The General Motors Industrial Design Award celebrates form and function in an efficiently designed machine that effectively achieves the game design challenge. The design award is granted to the team that best achieves these aims while having a highly competitive robot.

TEAM 341

MAKING IT HAPPEN WITH MINIMAL *MACHINING*

DESIGNING AND BUILDING A WINNING ROBOT WITHOUT THE NEED FOR COMPLEX MANUFACTURING

Team 341 of Wissahickon High School in Ambler Pennsylvania succeeded in the 2012 FIRST game without the need of extensive machining capabilities. They did so by emphasizing strategy, focusing on the design process, and utilizing products in their robot manufacturing that allowed a high degree of flexibility.

Their entry into the FIRST robotics competition, Miss Daisy XI, was the result of six weeks of engineering analysis and continuous testing and refinement. Miss Daisy was perfectly at home on the competition field among teams with entire machine shops at their disposal.

Triumphs, missteps, and countless iterations of mechanisms that never saw the light of day on a FIRST playing field resulted in an elegant and integrated machine.

The Spec Sheet: Breaking it Down

A robot's technical specification sheet is not much different than a football player's stat sheet. And just like sports statistics, the devil is in the details. A straight forward list of components and numbers might be hiding a monster that can swing a game just by being on the field.

MISS DAISY XI

CHASSIS

- 119.8 lbs.
- 27.5" x 37" x 53"
- Wide drive base for ease of fit on bridges
- Center of gravity 4" off the ground
  -robot must tip MORE than 90 degrees forward or back before not returning to its wheelbase

DRIVE

- 8 wheel, 4 CIM drive
- 6" performance wheels with blue nitrile tread
- 2 speeds: 5 ft/sec and 12 ft/sec
- Effectively climbs the barrier and bridges

INTAKE

- 37" wide because we really like picking up balls
- Deploys over the bumper to manipulate the bridge
- Powered by AM 9015 motor
- 2 stage funneling system (3->2 in intake, 2->1 in hopper) eliminates jams

SHOOTER

- Fixed shooter on opposite side of intake
- Dual 6" Skyway wheels powered by dual FP 0673 motors
- Can make shots anywhere in the offensive zone

STINGER

- Piston with nylon skid to aid in triple balancing.

SENSORS

- Encoders and dual axis (pitch, yaw) gyro on the drive
- Optical photosensor for accurately measuring shooter wheel speed
- Camera and dual LED rings for detecting the top target

SOFTWARE

- Completely automatic targeting via laptop-based *DaisyCV* image processing application
- Target detection code can run at more than 200 frames per second; it has no problems performing real-time tracking of the target regardless of lighting or even partial occlusion (such as from the rim/net)
- Camera system outputs are fused with onboard telemetry to perform high-speed positioning and shooter spin-up (camera commands azimuth to the gyro and RPMs to the shooter)
- Software-assisted balancing for an easy endgame
- Multiple autonomous routines

Simulating the game allowed the team to set priorities early in the design process, avoiding costly changes later in the season.

The team's season started with a full day of strategizing based on the rules for Rebound Rumble. Understanding the rules and enumerating all the ways to score was a top priority. Understanding how fouls could be drawn and given helped as well.

Simulated games formed the basis for Miss Daisy's design. The takeaways from these simulations and strategy sessions began to paint a picture of the robot they would build.

341's initial conclusions were:

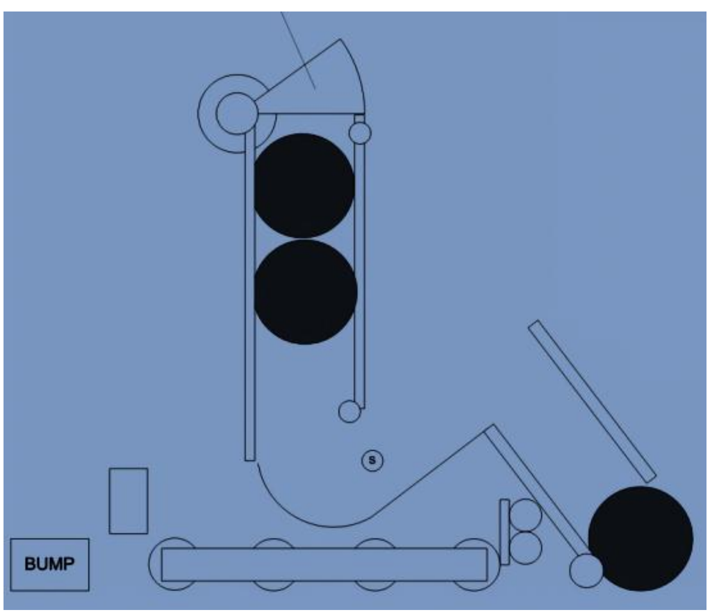
1. The 40 point balancing bonus in elimination matches was key.
2. Autonomous mode would be emphasized. Every ball scored constitutes points the opponent could not get back.
3. There were only 18 balls in the game. 3 per robot, and 2 per human player. Ball control was key.
4. Accurate shooting was required.

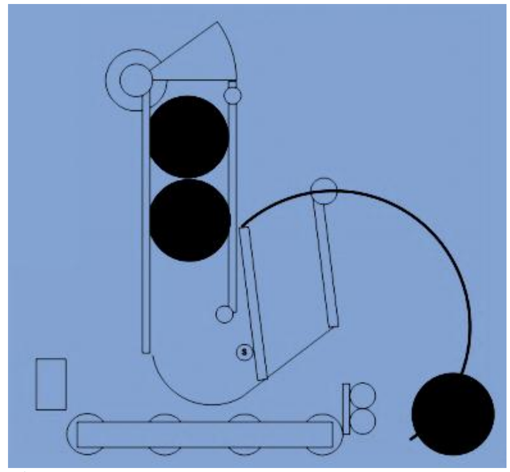
Mocking up game elements allowed the team to understand how difficult it was to balance on the bridge.

Driving Design Through Strategy

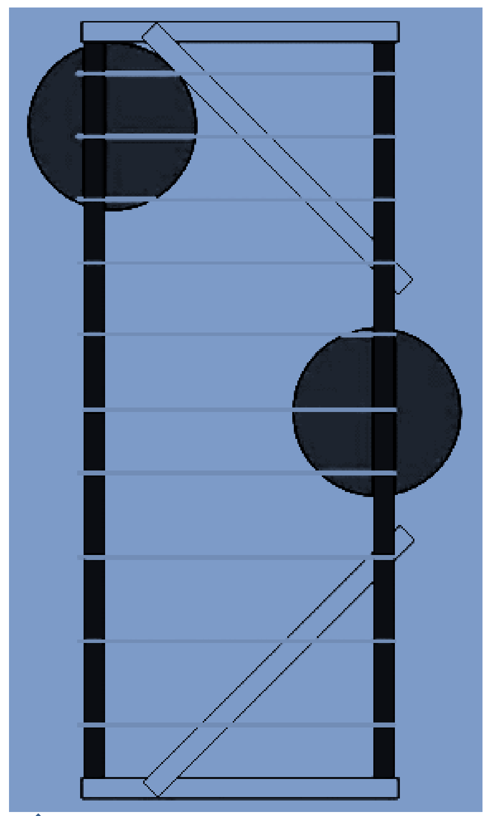
Simulation and prioritization resulted in a number of elements that became design requirements for the team. The robot would be a wide robot, but short in length to maximize the room on the bridge. The shooter would face the rear of the robot to allow balls to be picked up from the bridge and then fired at the basket without turning around. The pickup mechanism would be wide with quick acquisition. Shooting the balls would be handled by an automatic targeting system that would allow the operator to push a button and make a basket.

The game pieces presented their own challenge to the team. The team found that the balls were not uniform. They also discovered that when the balls were new, they tended to stick together. That would prove to be a lesson they would have to revisit later in their design.





The ball collector was designed to to quickly lower into place, then retract once balls had been collected to prevent damage.



A top view of the proposed ball collector has a wide intake that narrows.

A pickup mechanism that spanned the front of the robot insured they would never miss a ball.

Team Input and Buy-In to the Design

Team 341 had decided on their design priorities, but analyzing the game left them with a number of other options that needed to be weighed.

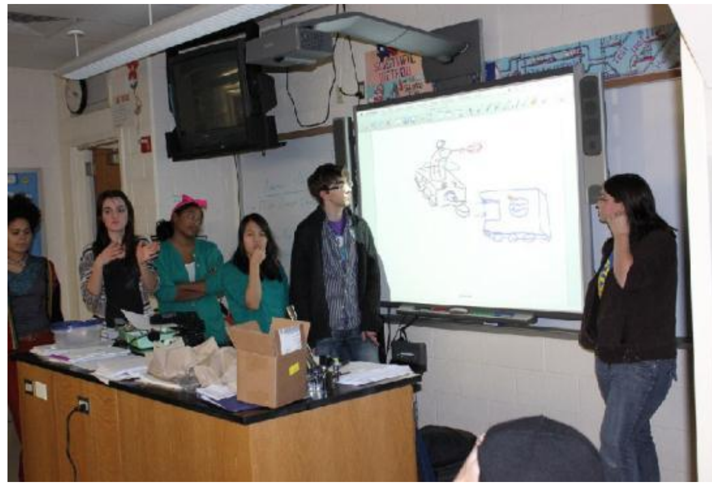
They used a team vote to decide additional design features that they would pursue then narrowed them down further with weighted objective tables and mentor experience.

Ball physics proved to be a major challenge. The team found that as the balls wore from use, their physical properties changed substantially. That drove the team to perform extensive testing to determine how they could decrease the effects of ball variability on shooting.

341 found that low angle, flat shots resulted in lower variability. In addition, they found that the outer covering of the ball was very sticky. If the balls touched as they moved through the team's ball acquisition and conveyor system, they would jam.

They also found that the balls would roll under anything. Even low bumpers didn't prevent the balls from wedging underneath the robot. As a result, they decided on a low slung smooth belly pan under the robot.

A two speed high track 8 wheel drive system rounded out their base design. A two speed drivetrain allowed a low gear that could power the robot up and over the bump, and a high top speed for getting to balls quickly.



Explaining concepts with a visual medium allowed the team to decide on a set of features that they could integrate together.

GAME STRATEGY

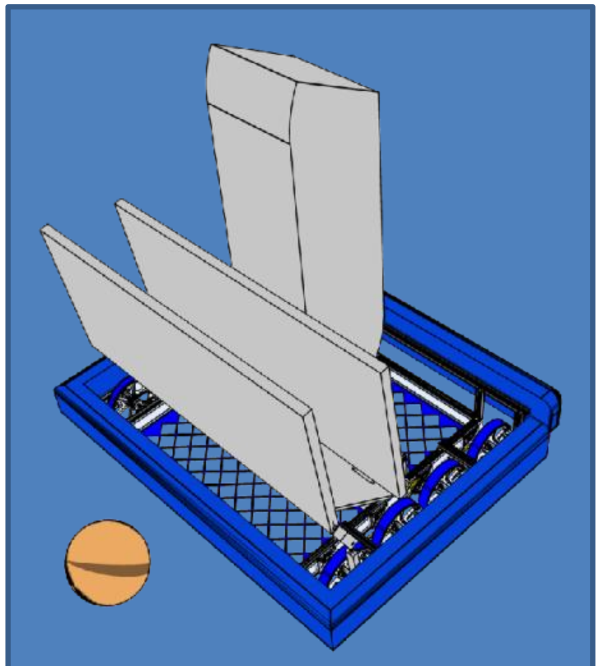
TASKS	VOTES
Pick up ball from floor	**17**
Shoot ball into high goal from long range	**8**
Shoot ball into goal from the lip of the key	**12**
Shoot ball into goal from top of platform	1
Dump ball into low goal	0
Plow ball into low goal	6
Kick/roll ball into low goal	1
Refill from human player	**9**
Intercept/block ball being shot	6
Drive up the ramp	**19**
Block other robots	4
Pin a robot	4
Change offense to defense	**9**
Sense the light/autoaim	**11**
Become unpushable	2
Block a low goal	1
Push other robots	3
Pick up other robots	1
Pass balls	0
Receive balls from other robots	1
Rebounding	2

Designing a Drivetrain by Committee

Team 341 used weighted objective tables to decide which drivetrain was best. A weighted objective table is a method of turning a decision that is subjective into one that can be numerically quantified. By assigning importance to each facet of a drivetrain, then determining how well each drive system performed in that given metric, a difficult decision became easy.

Now that their drivetrain, pickup mechanism, and shooter design directions had been finalized, a rough rendering of their robot could be created and the detail work could begin.

Due to their limited machining capability, the team chose to use Bosch Rexroth aluminum extrusion. Previous experience led them to start work on a belly pan immediately to improve structural rigidity.

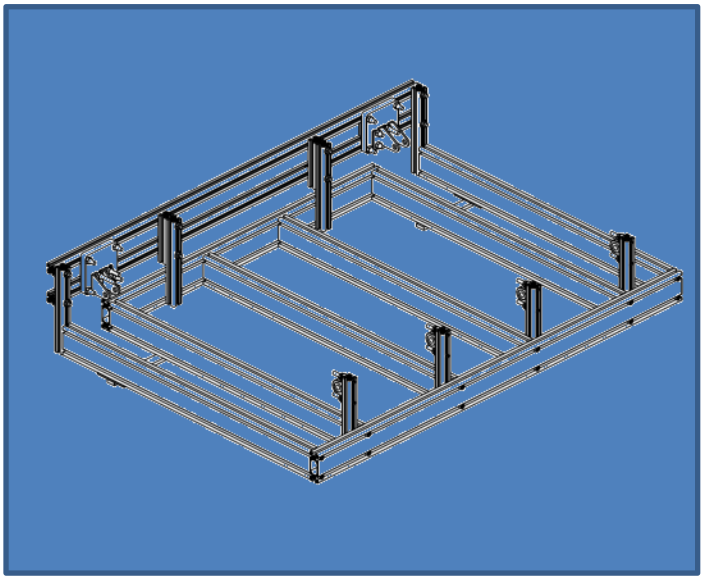


A concept rendering of the teams robot as they worked their way through different design phases shows the order in which the team placed their priorities. Finalizing the drivetrain was their first step.

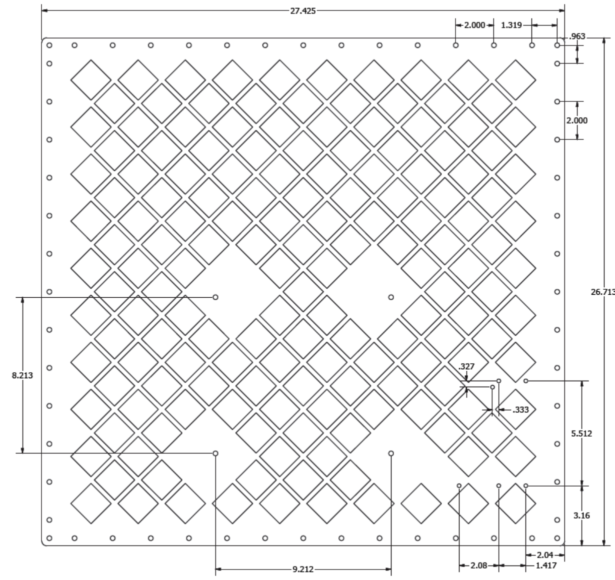
A weighted objective table helped to quantify a decision that would normally be subjective.

DRIVE TRAIN DECISION MATRIX

	WEIGHT	TANK DRIVE	OMNI	OCTOCANUM
Speed	3.5	**5**	4.5	5
Pushing	5	**5**	1	4
Strafing	2	**0**	5	4
Turnability	3	**5**	5	5
Bump climbing	4	**5**	3	4
Ramp climbing	5	**5**	5	5
Cool factor	3	**0**	0	4
Low Weight	3	**4**	4	1
Simplicity	5	**5**	3	1
Weighted Sum		**139.5**	109.75	121.5

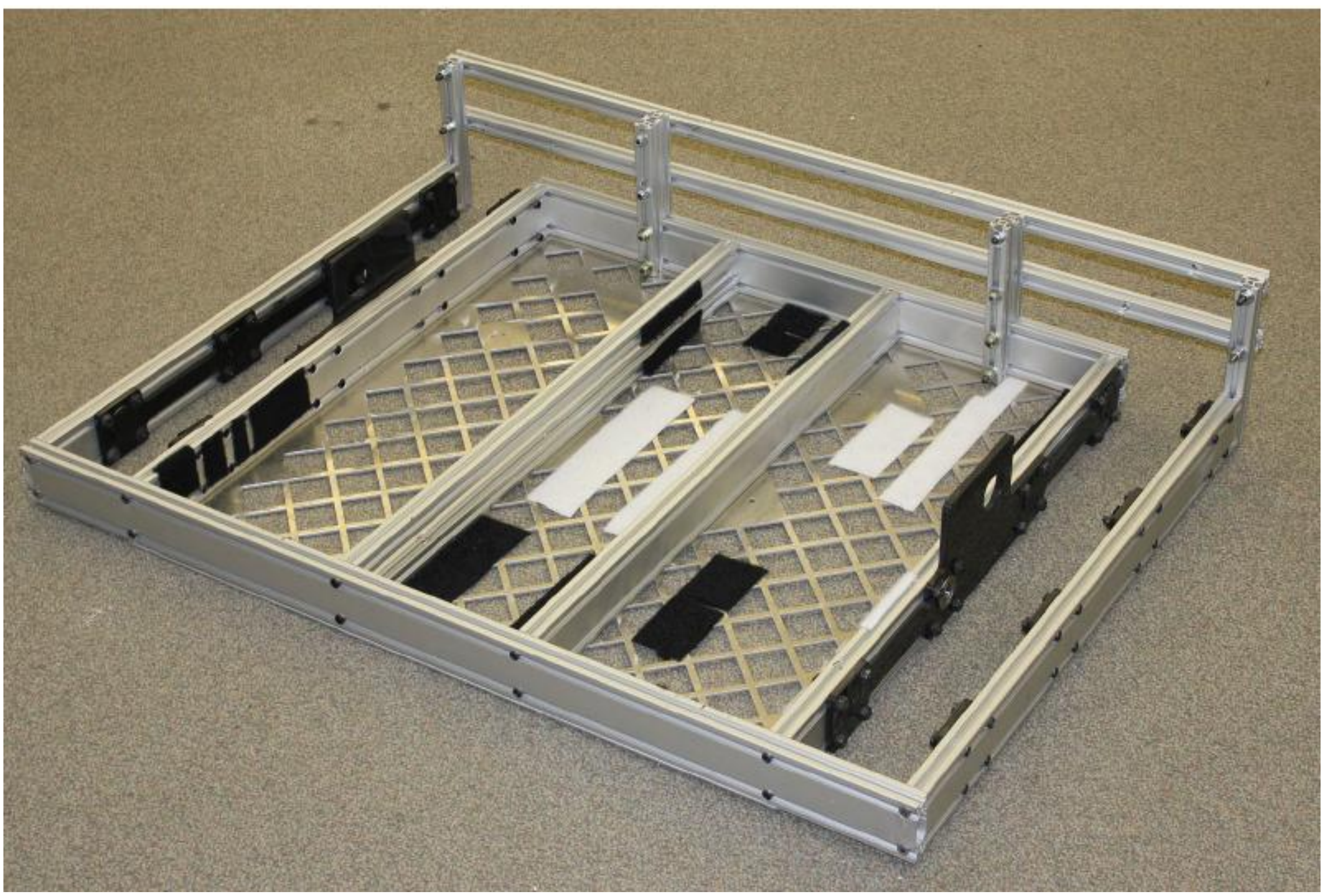


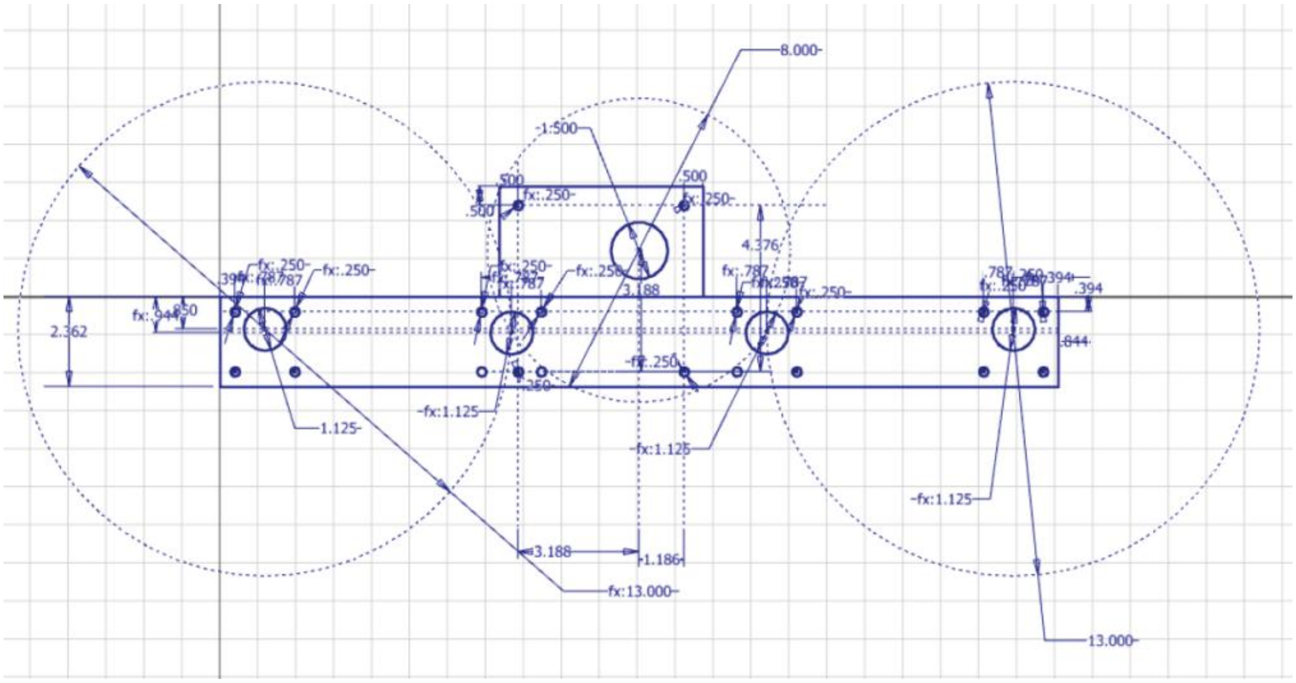
The initial concept of the chassis used Bosch Rexroth 20 x 60 mm profile. This profile is 7 times stiffer than the square profile, at only 2.3 times the weight.



A belly pan provided mounting points for most of the electrical components. More importantly, it provided rigidity to the frame.

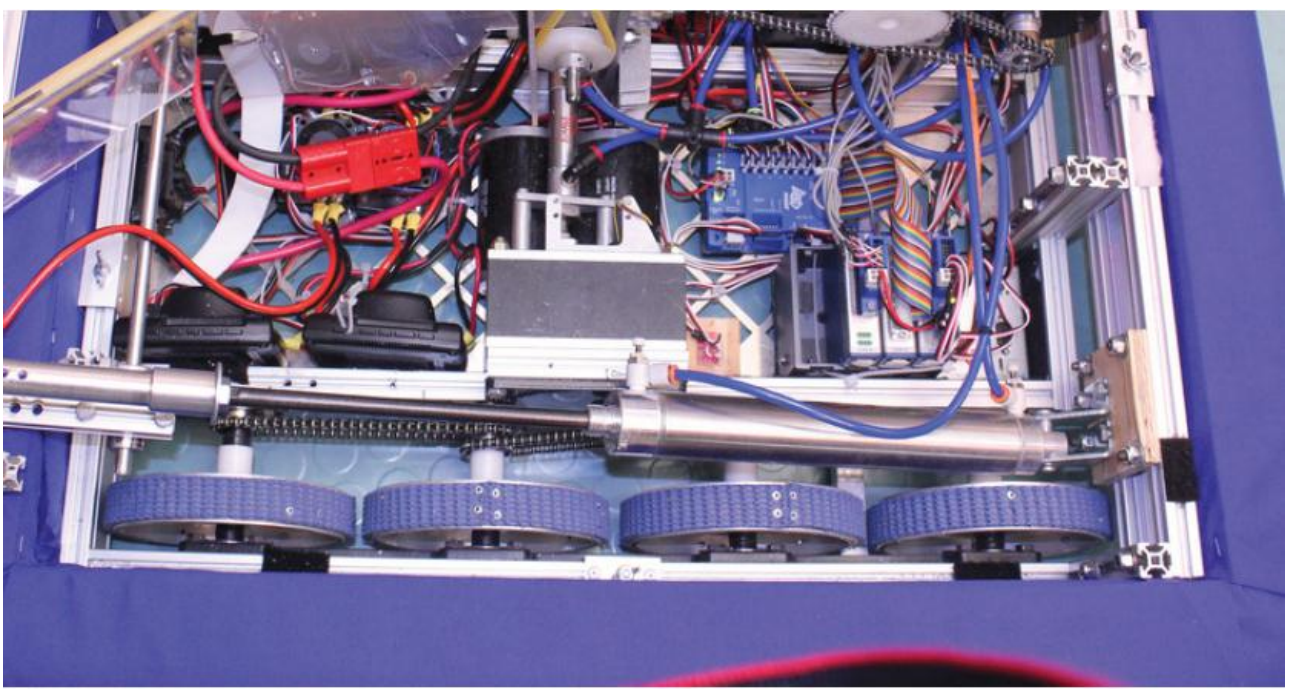
Without the need to machine or weld, the chassis comes together very quickly. The longest lead time item was the belly pan, which was designed immediately after the chassis shape had been decided.

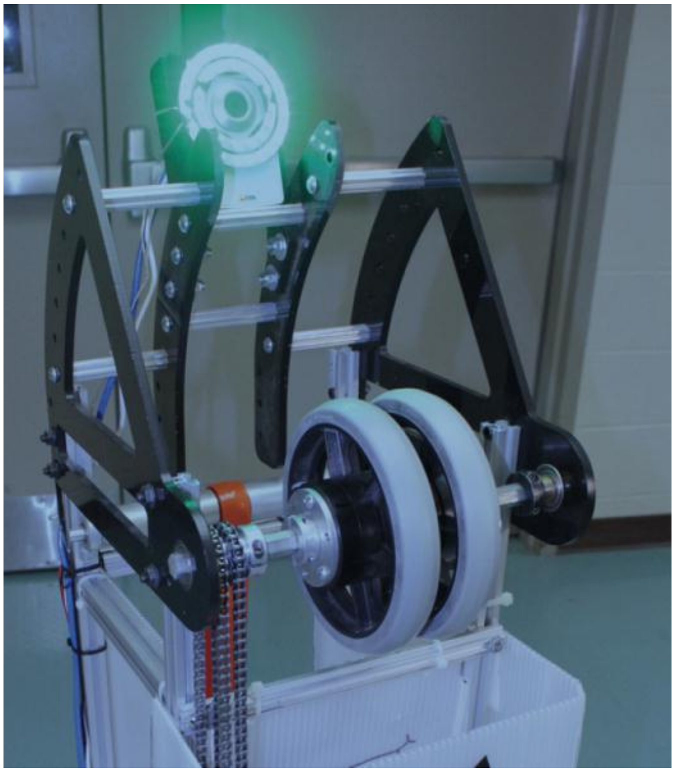




Precise distances between drive shafts allowed a drivetrain with no chain tensioners. The transmissions were also precisely placed. The middle wheels were dropped 3/32" to ensure a short wheelbase for fast turning.

The drivetrain, transmissions and electronics were assembled quickly. The two speed transmissions were pneumatically actuated.





The few machining resources team 341 had went into the creation of their shooter hood. Laser cut Delrin rails allowed smooth movement of the ball with an exit angle that the team had determined from prototype testing.

Twin skyway wheels driven by two Fisher Price motors totaling almost 600W of power allowed multiple balls to be fired accurately within fractions of a second.

Amazing Aim

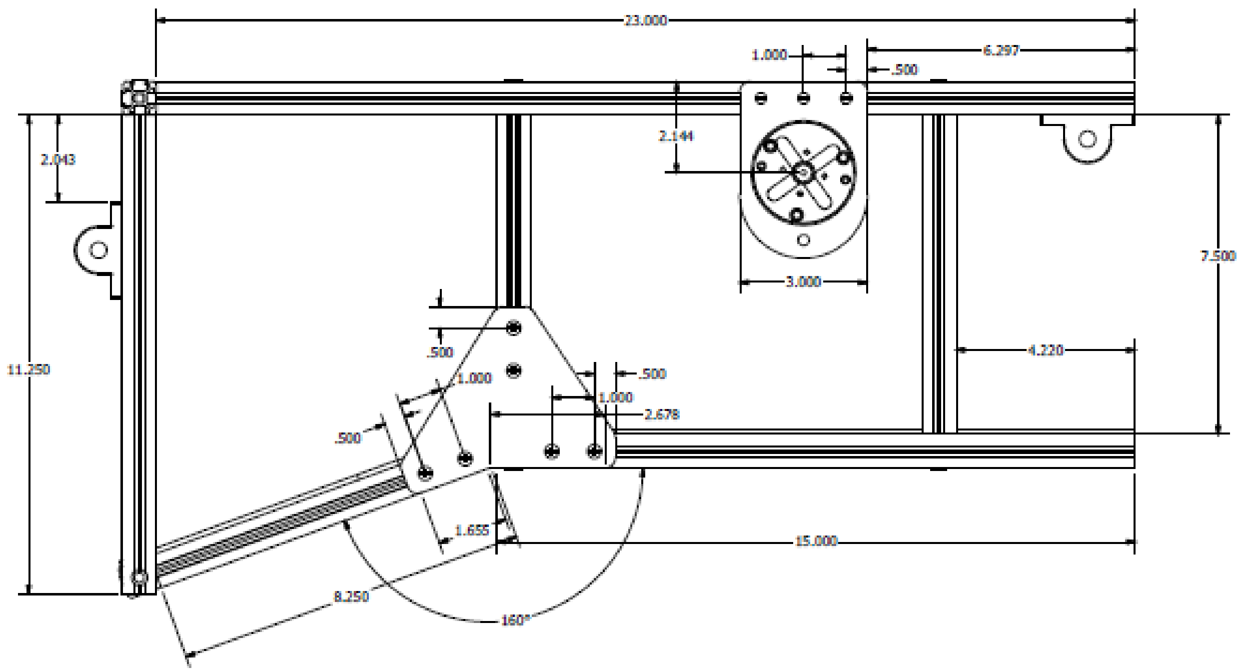
The shooter on Miss Daisy was the result of over a dozen iterations of prototyping, and a dozen revisions of CAD work.

The prototyping led the team to their dual-rail design. The dual rails were an improvement over a solid surface. They allowed for less ball compression which reduced variability due to the physical condition of the balls. The two skyway wheels with smooth surfaces provided enough friction to bring the ball to the required speed while not damaging the surface of the ball.

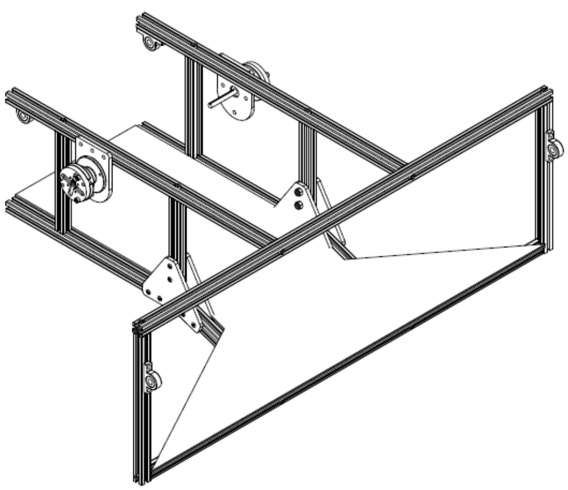
341 used a KOP Ethernet camera to obtain their images. Their innovation lay in the processing method. Instead of processing on board the cRIO control system, the team fed the data to their driverstation.

Their drivestation was running the open source vision processing software known as OpenCV. The team programmed OpenCV to accurately detect the vision targets in real time at around 200 frames per second, then feed that telemetry back to the robot.

The data fed back to the robot was used to determine the speed that the shooter motors needed to run, and turned the robot to the correct heading.



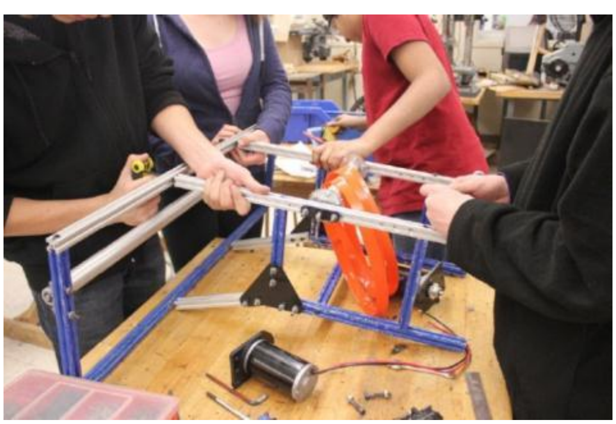
Team 341's ball acquisition system, or "claw" was straight forward. Simple gusset plates and off-the-shelf pillow block meant no machining was needed.



The wide opening at the end allowed easy acquisition, while the narrowing of the "claw" forced balls to enter the team's conveyor system in single file.

Daisy's ball collection system was designed for easy acquisition. The wide opening was designed to be the maximum width allowed: 37 inches. The maximum allowed robot dimension is 38 inches, and the team designed 1 inch under that to allow for errors in build or deformation during competition.

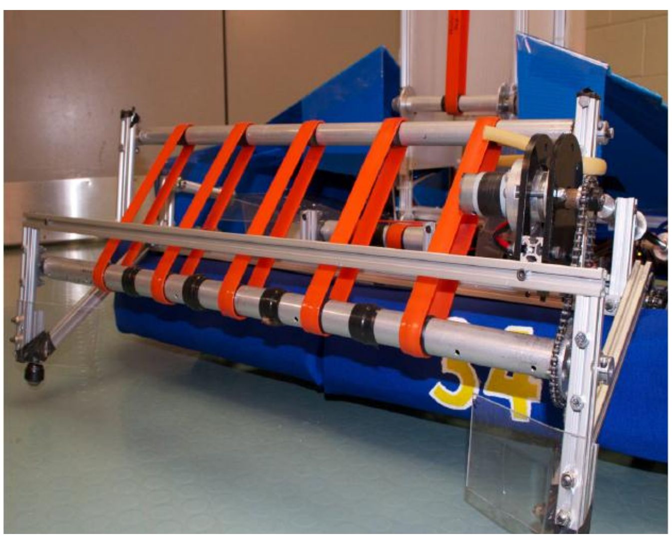
Even with extensive prototyping and design, the team ran into issues. Their design did not adequately account for the balls tendency to stick to one another. As a result their intake mechanism was jamming where the balls funneled down to a single row.



Assembly was easy with modular components purchased mostly off-the-shelf.

The claw system excelled at collecting multiple balls at the FIRST World Championship. It served double duty as a ball gathering device, and a bridge actuator.

The final iteration of the claw system was simple in theory and function. This was a common design among many top robots in 2012.



The team's solution was to completely remove the funnel portion of the claw. The new design would roll balls up and over their bumper, and a v-shaped surface leading into their vertical conveyor would allow gravity to move the balls into a row.

The final ball intake mechanism was still 37" wide. It utilized a double roller to pull the balls up and over the front bumper of the robot.

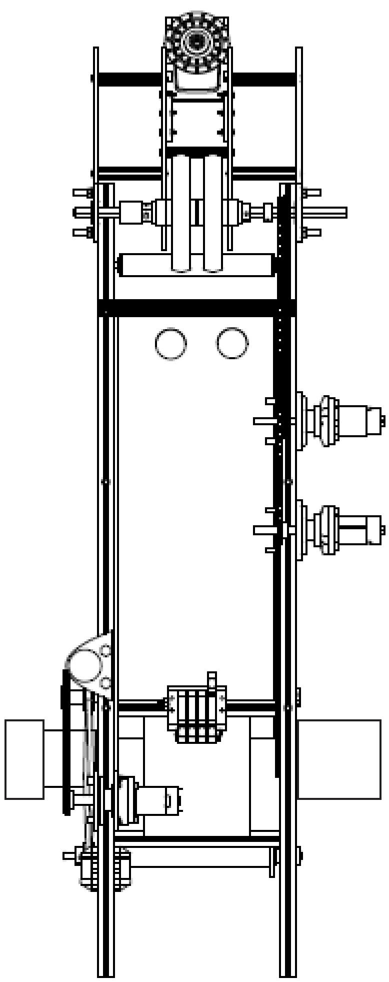
The rollers were powered by a type 550 motor. They were coupled together using flat urethane belting welded together in their shop.

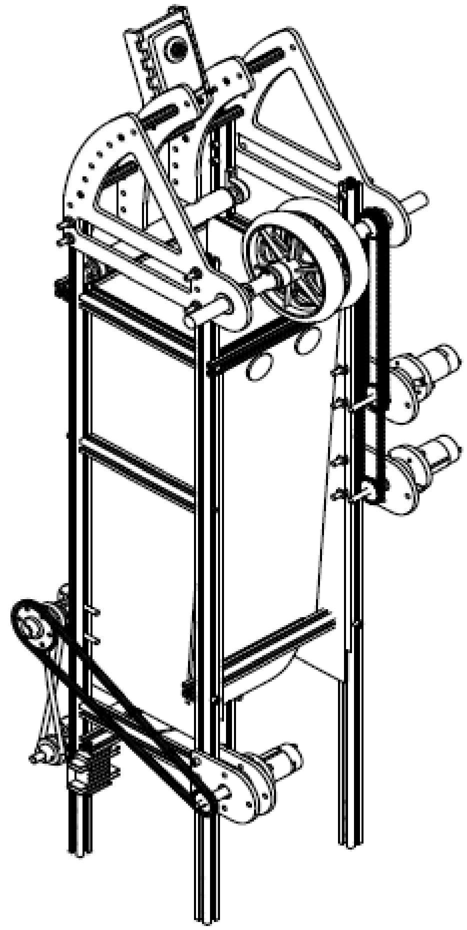
In addition, the claw itself was actuated by a pair of pneumatic cylinders. This provided enough force to lower the bridges on the playing field.

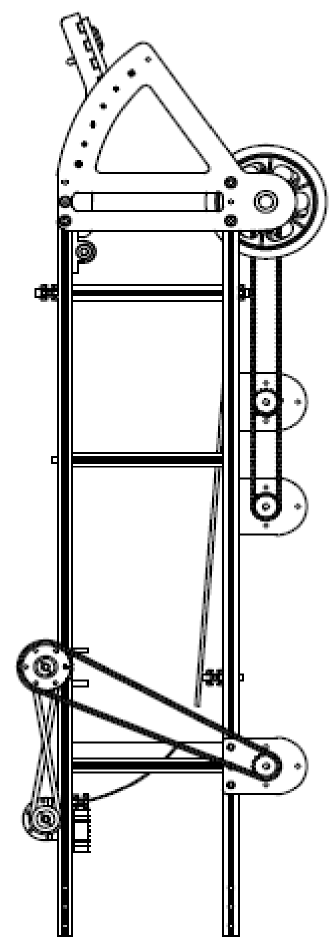
Tower Power

The team's tower was a simple framework of extruded aluminum. Flat urethane belting was used to move the balls, powered by small motors. At the top of the elevator, an optical sensor detected the presence of a ball to automate accumulation and ensure that no ball was in contact with the shooter wheels when the wheels were trying to achieve firing speed.

The tower also served as a mounting point for the shooter drive motors. The motors were set up in a unique drive configuration with an independent chain led to each. This allowed the team to use a transmission for each motor, rather than a single transmission that had both motors mounted in it. This allowed a wider selection of potential transmissions.







Team 341's decision to use materials that allowed fast assembly with a high degree of flexibility allowed them to adjust their design and address build problems quickly.

In addition, it allowed them to return and modify major components easily. Their claw redesign was critical to their success.

As a result of their choice, their modest resources were maximized, and the team built a robot that was able to compete toe to toe with the best robots in FIRST.