requirement.

Motor output speed = 3439 RPM

TORQUE

Next we need to determine the required motor torque. The starting torque on the 2 inch diameter sprocket is 59 lbs x 1 in (force x radius – see sketch below) = 59 in-lbs. This is on the output of the gearbox.



Speed and torque are inversely proportional (speed goes up, torque goes down). The torque at the gearbox output is 59 in-lbs so the torque at the gearbox input will be 59 in-lbs / 40 = 1.475 in-lbs. (The speed reduction through the gearbox is 40:1, so the input speed is 40 times higher than the output speed and the input torque is 40 times lower that the output torque.)

We are driving through a worm gearbox, with almost no back-drive. This means that the gearbox has a lot of internal friction, so it is not very efficient. If we assume 50% efficiency, this means that we need 2 times the torque input that the calculations have determined (the calculations assume 100% efficiency). So we need 2 x 1.475 in-lbs = 2.95 in-lbs torque capability from the motor.

The motor torque requirement is 2.95 in-lbs. Since the *FIRST* motor tables are listed in oz-in, we will multiply by 16 oz / lb to get 47 oz-in torque.

Motor torque = 47 oz-in.

MOTOR SUMMARY

Power = 60 Watts
Speed = 3439 RPM
Torque = 47 oz-in.

The next step is to look at each motors' performance data (specifically stall torque and free speed) to find an adequate motor. Any motor with less than 60 W max power can be eliminated from contention.

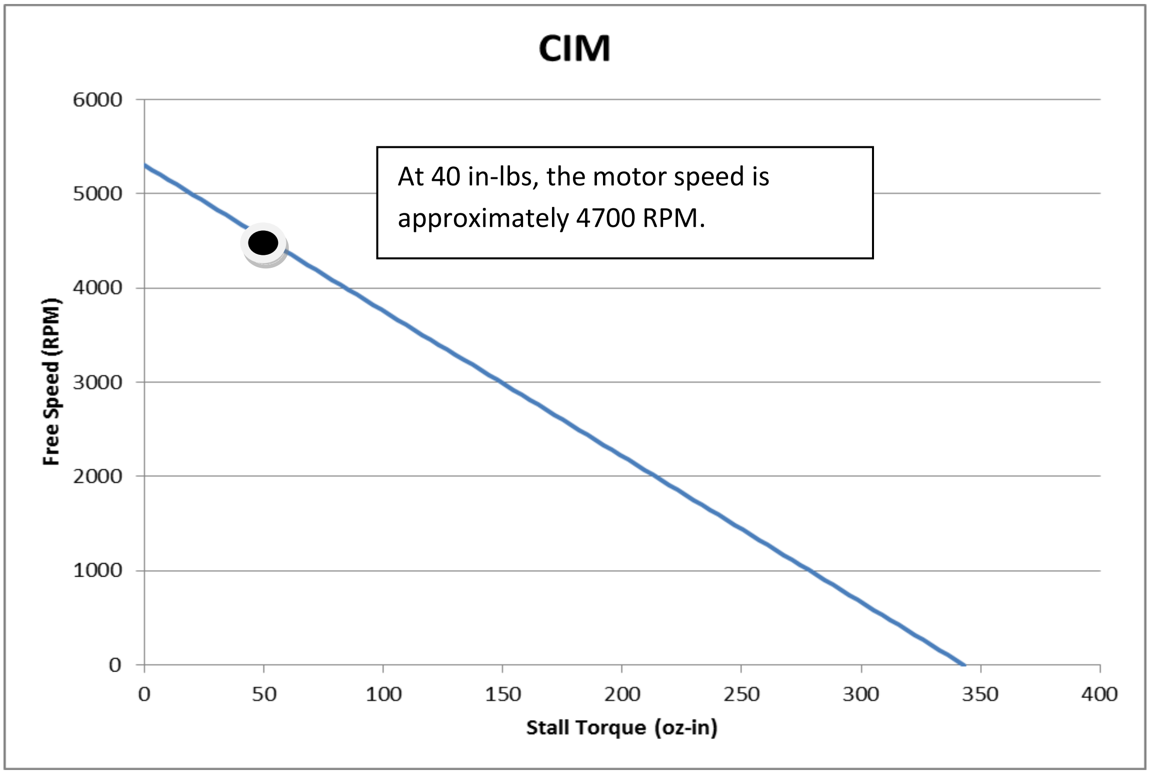
Make	Part Number	Max Power (W)	Stall Torque (oz-in)	Free Speed (rpm)	Free Current (A)	Stall Current (A)	Notes
AndyMark	am-0912	179	61	16000	1.2	64	
AndyMark	am-0915	45	1209	198	0.6	22	motor with PG27 gearbox
AndyMark	am-0914	45	3187	75	0.6	22	motor with PG71 gearbox
AndyMark	am-2193	33	6336	28	0.6	22	motor with PG188 gearbox
AndyMark	am-2235	30	1600	100	1.0	24	snow blower motor
BaneBots	M3-RS390-12	43	19	12180	0.3	15	
BaneBots	M3-RS395-12	48	17	15500	0.5	15	
BaneBots	M5-RS540-12	123	39	16800	1.0	42	
BaneBots	M5-RS545-12	74	24	16800	0.9	21	
BaneBots	M5-RS550-12 M5-RS550-12-B	254	71	19300	1.4	85	
BaneBots	M5-RS555-12	42	29	7750	0.4	15	
BaneBots	M7-RS775-12	83	61	7300	1.1	30	
BaneBots	M7-RS775-18	273	113	13000	1.8	87	
CIM	FR801-001	337	343	5310	2.7	133	
Denso	262100-3030 (Right)	23	1501	84	1.8	19	
Denso	262100-3040 (Left)	23	1501	84	1.8	21	
Denso	AE235100-0160	18	18	5300	1.0	7	Pinion: 12 tooth, 20°PA, 0.75 module
VEX	276-2177 (high speed)	4	134	160	0.2	4	At 7.2 Volts
VEX	276-2177 (standard)	4	215	100	0.2	4	At 7.2 Volts
VEX	217-3351	149	57	14000	1.8	41	
VEX	217-3371	229	198	6200	1.8	86	

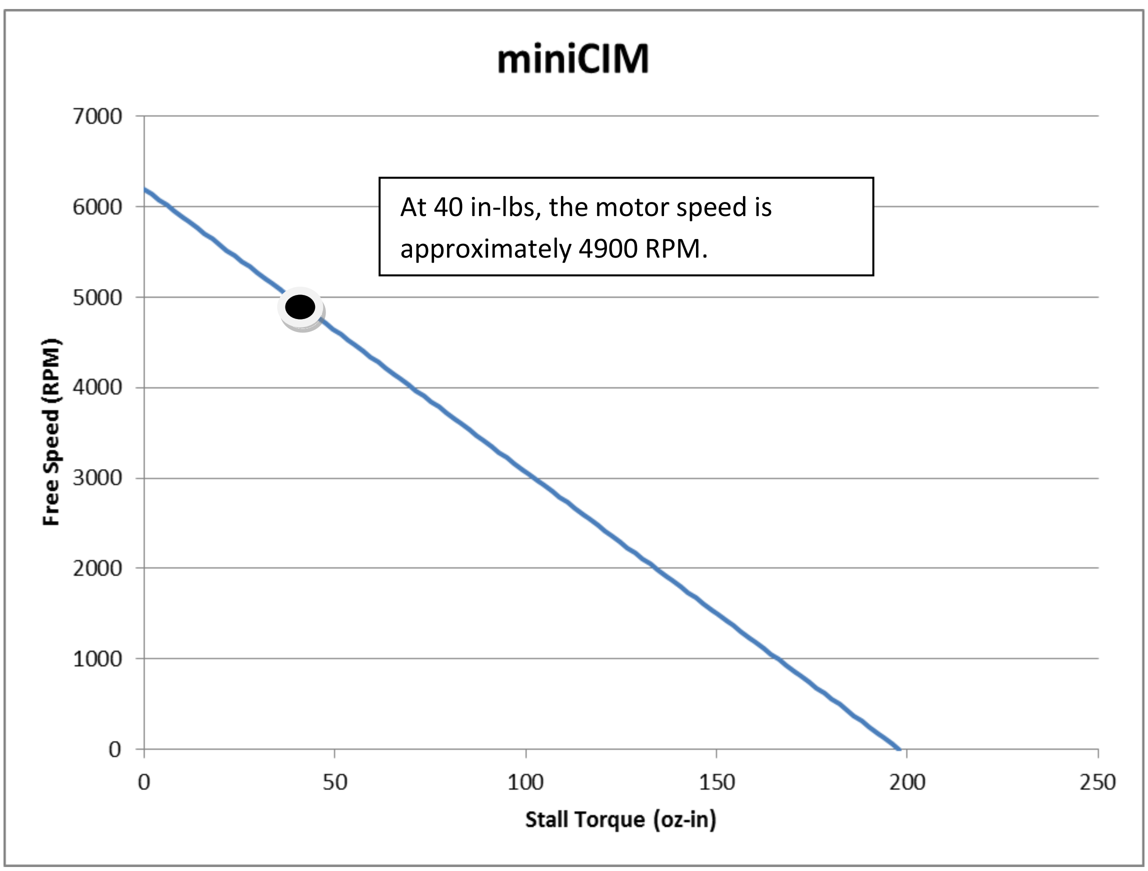
This leaves the AndyMark 9015, BaneBots 540, 550, and 775-18, the CIM, and the VEX miniCIM and BAG motors as options.

The AndyMark, BaneBots, and BAG motors have free speeds significantly higher than our requirements and stall torques that are only slightly higher than our required torque. This means that we would likely need another stage of gearing between the motor and the worm gearbox to meet our performance objectives. Since this introduces more complexity and inefficiency into the system, we will try to avoid one of those motors as our choice.

This leaves the CIM and miniCIM as our top contenders.

Now we need to check the motor curve for these two motors to determine if the required speed and torque can be accomplished together.


CIM
6000
5000
4000
3000
2000
1000
0
Free Speed (RPM)
0
50
100
150
200
250
300
350
400
Stall Torque (oz-in)
At 40 in-lbs, the motor speed is approximately 4700 RPM.


miniCIM
7000
6000
5000
4000
3000
2000
1000
0
Free Speed (RPM)
0
50
100
150
200
250
Stall Torque (oz-in)
At 40 in-lbs, the motor speed is approximately 4900 RPM.

At 40 oz-in output torque, the CIM's output speed is ~4700 RPM. At 40 oz-in output torque, the miniCIM's output speed is ~4900 RPM. Since each of these speed points is higher than the speed where we need that torque output, both motors meet the requirement.

Based on this motor performance, either will meet the requirements with significant margin.

Since the winch is a critical component of our robot, we will use the CIM. It has a significant margin of performance above our requirements and has close to the desired output shaft speed and we are not concerned about the additional weight.

Motor Selection – CIM

VERIFICATION

To re-confirm that our choices meet the design requirements, we will re-run the data to validate our choices.

CIM output at 40 oz-in = 4700 rpm
40:1 gearbox reduction = 118 rpm
118 rpm = 1.96 rps (revolutions per second)
1 revolution = 6.28 inches, 18 inches = 2.87 revolutions
2.87 revolutions / 1.96 revolutions per second = 1.47 seconds.

Time requirement = 2 seconds, expected time = 1.47 seconds. We met this requirement.

SUMMARY

Our key performance requirement was to pull down the launcher is less than 2 seconds and to have a system with virtually no back-drive. Given our loads, the components below will allow us to meet this goal.

CIM Motor
40:1 Reduction Worm Drive Gearbox
2" Sprocket