How to Select Gear Ratios

Nick Crispie

971 SPARTAN ROBOTICS

About Me

Nick Crispie

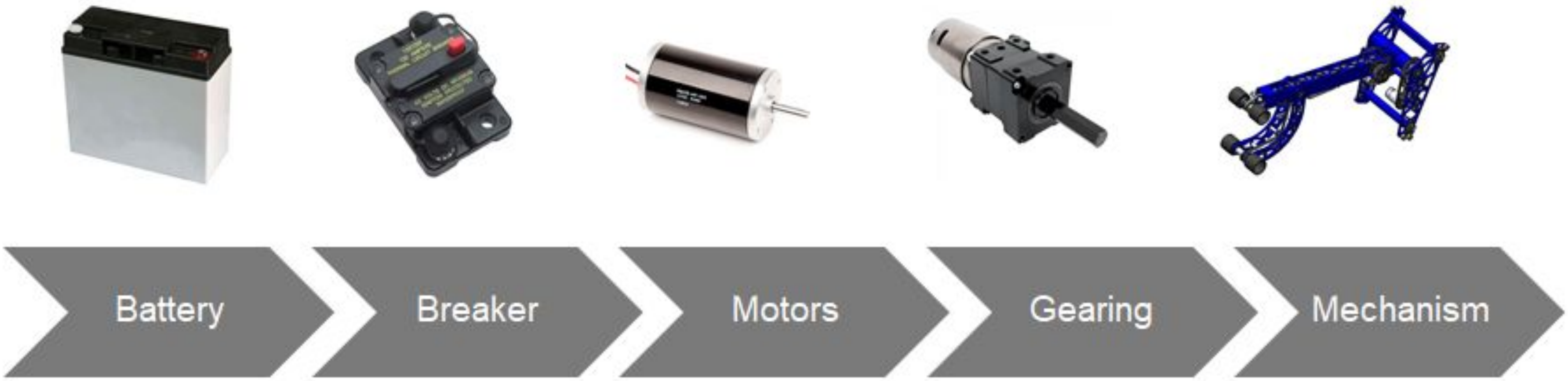
- Student, FRC 971 (2010 - 2013)
- College Mentor, FRC 971 (2014 - present), FRC 3504 (2018 - present)
- BS Mechanical Engineering, UC Berkeley (2017)
- Current: MS in Robotics, Carnegie Mellon University

Acknowledgements

This presentation is modified from one given at the *FIRST* Championship in April with Basel Alghamen (FRC 3504), who created much of the original material.

SPARTAN ROBOTICS 971

Power Flow



971 SPARTAN ROBOTICS

Battery

- Two important statistics: max voltage and internal resistance
- Max voltage should be anywhere from 12.7 to 13.2 V or even higher
- Internal resistance varies wildly:
  - The best I’ve measured is 17 mΩ, but some have claimed as low as 12 mΩ
  - A competition battery should never be over 22 mΩ (~1 year old)
  - I’ve seen as high as 30 mΩ; worth keeping for demos
  - Why does this matter? 5 mΩ * 200 A = 1 V
- Get a battery beak to measure! (CTR or AM)

Breakers

True or False: 120 A breaker does not allow more than 120 A, and 40 A breaker does not allow more than 40 A

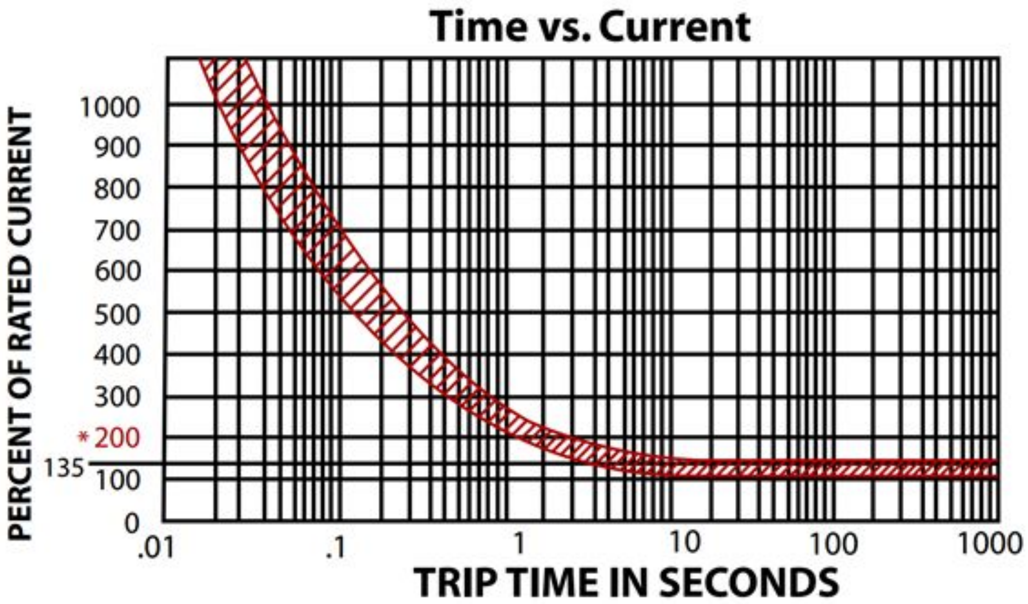
Breakers

True or False: 120 A breaker does not allow more than 120 A, and 40 A breaker does not allow more than 40 A

FALSE

Breakers are guaranteed to never trip at the rated current, but will allow greater currents for shorter periods of time (“short” periods in industry are pretty long in FRC)

Breakers: 40 Amp Breaker



150 % overload = 3.9 - 47 seconds
175 % overload = 2.2 - 9.2 second
* 200 % overload = 1.5 - 3.9 seconds
250 % overload = 0.8 - 1.8 seconds
300 % overload = 0.5 - 1.1 seconds
400 % overload = 0.3 - 0.6 seconds
500 % overload = 0.2 - 0.3 seconds

971
SPARTAN ROBOTICS

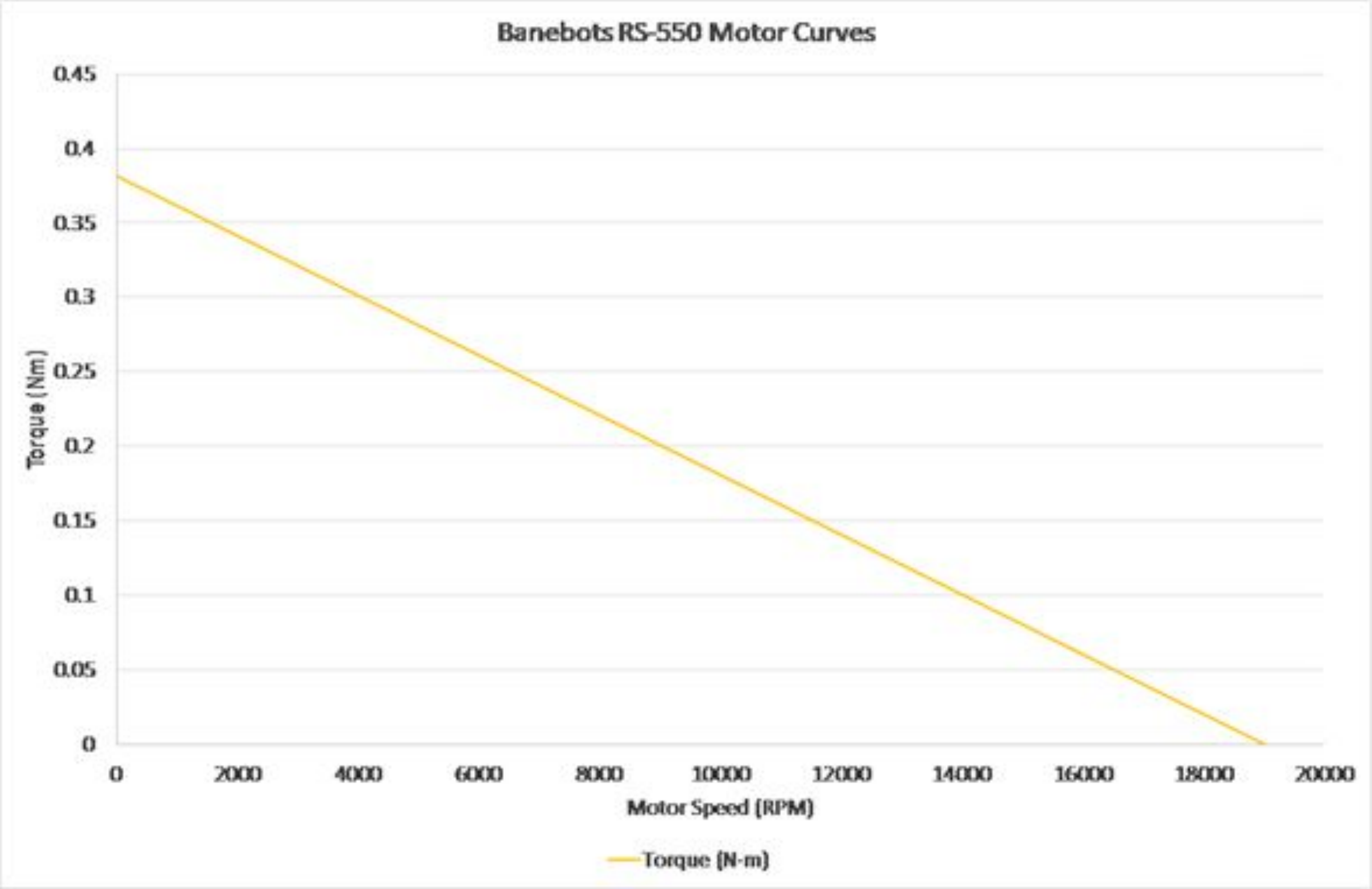
Motors

Lots of options – I like to look at motors.vex.com because they've done independent testing

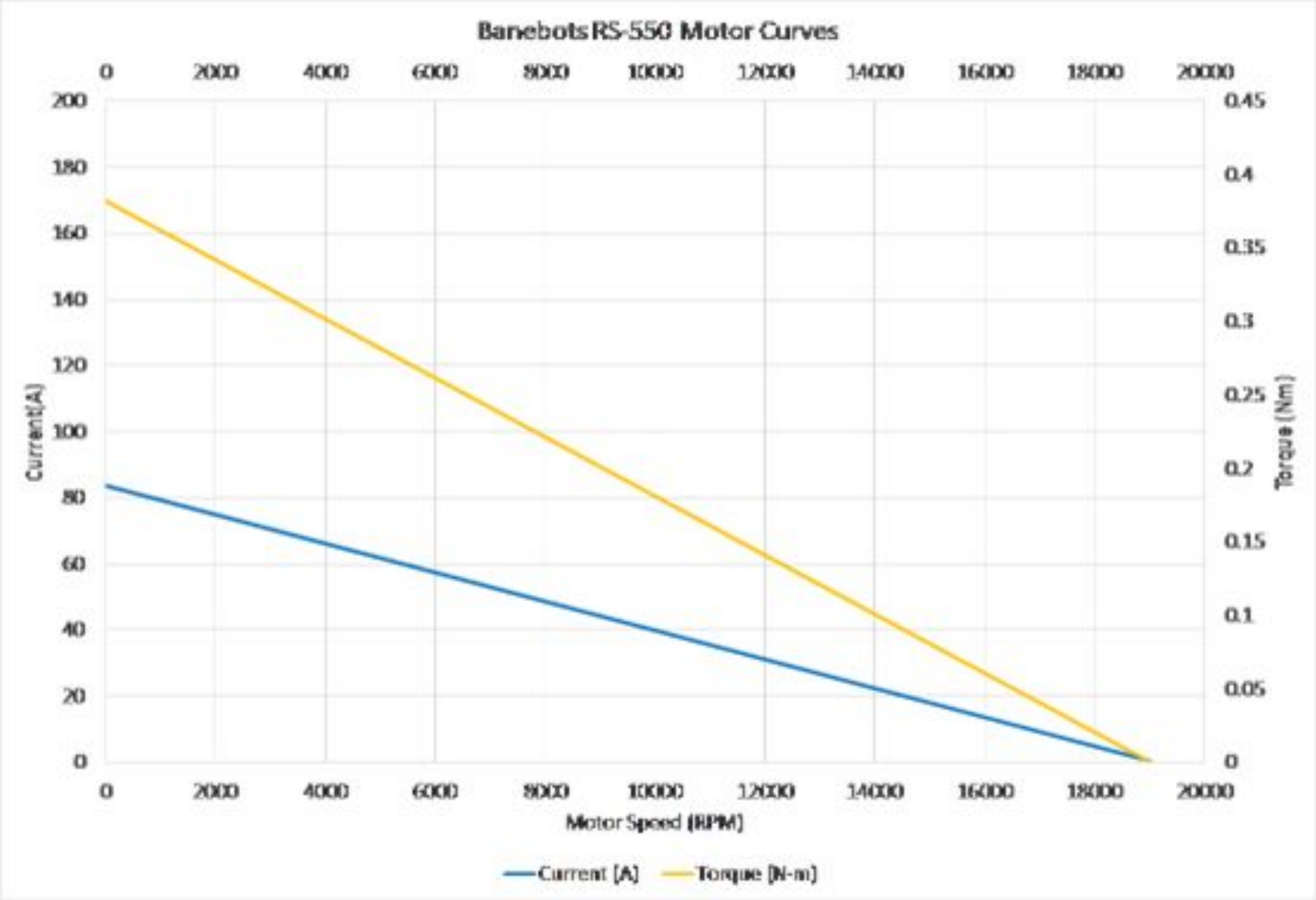
But that shows a bunch of statistics:

- Stall Torque
- Free Speed
- Stall Current
- Max Power

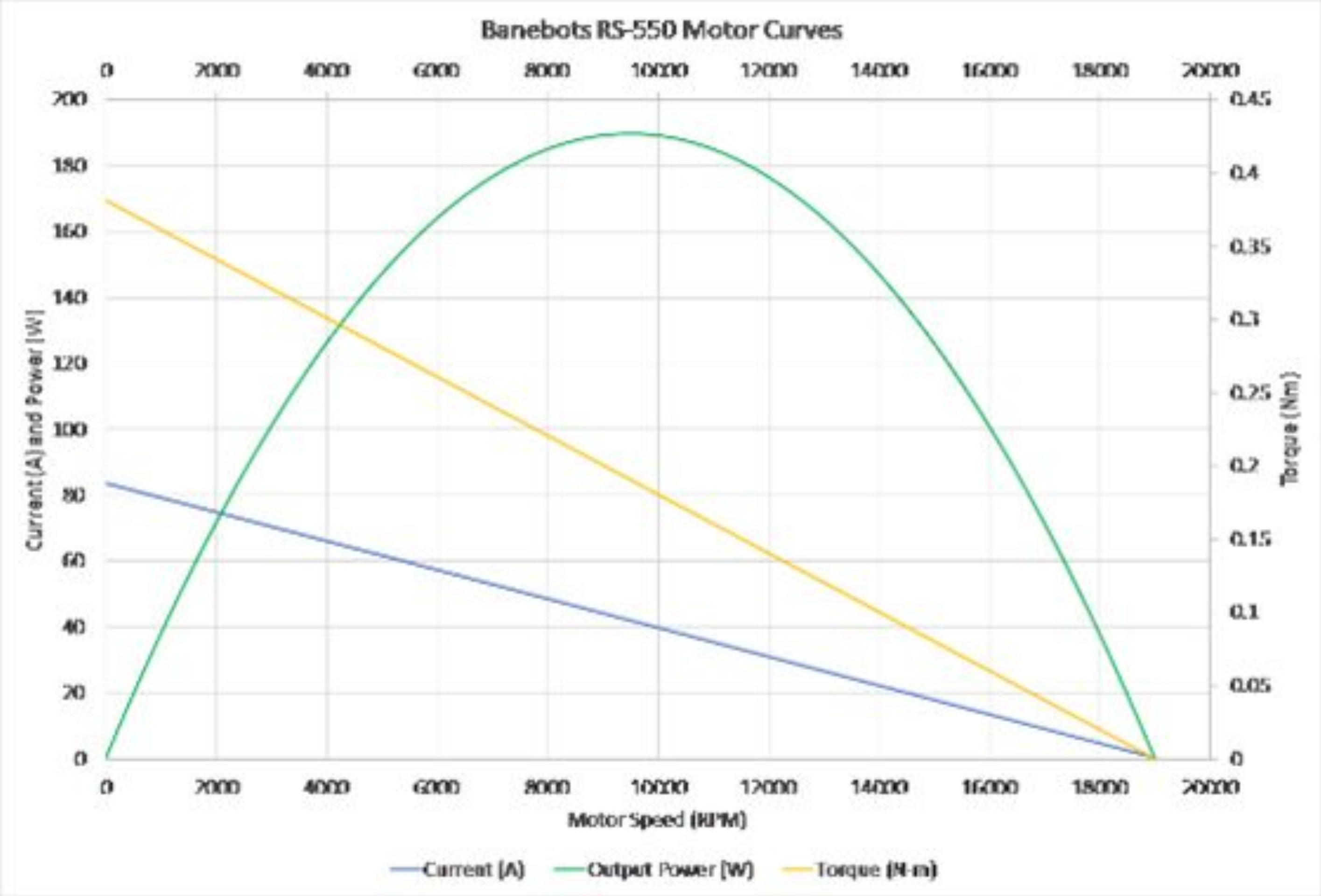
What does all that mean?



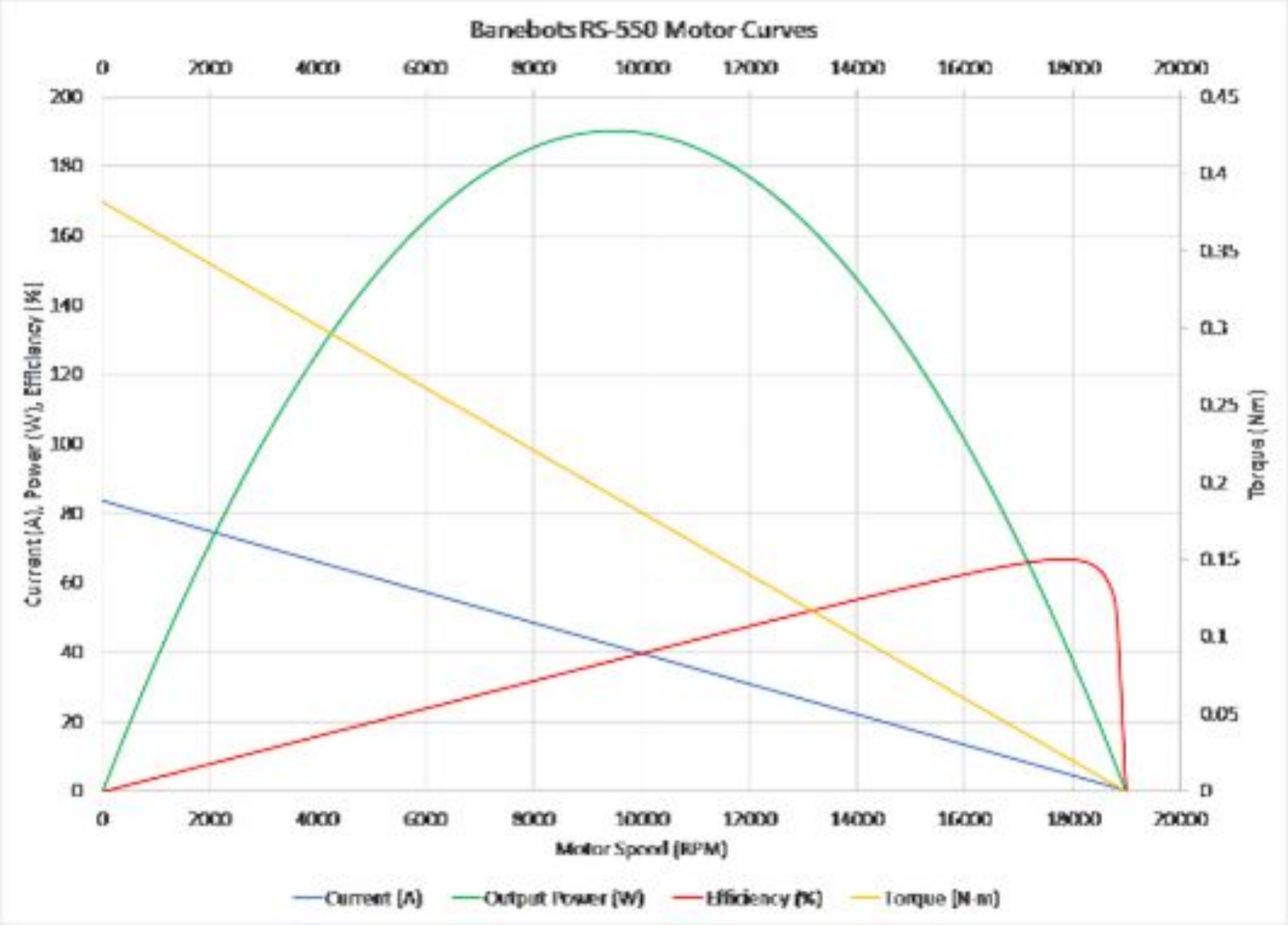
971
SPARTAN ROBOTICS



971 SPARTAN ROBOTICS



971
SPARTAN ROBOTICS



971
SPARTAN ROBOTICS

Motors

Try to use motors nearer to the top of their speed range than the top of the torque range

“Open” motors (775s, 550s) should be used very differently versus “Closed” motors (CIMs)

- An open motor should never or hardly ever be stalled, especially at high voltages
- If an open motor is able to move, especially above 50% free speed, it’ll basically go forever
- Closed motors can be stalled for a long time, but take a long time to cool down
- Some teams end up using coolant (upside down compressed air cans) to cool down CIMs b/w matches

Take a look at VEX’s locked rotor (stall) and max power tests to see if the motor will die if you use it in the way you’re considering using it

971
SPARTAN ROBOTICS

Gearboxes

So many options! Categories:

- Single-speed vs shifting (usually for drivetrains)
- Planetary (I like VEX VPs, also Banebots and AM Sport / PG)
- Various input types (1 to 3 CIMs, 1+ 775/550, etc.)
- Custom (rarely worth it for most teams)

Key suppliers: AndyMark, VEX (or local distributors), West Coast Products

971 SPARTAN ROBOTICS

The Mechanism

What kinds of mechanisms are there?

- Intakes
- Arms
- Shooters
- Elevators / Lifts
- Climbers
- Drivetrains

How do they vary:

- How fast is the thing going?
- What's the load on the thing?
- How long are you doing the thing?

971
SPARTAN ROBOTICS

Intakes

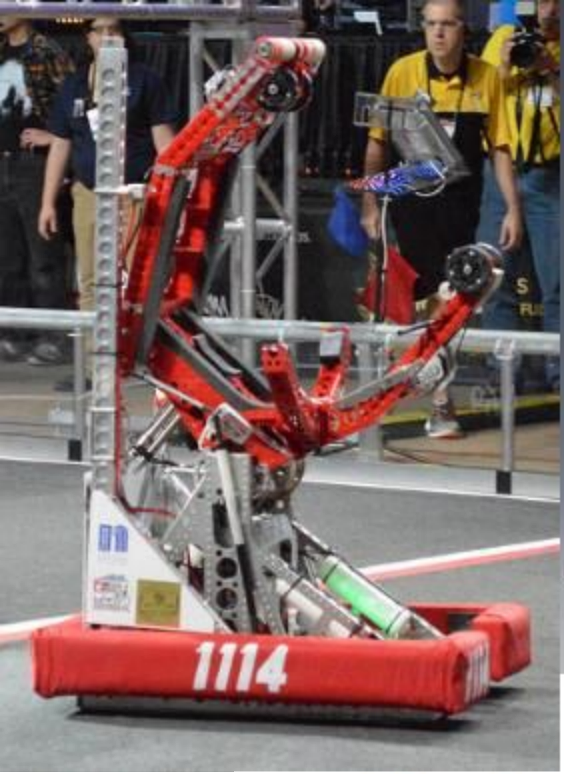
Let’s characterize it:

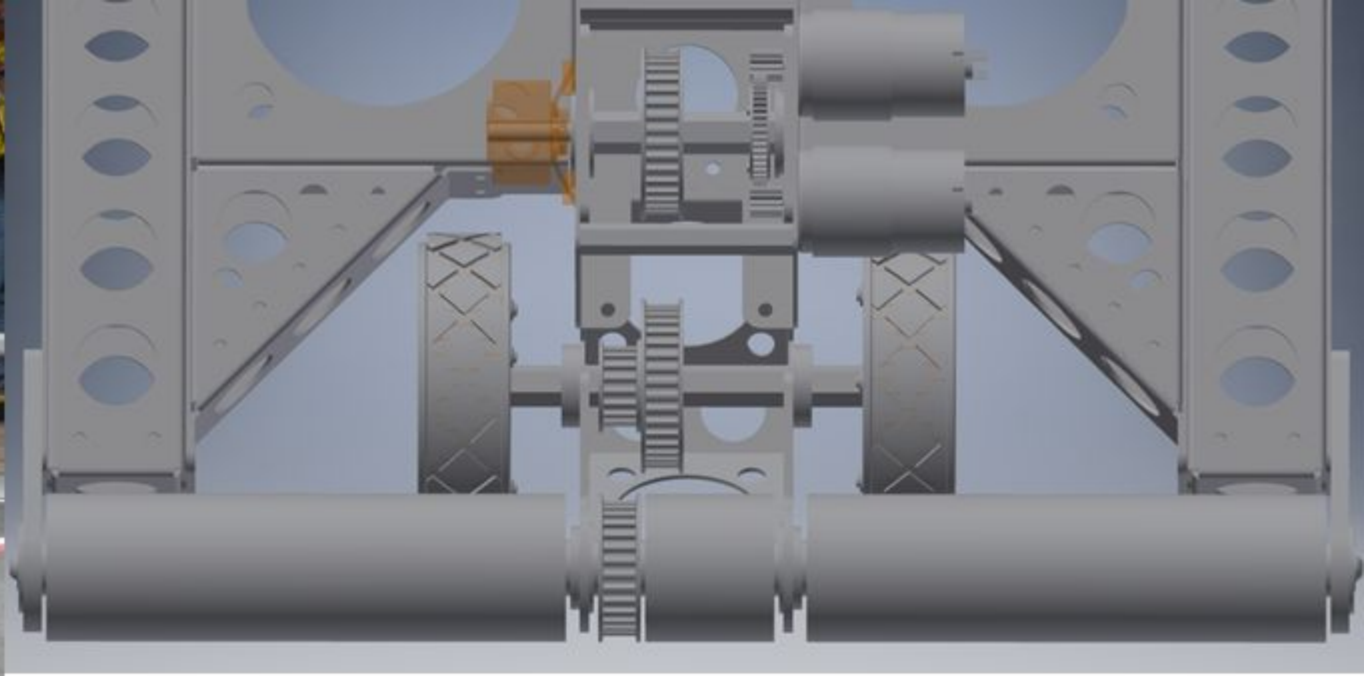
- Surface speed should be on the order of your drivetrain speed (15 fps)
- Torque is extremely hard to put a number to
- For the same game piece, diff. mechanisms with diff. compression, etc. will require different torques

What should you use

- You’ll have to do some testing, but in general, this is a good place to use extra power
- Nobody has ever had an intake that was too powerful
- Since speed is high, good application for an open motor like a 775

971
SPARTAN ROBOTICS

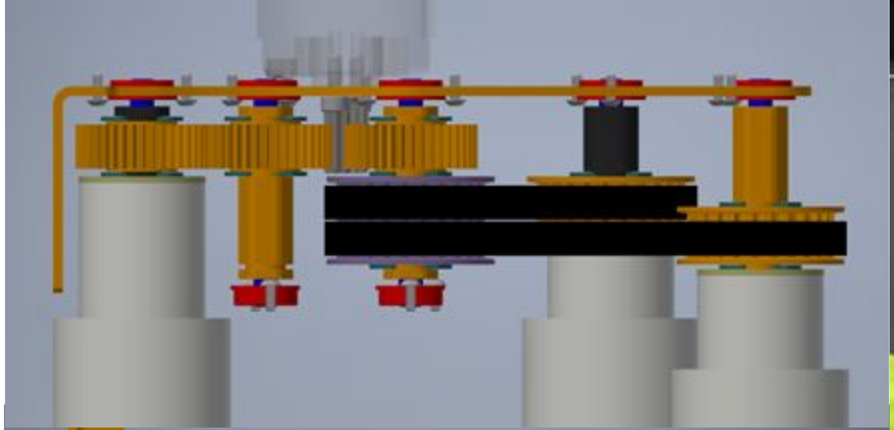


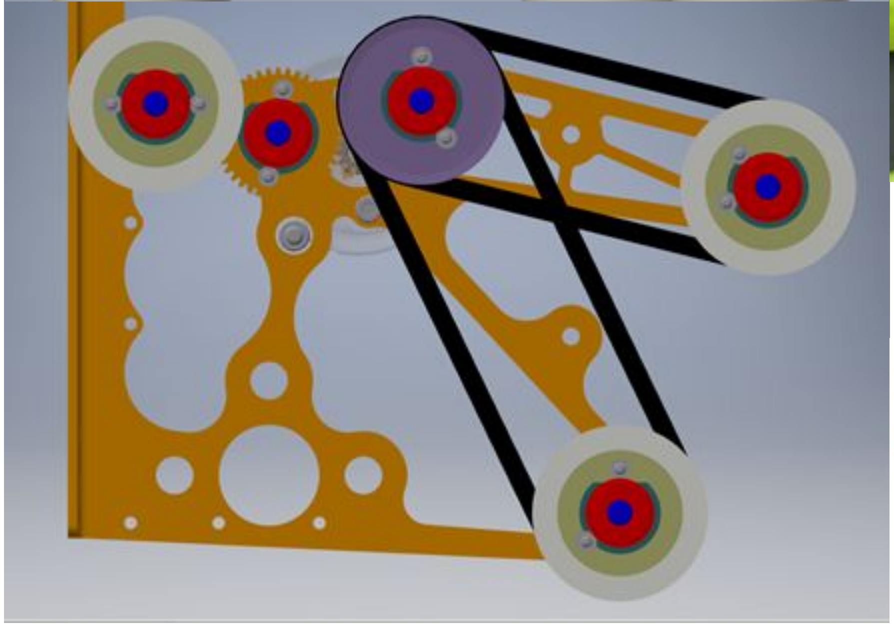


Two RS-550 motors
4:1 gearbox reduction
30:18 pulley reduction
2” roller

2x190 = 380 watts
25 fps free speed
45 lbf at stall

971
SPARTAN ROBOTICS





One Banebots 775
4:1 gear reduction
1:1 pulley
1.75” roller

246 watts
24.9 fps free speed
29 lbf at stall

Arms

Let's characterize it:

- Speed is on the order of 90-180 degrees per second (this is really slow!)
- Remember that a lot of the time, the speed needs to be exactly 0
- Torque depends on the weight and length of the arm and how much it's counterbalanced

What should you use

- Honestly, pneumatics are the easiest way to go
    - Design the force around the worst case (for gearing it's when the gravitational force is at a maximum, but for pneumatics it's often when the angle between cylinder and link is smallest)
- 5300 rpm (CIM free speed) to 180 degrees per second = 177:1 gear ratio
- That's a lot of gearing! No matter the torque, getting your free speed that low is a lot of gearing
- Let's look at how good teams achieve this

971 SPARTAN ROBOTICS

Two 1.5” bore cylinders
70° worst case angle
5” stroke

→

0 watts
66 ft-lbf worst case

971
SPARTAN ROBOTICS

So you really want to gear an arm...

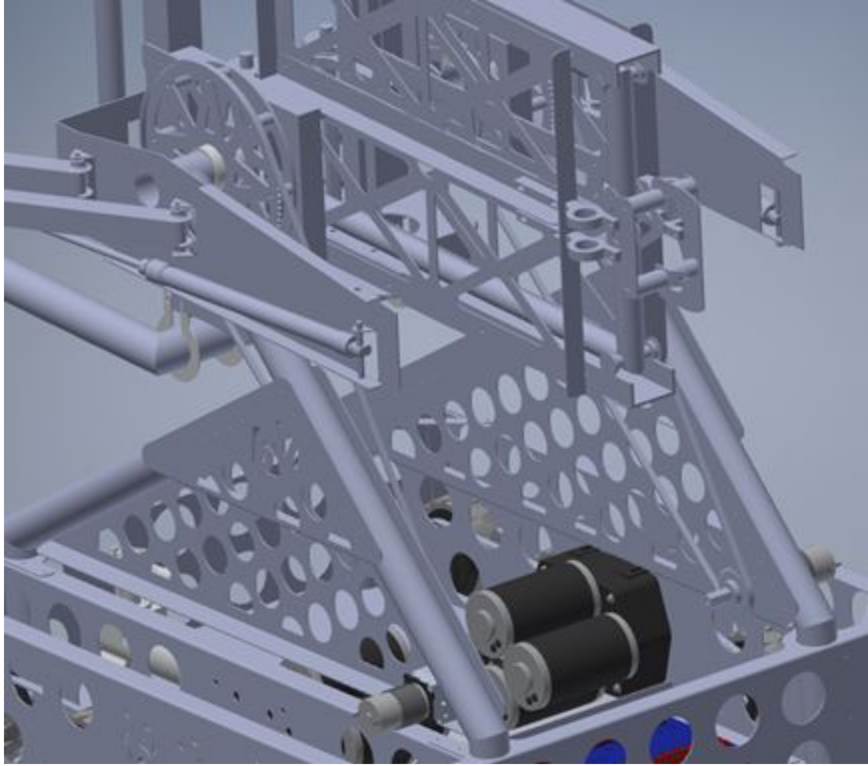
Get your torque in the right region:

- Ideally, your arm will not move even if you aren't applying any power
- This happens due to gearbox inefficiency (at least 5% inefficiency per stage)
- Since you're using a few stages, if your torque is 5 to 10 times the peak gravitational force, you're good
- Alternatively, induce inefficiency! Worm gears are very inefficient, so they're great for arms
- Why isn't this a problem? Since arms are moving so slow, most FRC motors (geared sufficiently) can provide more than enough power to move the arm as fast as you need

A great way to make the last step easier: minimize the peak force

- Make the arm short and light
- Put heavier things closer to the rotation point
- Counterbalance using simple weight or using springs

971
SPARTAN ROBOTICS



Two RS 775 motors
100:1 VP gearbox
100:22 chain reduction

246x2 = 492 watts
172°/s free speed
482 ft-lbf at stall

Shooter

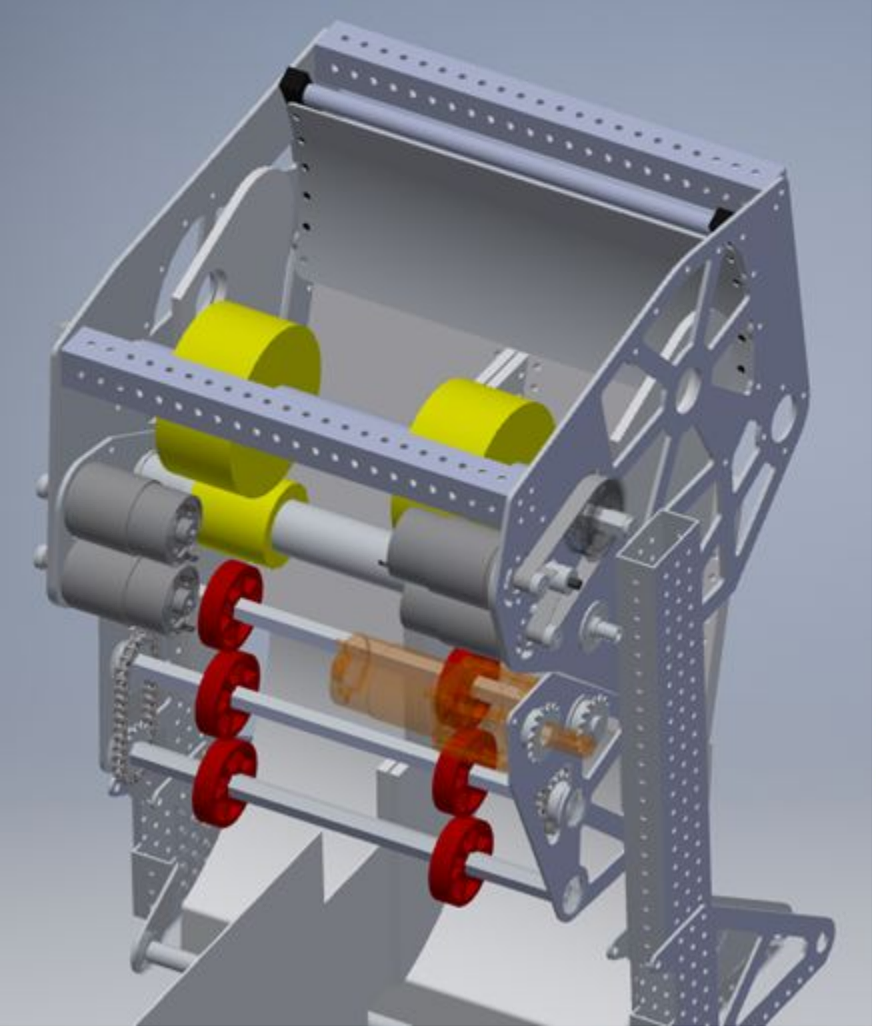
Let's characterize it:

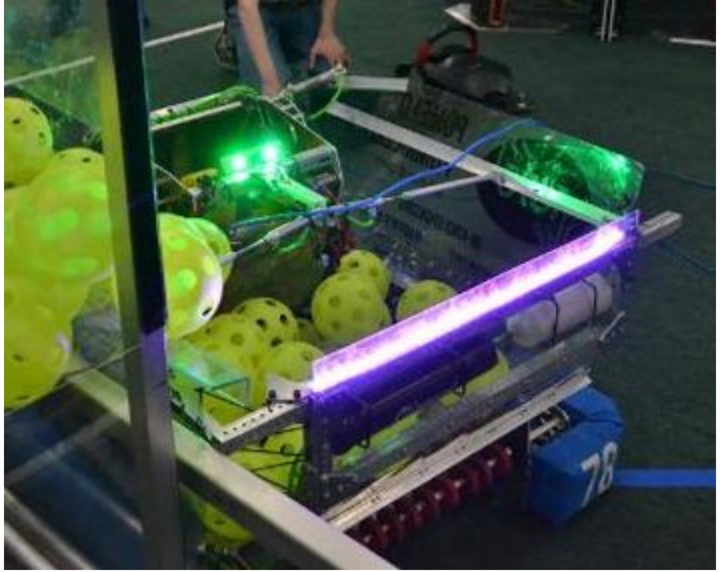
- Target speed will usually be a few thousand RPM or so, depending on shooter wheel size, but you should gear faster to have room for tuning and still have torque at that speed
- Torque is highly variable, but a decent approximation is to look at power out (energy imparting to game pieces per second = $\frac{1}{2} mv^2$ * game pieces per second)
- Testing will tell you what works, but power in will be at least 2x the power out, and to start you should plan for at least 3x
- More compression = more torque AND more inefficiency

What should you use

- Open motors are definitely nicer. Even at high speeds (near peak efficiency), a closed motor running all the time will heat up
- A single planetary or pulley reduction will be enough to do the trick
- A flywheel could help you shoot bursts of balls without as much motor power

971
SPARTAN ROBOTICS





Two 775pros
4:1 pulley reduction
4” wheel

→

2x347 = 694 watts
82 fps free speed
25 lbf at stall

1 775pro
10:1 VP reduction
2” wheels

→

347 watts
16 fps free speed
63 lbf at stall

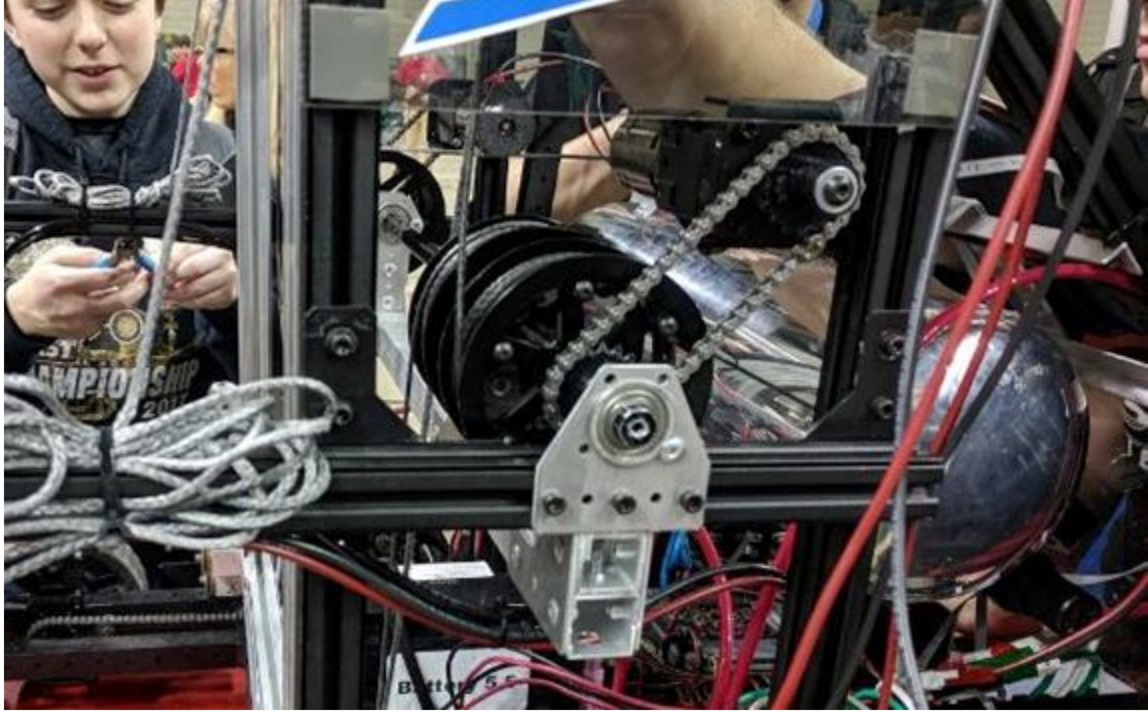
Elevator

Let's characterize it:

- Target speed: Get up to target height within 1.0 seconds
- Once it's that fast, you don't have to wait on it
- With a 1.5 in sprocket & 6 ft target height, around 1000 rpm
- Torque depends entirely on the lifted weight, friction, & winch size

What should you use

- Counterbalancing can eliminate gravity, but not mass or friction
- Counterbalance if multi-stage elevator or heavy shuttle
- Minimize lifted weight, use two motors if objects are heavy (2015)
- Open motors with a holding solution (counterbalance or a brake), closed if you'll be holding with motor torque



2 775pros
35:1 VP reduction
3.5” winch

347x2 = 694 watts
8 fps free speed
251 lbf at stall

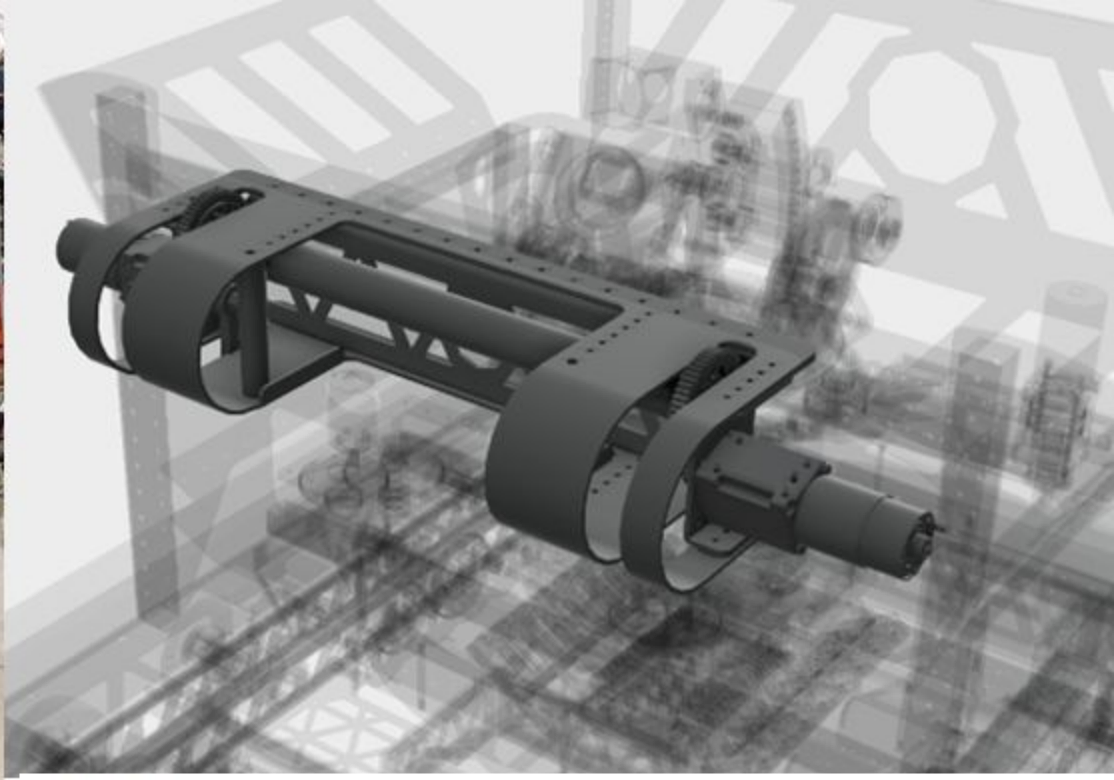
Climber

Let's characterize it:

- Target speed: as fast as possible!
- Torque depends on robot weight and winch size

What should you use

- 1 CIM or 775pro is typically enough power, two if you want speed
- Climbers tend to late additions, so often teams need to use as little weight as possible
- That means open motors and minimal reduction (through minimal winch size)
- Open motor means don't hold with torque, so add a ratchet



2 775pros
25:1 VP reduction
54:16 Gear reduction
1.25” winch

347x2 = 694 watts
1.21 fps free speed
199 lbf at stall

Drivetrain

Let's characterize it:

- This should not be a surprise but they're pretty complicated
- Target speed will be in the range of 10 to 20 fps
- Force tops out at roughly 1.1x to 1.3x robot weight
- Shifting gears is an available option
- Really what you care about is how quickly you get from Point A to Point B

You can use tools:

- JVN Mechanical Design Calculator
- Drivetrain Calculator (there are several like it, this is Basel's variant on one by Michael Hill)

971
SPARTAN ROBOTICS

Drivetrain Examples

Year	Notes
2017	Long distances to cover
2016	Short distances, but needed low gear for defenses
2015	Very short distances and no pushing
2014	Tons of pushing around, medium distances

Team	Year	Motors	Speeds
33	2017	6 miniCIM	15 fps*
254	2017	4 CIM	19.6 / 7.7 fps
3322	2017	6 miniCIM	21 / 10 fps
254	2016	4 CIM	14.6 / 7.1 fps
1114	2016	4 CIM	14 / 7 fps
254	2015	4 miniCIM	12 fps
67	2014	6 CIM	17 / 6.4 fps
1114	2014	4 CIM	13 / 5.7 fps

Drivetrain

General principles:

- Design low gear to slip at around 240 A for 6 motors or around 200 A for 4 motors
- Design high gear to maximize time to distance (higher speeds for longer distances)
- If these are remotely close together, it's probably worth just using the high gear or something in between, and, if needed, using your code to limit the current for low speed operation
- That said, your batteries will thank you for having a low gear

971
SPARTAN ROBOTICS

Thank You!

Questions?

Feel free to contact me

ncrispie@andrew.cmu.edu

971

SPARTAN ROBOTICS