



# BACKLASH



2019  
Technical Binder



## Foreword

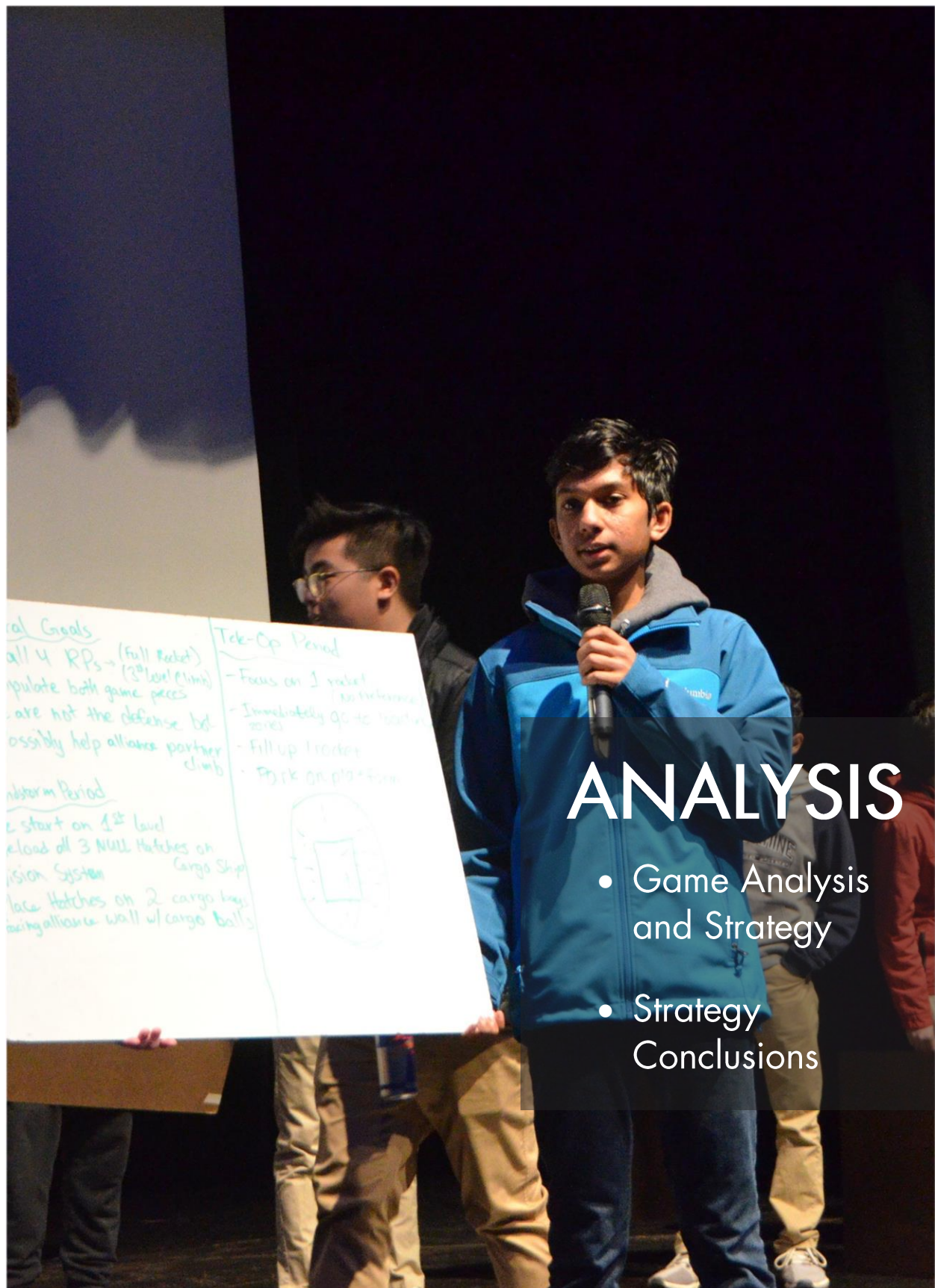
Our season started with a few members attending our local FIRST kickoff and the rest of the team viewing the live-cast from our lab. The subsequent game analysis helped the team determine the optimal strategies and robot requirements. With these requirements, extensive prototyping on all subsystems was conducted throughout the build season, along with several revisions, until final robot designs and manufacturing were completed towards the end of the competition season. This Technical Binder details the game analysis, decisions, outcomes, and technical designs that guided us from kickoff to our final robot for the 2019 FRC Season: *BACKLASH*.



# TABLE OF CONTENTS

<b>Analysis</b>	<b>7</b>
<i>Game Analysis and Strategy</i>	9
<i>Strategy Decisions</i>	11
<b>Robot Design</b>	<b>13</b>
<i>Drivetrain</i>	17
<i>Drive Gearbox</i>	18
<i>Turret</i>	19
<i>Elevator</i>	20
<i>Carriage</i>	21
<i>Arm</i>	22
<i>Intake</i>	24
<i>Suction Climber</i>	26
<i>Former Designs</i>	28
<b>Programming</b>	<b>29</b>
<i>Vision Targeting</i>	29
<i>Superstructure Motion Planning</i>	29
<i>Autonomous Navigation</i>	30





Initial Goals  
all 4 RPs → (Full Rocket)  
(3<sup>rd</sup> level climb)  
operate both game pieces  
are not the defense but  
possibly help allies portway  
climb

Midterm Period  
start on 1<sup>st</sup> level  
load all 3 Null Hatches on  
Cargo Ship  
Vision System  
Place Hatches on 2 cargo bays  
bring alliance wall w/ cargo balls

Tech-Op Period  
- Focus on 1 rocket  
(no interference)  
- Immediately go to 1st level  
- Fill up Rocket  
- Park on platform



# ANALYSIS

- Game Analysis and Strategy
- Strategy Conclusions





# GAME ANALYSIS

Game analysis began with students splitting into groups to brainstorm possible strategies. The team then reconvened to share conclusions and review the game manual, line by line. The overarching goal of designing a robot capable of winning the world championship guided these discussions, resulting in a set of strategic priorities for this year's robot, outlined in the chart below.

Game Aspect	Priority	Criteria
<b>Sandstorm Period</b>	<b>Must Haves</b>	<ul style="list-style-type: none"> <li>2 hatches placed on rocket in qualification matches or cargo ship in elimination matches</li> <li>Drive off level 2 of HAB for extra 3 points</li> </ul>
	<b>Nice to Haves</b>	<ul style="list-style-type: none"> <li>2 hatches placed on rocket and 1 cargo in rocket</li> </ul>
	<b>Explore</b>	<ul style="list-style-type: none"> <li>Fit 2 robots on one side of the HAB level 2 for extra points</li> </ul>
<b>Intake</b>	<b>Must Haves</b>	<ul style="list-style-type: none"> <li>Floor intake for cargo</li> <li>Aligning mechanism and wall intake for hatches</li> </ul>
	<b>Nice to Haves</b>	<ul style="list-style-type: none"> <li>Floor intake for hatches</li> </ul>
	<b>Explore</b>	<ul style="list-style-type: none"> <li>Designs that can acquire hatches on far side of field from within robot's frame perimeter</li> </ul>
<b>Scoring</b>	<b>Must Haves</b>	<ul style="list-style-type: none"> <li>Score cargo and hatches on all levels of rocket (get RPs in quals) and cargo ship (faster for elimination matches)</li> </ul>
	<b>Nice to Haves</b>	<ul style="list-style-type: none"> <li>Score from both sides of the robot to reduce cycle times</li> <li>Score from side of robot aids in auto and score on far side of rocket</li> </ul>
	<b>Explore</b>	<ul style="list-style-type: none"> <li>Score onto far side of cargo ship by shooting over the top</li> </ul>

<b>Climbing</b>	<b>Must Haves</b>	<ul style="list-style-type: none"> <li>• Climb quickly in a small amount of space in last few seconds of match to HAB level 3</li> <li>• Cycle while other team is climbing</li> <li>• Climb quickly in a small amount of space while partner is on top of platform</li> </ul>
	<b>Nice to Haves</b>	<ul style="list-style-type: none"> <li>• Climb with suction on corner of HAB level 3 so we can climb after 2 partners already on platform</li> </ul>
	<b>Explore</b>	<ul style="list-style-type: none"> <li>• Lifting 1 Alliance Partner</li> </ul>
<b>Programming</b>	<b>Must Haves</b>	<ul style="list-style-type: none"> <li>• Maximize the amount of hatches and cargo scored during the match by using vision targets to align scoring system</li> </ul>
	<b>Nice to Haves</b>	<ul style="list-style-type: none"> <li>• Autonomously drive during Sandstorm period to improve reliability</li> </ul>
	<b>Explore</b>	<ul style="list-style-type: none"> <li>• Use field-oriented controllers to simplify driver inputs</li> </ul>
<b>General Design Goals</b>	<b>Must Haves</b>	<ul style="list-style-type: none"> <li>• Fast acceleration to sprint short distances</li> <li>• Two gearbox speeds with very high acceleration but lower top speed</li> <li>• Goal robot weight: 90 -110 lbs</li> </ul>
	<b>Nice to Haves</b>	<ul style="list-style-type: none"> <li>• Easily accessible wiring and pneumatic systems for debugging and testing</li> </ul>
	<b>Explore</b>	<ul style="list-style-type: none"> <li>• Minimize weight with small wheels and 0.0625" Wall tubing in chassis</li> </ul>



## General Design

Our overarching goal was to build a competitive robot that wins the FIRST Championship. We determined that the rocket RP is much more difficult to achieve than the HAB climbing RP, so our robot needed to be designed around achieving the rocket RP solo to maximize our rank from qualification matches. To achieve this, we needed to have a fast cycle time when acquiring and scoring both hatches and cargo.

We learned from our experience with *LOCKDOWN* last season that it is faster to reorient our manipulator to face the goal than turn the drivebase. For this reason, we decided that our manipulator needed 4 degrees of freedom: turret, elevator, and arm with shoulder and wrist joints.

## Sandstorm Period

For qualification matches, we wanted to maximize our chances of completing a rocket so we would ideally start in HAB level 2 for the extra points and then score panels onto the Rocket. Null hatch panels on the cargo ship would guarantee points and allow for simpler ball scoring. In eliminations, depending on our alliance, we would remove null hatch panels and instead place hatches on the Cargo Ship. In the beginning of the season, our Sandstorm Period relied on a lot of human driven control, but by the World Championship, we had a tuned autonomous routine that could score faster and more reliably.

## Tele-Operated Period

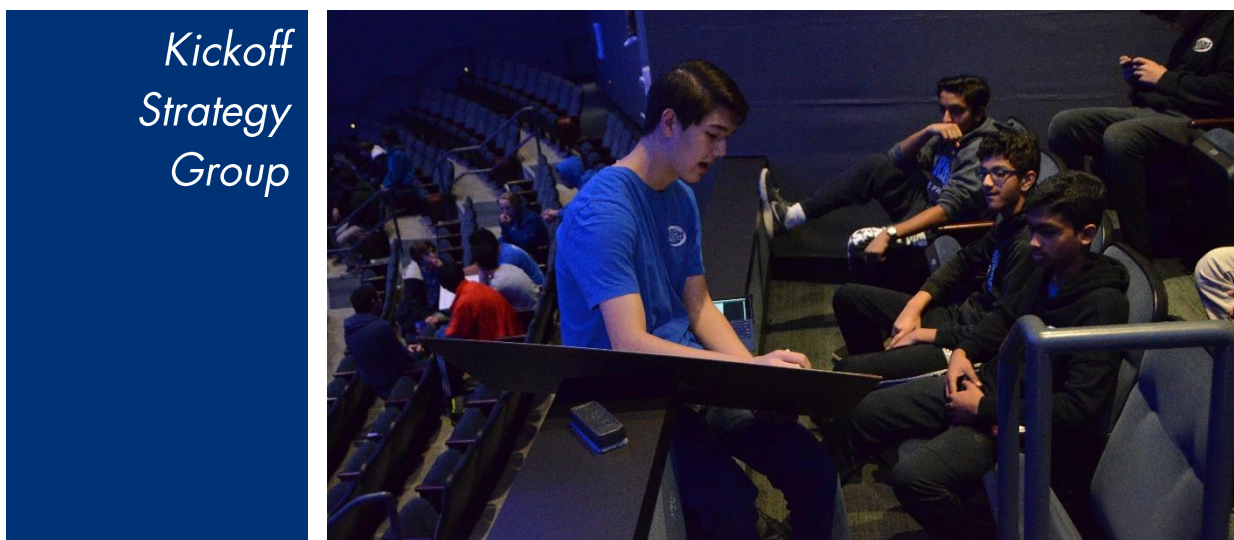
To achieve our goal of maximizing ranking points, we used the tele-operated period to score points to win the match and also score in the rocket for its extra RP. Due to the placement of hatch panels, and cargo relative to the rockets, our robot had to score out of all sides for faster placement under defense. With a “yaw” degree of freedom and the ability to score out the side of the robot, the drivetrain was used to push away a defender while the robot automatically scored into the rocket or cargo ship.

To further improve cycle times, the drivetrain had a high acceleration so it could reach top speed during the short “sprint distances” between the loading station and the rocket. Both the driving and scoring operations were aided by software wherever possible to further decrease cycle times.

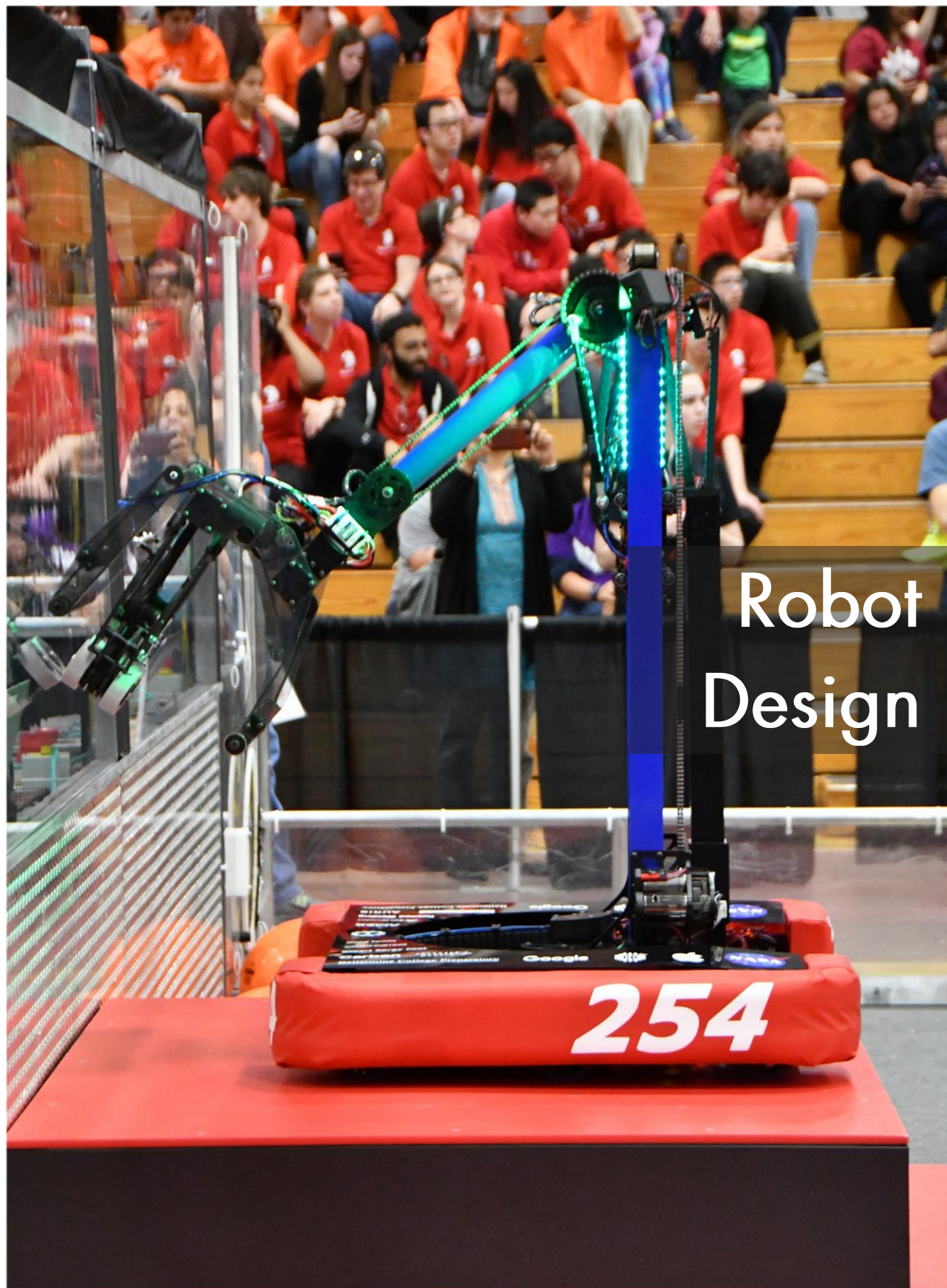
## End-Game

In qualification matches, our endgame goal was to earn the ranking point for climbing onto the HAB. This was most reliably achieved if our robot did the level 3 climb, which left the simpler task of driving on level 1 to our partner.

In elimination matches, we wanted to climb to level 3 and fit onto the platform with at least one other partner. We decided that picking up other robots was not a worthwhile strategy to pursue, because we would be able to better spend that time scoring game pieces. The point difference between three level 3 HAB climbs and two level 3 HAB climbs and one level 2 HAB climb was 6 points. This difference in points was made up for by scoring 2 balls, an easier task. Due to the small size of the level 3 HAB, a climber that used suction to allow our robot to hang off the side and leave the rest of the platform available was valuable for maximizing end-game points.



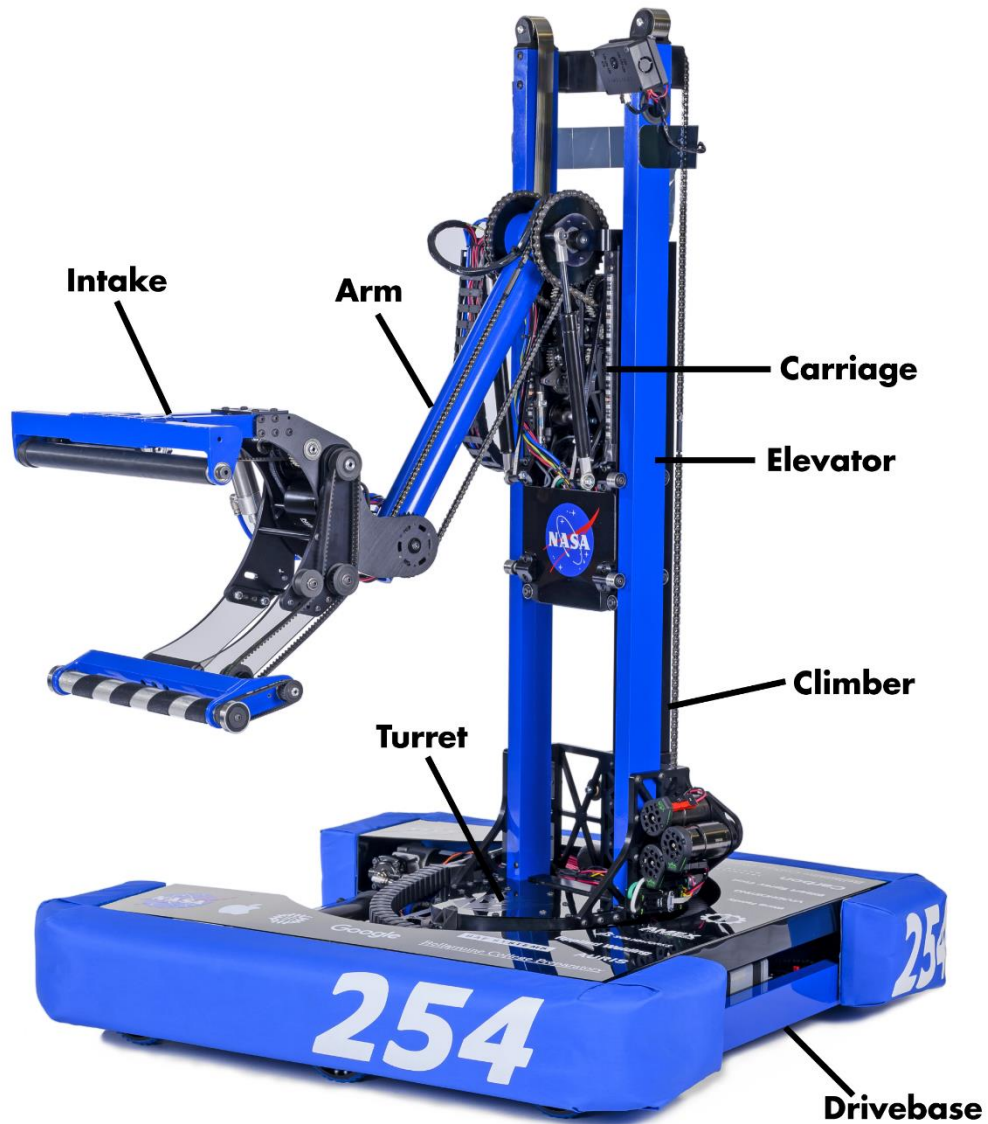




# Robot Design



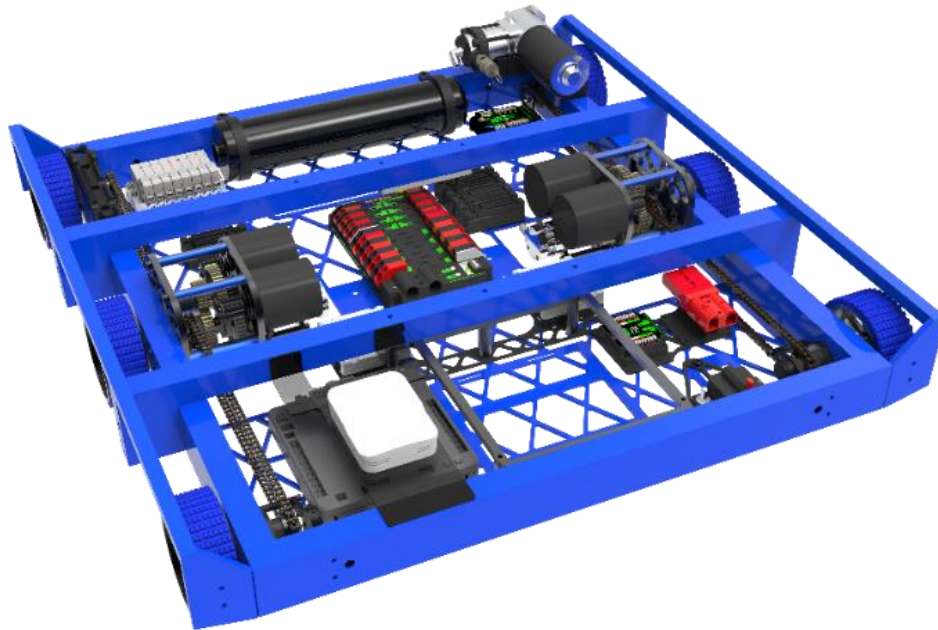
# BACKLASH







# DRIVETRAIN



The drivetrain quickly and accurately maneuvers the robot around the field. The “West Coast Drive” features nitrile wheels on a compact, square chassis.

## **West Coast Drive**

- 6 Traction Wheels with 1/8" center drop
- Familiarity with design
- Aids turning and climbing platform
- Strong and lightweight
- Easy to mount to superstructure
- Maximizes space for electronics and wiring

## **Compact square drive base**

- 28" x 27.5" frame
- Small enough to potentially fit on HAB with other robots ("sneaky climb")
- Optimal turning and maneuverability
- Square perimeter allows for scoring out of each side of the robot

## **Nitrile Treaded Wheels**

- 4" OD Nitrile Treaded wheels from West Coast Products
- Traverse platform without high-centering, while also maintaining low CG and minimizing overall weight compared to larger wheels
- Maximize traction to fight through defense and have reliable autonomous mode

# DRIVE GEARBOX



The drive gearbox provides the reduction from the drive motors to power the wheels of the drivetrain. Two 2-speed gearboxes, each powered by 2 NEO Brushless Motors enables the robot to accelerate quickly and push through defense.

## **2-Speed Dog Shifting Gearbox**

- 11.9:1 Low Gear (8.32 ft/s)
- 7.33:1 High Gear (13.5 ft/s)
- High acceleration to sprint short distances
- Low gear offers control during the sandstorm period and when overpowering defense
- High gear allows for fast cycles and long-distance travel to fill rocket by ourselves

## **4 NEO Brushless Motors**

- Smaller NEO motors package into superstructure better than mini-CIMs
- 4 NEOs provide comparable power to 6 mini-CIMs
- US Digital Optical Shaft encoders on front drive axles record wheel rotations for autonomous driving after backlash of gearbox and chain

# TURRET



The turret rotates the elevator, arm, and intake to score out of any side of the robot. It is powered by a 775pro motor and features a horizontal reverse bend radius IGUS for wire management.

## **Powered by 775pro motor**

- 227.81:1 reduction driven with belts, gears, then #25 chain (~82.2 RPM)
- SRX Absolute Magnetic Shaft Encoder tracks rotations for PID Control
- Custom hex shafts reduce backlash, improving turret aiming accuracy

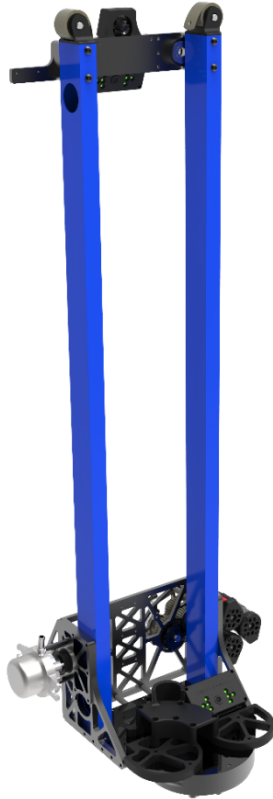
## **Double bearings to support superstructure**

- 7.25" OD 6.5" ID primary bearing with a 2" OD 1" ID lower bearing
- Lower bearing increases moment load capacity
- Double bearings withstand impacts from robot contact and falling off HAB

## **Wire management with Horizontal Reverse Bend Radius IGUS**

- Allows for +315°, -135° rotation
- Polycarbonate cover serves as shelf to support IGUS from bottom and prevent interference with turret gearbox
- Rotation allows for intaking and scoring on all sides of robot

# ELEVATOR



The single-stage elevator linearly raises the carriage and provides a degree of freedom for scoring. It holds two Limelight cameras for auto-alignment of the turret to vision targets and is powered by three 775pro motors.

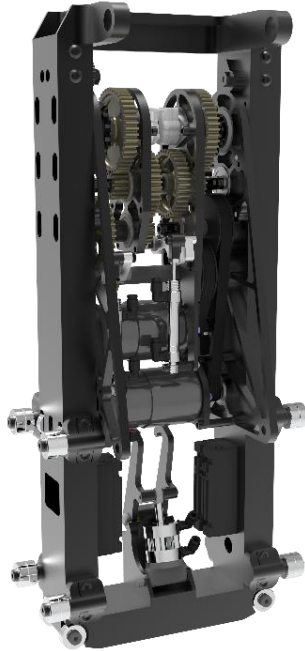
## Single Stage Elevator

- Simple gearbox and single chain loop, no complicated runs or redirect pulleys
- Works with arm to reach level 3 of the rocket
- Linear motion allows for simple deploying of suction climber
- Chain tensioned with an in-line turnbuckle to minimize backlash
- Bearings ride on 2x1x1/16" 6061-T6 box tubing uprights

## Powered by three 775pro motors

- Custom gearbox with 29.87:1 reduction drives #25 chain attached to carriage
- Estimated linear speed of 5.47 ft/s
- 3 motors provide enough power to quickly climb
- Pneumatic cylinder actuates pawl into ratchet for engageable elevator brake to hold robot up after suction climbing

# CARRIAGE



The carriage, linearly raised by the elevator, features gearboxes for the arm's shoulder and wrist. Ball bearings mounted to carriage tubes allow carriage to smoothly slide up fixed elevator uprights and are rated to take loads from climbing.

## **Shoulder and Wrist Gearboxes packaged together**

- 775pro motor powers each revolute joint
- Wrist motor and gearbox on carriage minimize arm mass for faster scoring
- Compact to reduce weight; fits between 4.75" wide carriage uprights
- Two SRX Absolute Magnetic Shaft Encoders measure shoulder and wrist pitch
- Final stage of reduction with 12:36 sprockets and #35 chain absorbs shock

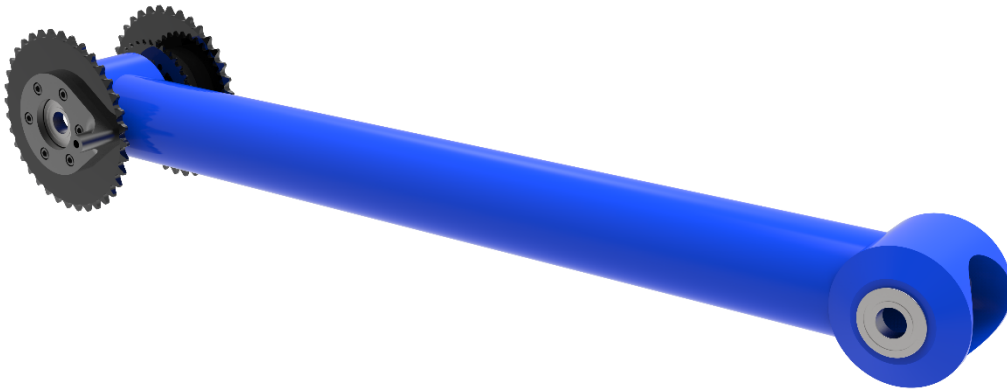
## **Ratchet, Pawl, and Comb Brake System (Former Design)**

- Brake mechanisms save power and limit motor stalling while holding the shoulder and wrist in position for climbing with the Stinger
- Climbing pneumatics plumbed together to minimize lines in turret and elevator IGUS
- Brake system not needed with suction climber since no loads pass through arm or wrist

## **Kickstand: Pneumatically Deployed Hooks for Suction Climber**

- Compact pneumatic cylinder deploys kickstand that hooks onto and pulls down suction climber carriage with elevator power
- Guarantees suction climber deploys at same rate as locked arm

# ARM



The arm consists of shoulder and wrist revolute joints to provide more degrees of freedom and reach for scoring. It is composed of a round tube with welded endcaps holding thunderhex axles.

The pre-Champs arm (16.5" shoulder-wrist center-center) was designed alongside the larger pre-Champs intake to allow scoring hatches on rocket level 2 without inverting the arm. However, the drawbacks of such a large intake and short arm, with unoptimized gearboxes causing brownouts, necessitated that a longer (21" center-center) and lighter (1 lb less, now 0.040" vs 0.0625" wall) arm be implemented for the Championship. This longer arm required inversion to score on rocket hatch level 2, but had improved reach for cargo on rocket level 3.

## **2" OD x 0.040" Wall Round Tube**

- Stronger than box tubing at withstanding side loads from hits with other robots
- Combines with elevator to position intake to score at all levels of rocket
- Shoulder and wrist on dead axles offboard wrist gearbox, minimizing weight of wrist and lightening load for arm gearbox

# ARM Cont.

## **Chain driven wrist**

- #25H chain with turnbuckle for tensioning to minimize backlash
- Chain absorbs shock loads created from running into field or other robots
- Chain creates virtual 4-bar: can move arm and keep wrist level with minimal power
- CNC Billet end caps hold bearings for shoulder and wrist dead-axle pivots

## **Gas spring counterbalancing**

- Gas springs for the shoulder (130 lbs) and wrist (40 lbs) counterbalance the torques from gravitational forces
- Minimizes the current drawn and reduction needed from gearboxes in carriage

# INTAKE



The intake strives to “touch it, own it” with a horizontal top roller to acquire cargo and wheels on pivoting jaws to center cargo or acquire and score hatches. It is positioned by the elevator and arm to all intaking and scoring positions and is composed of polycarbonate plates to maximize strength and shock absorption.

The intake used at our regionals featured dual horizontal rollers and was much longer to accommodate the shorter arm. The new intake made for the Championship is more compact, allowing game elements to remain fully within the bumper perimeter while operating the turret and being lighter and shorter to reduce torque requirements. With the suction climber the bottom roller is no longer needed and the intake now uses the horizontal flex wheels to hold the cargo. This greatly simplifies and reduces the weight of the intake (10.2 lbs vs 15.7 lbs) and allows intaking discs from the feeder station over a ball and grabbing balls on all sides of the robot, not just between bumper cutouts.



# INTAKE Cont.



## Top Roller for acquiring cargo

- 1" OD x 0.0625" Wall Aluminum Rollers with 1.25" OD neoprene sleeves are lighter, smaller, and stronger than thunderhex shafts with wheels
- Roller pulls cargo into horizontal flex wheels so they can funnel and hold ball
- Retroreflective Banner sensor detects presence of cargo to signal auto-stowage

## Horizontal Flex Wheels for acquiring hatches and centering cargo

- 3" OD Flex Wheels are compliant and deform to intake hatch via center hole
- Wheels intake hatch when jaw is closed or pneumatic cylinder opens jaw so rollers can center and hold cargo

## Polycarbonate side and jaw plates

- Enables robot to crash into walls or other robots without breaking because polycarbonate absorbs stress by bending and springing back into original shape
- 1/4" polycarbonate is stiff enough to minimize oscillations from rapid accelerations

## Powered by 2 NEO Brushless Motors

- Sufficient power and Brake Mode rapidly eject cargo or securely hold hatch
- 2:1 reduction for top roller and 10.125:1 reduction for flex wheels
- Lighter than mini-CIMs, keeping intake lightweight at end of long arm
- Gears used to reverse direction of flex wheels

# SUCTION CLIMBER



The Suction Climber is used to quickly climb onto the edge of HAB level 3 with another robot already on the platform. It consists of an arm, deployed via a bi-stable overcenter linkage, featuring a suction pad and pivot foot that reacts on the HAB platform. The kickstand on the elevator carriage pulls the climber carriage ssdown, raising the robot and bumpers higher than the platform. An engageable ratchet in the elevator gearbox ensures the robot doesn't fall back down at the end of the match.

The previous climber featured a motorized roller at the end of a "stinger" that would lift the robot up and drive onto the platform. The new suction climber allows the robot to climb hanging off the edge of the HAB, such that 1, or perhaps 2, other robots can climb up first and we can quickly climb on the edge at the last second.

Vacuum Pump powered by 775pro

- 3:1 belt reduction drives GM Vacuum Pump
- Inline ball check valve and pressure transducer restrict and measure flow for automatic climb initialization
- Suction pad features ¼" thick closed-cell foam to form initial seal on platform

## SUCTION CLIMBER Cont.



Arm deployed with Bi-Stable Overcenter Linkage

- Pneumatic cylinders actuate multi-part linkage that overcenters to lock suction arm in open position
- Bi-stable retains ability to retract arm in case of accidental triggering or canceling climb

Climber Carriage constrained by bearings and low-friction Teflon blocks

- R4 ball bearings react climbing moment loads in front-back axis
- Low-friction Teflon blocks on left and right have lower profile than ball bearings and are acceptable for minimal side loads

Kickstand deployed from carriage lowers Climber Carriage

- Small, lightweight system uses a single pneumatic actuation and dodges components in the elevator and arm gearbox
- Hooks stow within carriage and catch bar on climber carriage when deployed
- 3 Elevator Motors provide power for fast HAB Climb
- Constant force springs pull carriage up and clear of turret swept plan

## FORMER DESIGNS



**Intake V2**

**San Francisco Regional & Silicon Valley Regional**



**Stinger Climber**

**San Francisco Regional & Silicon Valley Regional**



# PROGRAMMING

## *Vision Targeting*

Two Limelight cameras provide information about vision targeting and tracking to automatically align turret, elevator, and arm to intake and score quickly, ensuring fast cycle times.

### **Target Tracking**

- Uses known height of targets along with the x- and y-angle data sent by the Limelight to calculate angle from the robot to the target and aligns the turret to that angle
- Goal trackers let the robot remember the position of a target even if it can't be seen anymore and smooth the target's position to account for noise and error in camera

## *Superstructure Motion Planning*

The Superstructure Motion Planner prevents collisions among the tightly integrated degrees of freedom and controls a field-relative turret.

### **Prevents collisions**

- Prevents arm and wrist from colliding with base and elevator
- Prevents turret rotating with the end effector in the bumper cutout
- Coordinates motion between 4 degrees of freedom
- Uses a "tuck" motion planner to keep superstructure within frame perimeter

### **Field-relative turret**

- Drivers can control turret based on field orientation
- Uses robot's gyro heading to turn to cardinal directions for scoring on rocket and cargo ship and obtaining hatch panels at the feeder station



## *Autonomous Navigation*

The robot smoothly follows pre-determined paths autonomously during the Sandstorm Period through the use of a steering controller, which controls the speed of the robot's travel.

### **Robot State Estimator**

- Drivetrain encoders and gyro keep track of the robot's position on the field
- Field-relative positioning through non-linear state estimation

### **Adaptive Pure Pursuit Controller**

- Steering controller calculates necessary velocities to steer towards a lookahead point on the path
- Uses a custom trapezoidal motion profile generator and follower to control velocity
- Paths are built from collections of waypoints, forming segments or arcs
- The distance to lookahead point from current position increases as position error increases, allowing the robot to iterate and reach its final target

### **Motion Profiler**

- Controls speed of robot for smooth acceleration to avoid jerk
- Allows for accurate path following to ensure that autonomous paths are precise and repeatable





