2010 FRC Build Season Journal:
"Building Armadillo"
By: John V-Neun

Introduction

This paper is a documented look at the Robowranglers 148 build season. It is meant to serve as the companion to my prior paper "Using the Engineering Design Process for Design of a Competition Robot." Many of the concepts discussed in the Engineering Design Process paper will be mentioned here. I strongly recommend everyone read the Engineering Design Process paper before reading this build journal.

My goal for this season was to spend more time documenting the process our team uses and logging our analysis of "Breakaway." Hopefully this documentation will help other teams learn how we do things, as well as help our team analyze and improve our own methods.

As always, your mileage may vary. The Robowranglers have access to some incredible resources (both personal and material), which allow us to run our team the way we do. Also note, we are not perfect; there are many instances where we do not "practice what we preach." We may know the "right" way to do things, but that doesn't mean we always do things the "right" way. There is always a risk in opening private areas for the public to see, try not judge us too harshly.

JVN's Facebook Wall Posts:
I posted text updates from each day of the build season on the wall of my Facebook profile. These posts will serve as touchstones to remind me what part of our process we were in on a given day.

As part of this paper, all of these posts will be quoted verbatim in red boxes like this one.

It is interesting to note, that many of these posts were intentionally vague. Our team does not release information about our strategy or robot to the public until our unveiling (which occurs sometime around ship date). In particular, NO mention of our full collaboration with Team #217 – The Thunderchickens was mentioned. I will do my best to fill in some of the "background" and explain what pieces of the puzzle were omitted from the Facebook updates.

Disclaimer:
This is a first person journal from my point of view. I am the lead engineer of a team that is committed to a side-by-side collaboration between mentors and students. Mentors and students work as peers and split the work 50/50 in all aspects of our team including the design and construction of our robot. If your team's philosophy differs greatly from this approach then you may or may not get much out of reading further.

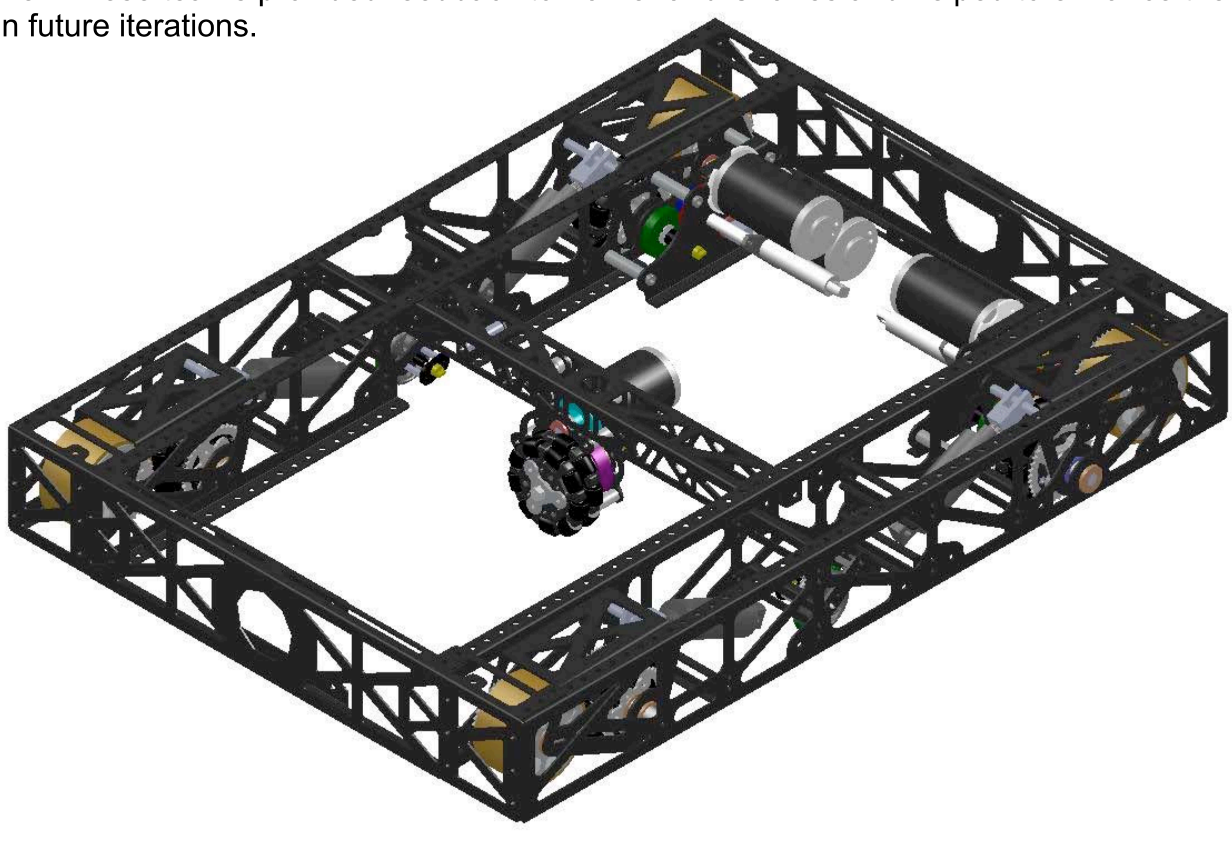
Preseason (Fall 2009)

Our team uses the fall to train and prepare for the build season. We have a robotics class as part of the curriculum at Greenville HS which is linked to our team. As part of this class, Robowrangler students participate in the VEX Robotics Competition (www.vexrobotics.com). We divide our team into five groups, balancing veterans with rookies, and build five VEX robots to compete. When building our VEX robots, we utilize the same process that we use for FRC. This allows our students to get a feel for the process and results in them being MUCH more prepared in January for the FRC kickoff. Even our rookie members will have "broken down" a game, determined a strategy, and built a robot before kickoff. This definitely helps our team hit the ground running in January.

In addition to our typical VEX activities we sometimes do some FRC prototyping work. This is not an every-year thing. We only do this if there is something in particular we'd like to try. During the 2009 season our team decided they wanted to try to build a drivetrain that would be better at scoring while being defended. Our inspiration came from something we call the "Slide Drive." This drivetrain was utilized by two of our VEX Robotics Competition teams during their 2008-2009 season; it consists of four omni-directional wheels mounted in a "normal" drive configuration, with a fifth wheel mounted in the center of the robot and perpendicular to the others.

Two of our "Class of 2010" seniors (Parker Francis and Charles Wensel) chose to adapt the slide drive for use in FRC as part of an independent study project for course credit at GHS. One major enhancement to the slide drive design was the addition of four high-traction drop-down wheels. If the robot needed additional traction for a pushing match, these wheels could be deployed. 5 Omni-Wheels + 4 Traction Wheels = 9 Total Wheels = "NONADRIVE."

Due to the manufacturing efficiencies of sheet-metal fabrication, it was a simple task to build two additional sets of Nonadrive sheet metal. Both Robowrangler collaborative partners, the Simbotics (1114) and Thunderchickens (217) were sent the parts to build and evaluate their own Nonadrive. These teams provided feedback to Parker and Charles and helped to enhance the design in future iterations.



Build Season (Q1 2010)

On January 9th, our team met for the first time in 2010. We followed our standard kickoff process. Team 148 uses the same process for all kickoffs (both VEX and FRC). As the lead engineer, I'm the one who typically leads the team through kickoff. Here is the outline I use:

Robowrangler Kickoff Agenda:

Intro Speeches

- Introduction to Kickoff
  - The start of the 2010 season...
  - Every year we gather to blah blah…
- Engineering & Design
  - What is engineering? What is design? Identification of ideas/needs, Completion of Task, Testing/Evaluation.
- Outline schedule for the day:
  - Do a quick game overview.
    - See what twists they've thrown at us this year.
  - Go over the manual as a group – Need to understand the rules before we can play the game.
  - Before we begin figuring out what the robot will do… do some basic analysis.
  - More advanced brainstorming:
  - Robot Strategy Discussions – WHAT, not HOW.
  - Prototyping & Testing.
- Let's get down to it…

Watch Kickoff Broadcast

Go over game manual as a team

- Make sure everyone understands every rule
- Start Listing Questions… What aren't we clear on?
  - Try to resolve questions as we go.
  - Unresolved rules questions should be asked on the Q&A.
  - Unresolved performance questions should be settled by Prototyping.

Brainstorming Process

- Explain "Consensus Building" and how decisions will be made.
- Discuss Brainstorming – What is Brainstorming?
  - Lone amateur built the ark... large group of professionals built the Titanic!
- Before we begin figuring out what the robot will do…
  - List all the ways to score.
  - List all the ways to de-score.
  - Do some rough scoring analysis.
  - Ratios, does difficulty match reward? Cost-Benefit Analysis?
- More advanced brainstorming:
  - List all the ways to play defense.
  - List other robot actions.
  - Robot power moves.
- Robot Strategy Discussions – WHAT the robot will do, not HOW it will do it.
- Initial Prototyping… Answering our unresolved Questions.

End Meeting

- Outline the schedule for the next 6-weeks:
  - More Brainstorming & Prototyping.
  - Decide what we're building - some games are easier to analyze than others!
  - Iterative Design Process.

Tip for Kickoff:

Get a giant whiteboard. Write down EVERYTHING mentioned during brainstorming. If you fill the whiteboard, take a picture of it before erasing. Lather, rinse, repeat...

Day 1:
The team did a great job breaking down the game. We did our scoring analysis, made a list of questions we need to answer through prototyping, made a giant list of everything a robot can do, then chose some robot actions we think are most important to fulfilling our goals. Divided the robot into subsystems and came up with concept designs for each subsystem.

Our team goes through the manual (the “Game,” “Robot,” and “Tournament” sections) as a group. We read every rule, and make sure every team member (both students and mentors) understands the meaning and intent. Our team tries to understand the “letter of the law” as well as the intent of the rule; in some situations we find examples where we think these don’t match. When this happens, we make a note to ask for clarification later. Our team also frequently errs on the side of caution; we make conscious decisions not to be the team that toes the line of the rules. We don’t want to be “that guy.” Just because we read through the key rules as a team doesn’t mean we get everything right the first time through. Every member of our team has a copy of the key manual sections, and we refer back frequently during brainstorming.

This year during the run-through, we found (obviously) several changes from previous years that stimulated discussion. In particular our team spent a significant amount of time discussing the changes to the ranking rules.

To start off our brainstorming, like in any engineering design process, we began by defining the problem. What goal are we trying to accomplish? The team suggested things like “score points”, but this doesn’t address the core problem. Our team is ultimately trying win a World Championship and that is the problem we’re trying to solve.

Ultimate Goal: Win a World Championship
Keep our eyes on "Einstein!"

How do we do that?
Win elimination matches.

How do we win elimination matches?
Our alliance scores more points than our opponents.

How do we ensure that?
Get on a good alliance.

How do we ensure that?
Be a desirable pick.
Seed High.

How do we do those things?
Build a robot that can score a lot of points, ensure we score more than our opponents in every match.
Score a lot, score quickly.

The first step our team always takes during scoring analysis is to list all the ways a team/robot can score. Then, in games involving win/loss, we look at all the ways to prevent an opponent from scoring. We also look for ways to decrease the opponent's score, though recently the GDC has eliminated most forms of de-scoring. Our scoring analysis for "Breakaway" is as follows:

Scoring Analysis:

Ways to score points:

- Hang (2 points, maximum of 6 per alliance)
- Hang from a partner (3 points, maximum of 8 per alliance)
- Score a ball (1 point, no max)
- Climb onto platform (2 points, maximum of 6 per alliance)

Ways to prevent opponent from scoring:

- Block a goal
- Block shots
- Block opponent from hanging / getting on the platform
- Pin opponent (< 5 seconds)
- Play "ball keep away"
- Intercept passes
- Control balls

Ways to reduce opponent's score:

- Knock opponent off platform / off bar (before finale)

Where is the max score? Where are the big points?:
This cannot be determined at this stage in the process because of the "no max" nature of scoring balls and unfamiliarity with the goals (difficulty of scoring, sweet spot, etc.) Our team will need to experiment to determine how many balls we estimate a team will score in a match (i.e. in an average match - elite teams will score 9 balls, good teams will score 6, average teams will score < 3).

Scoring Locks:
Get ahead by 8 points and control all the balls. (Difficult to control all the balls given nature of the robot rules.)

Estimated Average Scoring:
This cannot be determined at this stage in the process. See "What is the max score?" above.

The next thing our team does on the day of kickoff is try to make a list of ALL the things a robot can do. We make a big list of “WHAT” the robot can do, but we don’t talk about “HOW” it would do them. We then decide as a team which “WHATs” are most important to fulfilling our overall goal. Note, this list is our actual initial list from kickoff. Our team’s values changed as the season progressed.

WHAT can the robot do:

Legend:

Blue- Necessary Universal Functions - Does not require specialized mechanism (integrated into overall robot)
Red- Most Important Specialized Functions
~~Strikethrough~~ - Rejected Functions (not our style)

- Score from far away
- Kick balls over 1 bump (short kick)
- Kick balls over 2 bumps (long kick)
- Possess and control a ball
- Score from close up (plow/puke)
- Drive over a bump
  - Jump off the bump - "Dukes of Hazzard"
  - Roll over the bump - smooth transition over.
- Hang from the bar
- "Curl" robot up onto vertical bar
- Hang Quickly (< 5 seconds left)
- Climb onto platform
- Hang from a partner robot
- Lift partner robot
  - Passive lift - latch on, let them hang from us (provide some type of mechanism they can hang from)
  - Active lift - pull them up
  - Active lift - let them drive onto a ramp, and lift it
- Aim shots
- Herd balls
- Drive through tunnel
- Block a goal
- Play defense (see defense list)
- Score in autonomous
- Camera "lock" onto goal
- Evade defense
- Self-right our robot
- Self-right a flipped partner
- ~~Knock opponent off bar~~
- Avoid accidentally carrying balls (penalty)
- Don't flip over (stable)
- Deflect balls from ball track to home zone or goal
- Shoot rapid fire
- Pin other robots
- Drive FAST
- Accelerate FAST
- Push HARD
- Drive in all directions
- Shoot independent of drive train direction (turret)
- Scatter piles of balls
- Don't drive over or get hung on balls
- Spin around a ball
- Shoot accurately
- Shoot with high repeatability
- Shoot in known direction relative to robot (aim-able)
- Vary shot distance
- Shoot off multiple sides of the robot

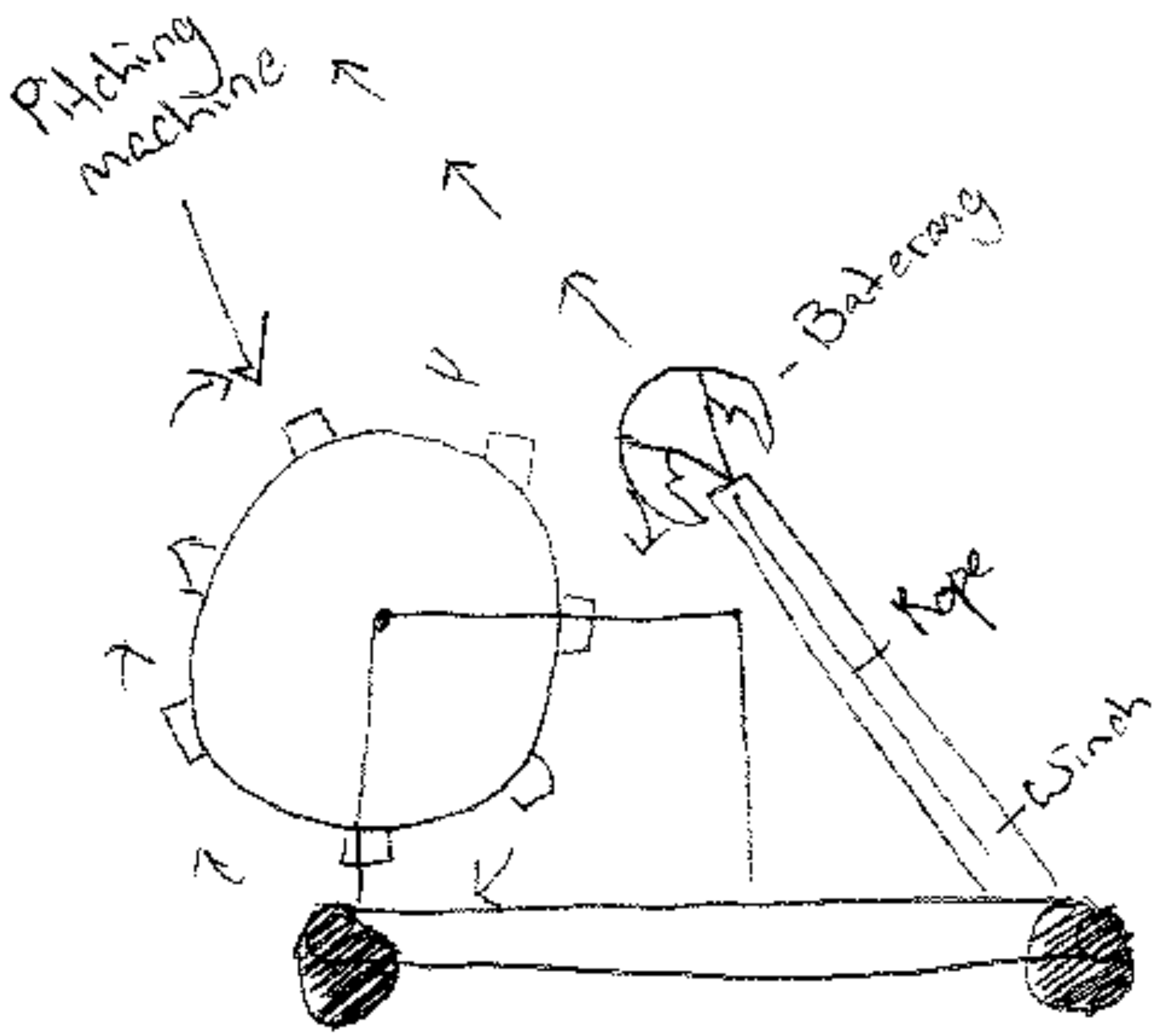
Once we have some rough determination of “what” we want the robot to do, we begin to figure out “how” the robot is going to do it. Our initial analysis yielded the following “direction:”

“We want to build a robot that can grab and control a ball, kick it across two bumps into the goal in a controlled manner, maneuver effectively over the bumps and around the field, and hang quickly.”

Based on this direction we subdivided the robot into several subsystems to be prototyped and as a team brainstormed a few key thing we wanted to prototype for each.

Hanging Subsystem:

- Prototype a 2-hook design. “How hard is it to align effectively on the bar?”
- Prototype a 1-hook design.
- Prototype a carabiner type bar latch.
- Prototype a telescoping hanging arm. (determine geometry)
- Prototype a multi-joint hanging arm. (determine geometry)
- Prototype a mechanism to hang from the vertical pole. (determine geometry)
- Prototype a gate-latch/gripper to attach to the vertical pole.
- Prototype the geometry to hang from the bump.
- Determine the best “approaches” the robot has to the tower. What is most accessible?



Ball Manipulator (Ball Magnet) Subsystem:
Big Question – *CAN WE CONTROL A BALL*?

- Prototype a suction-cup / vacuum system.
- Prototype a vertical roller claw (right/left rollers).
- Prototype a horizontal roller claw (top/bottom rollers).
- Prototype a combination roller claw (3-sided, 4-sided).
- Prototype a “pincher” ball grabber.
- Prototype a rolling “ball dribbler” (ball spins in place).
- Prototype a 3-inch deep ball funnel. “Can we center the balls on the robot?”
- Prototype a mechanism which grabs the ball in the bumper zone for less than 2 seconds.

Ball Kicker

- Prototype a linear puncher.
- Prototype a "leg style" kicker.
- Prototype a pitching machine type kicker.
- Determine power requirements:
    - Motor Direct Driven
    - Pneumatic Direct Driven
    - Energy Store then Release Driven (via pneumatic cylinders or elastic tubing)
        - Stored via pneumatic or motor input?
- Determine what parameters affect kick distance/accuracy the most.
- Determine what types of shots are best for scoring.
    - Does ball spin matter?
    - Does trajectory matter?
    - Should we roll the ball in or blast it into the chains?
- Determine if it is possible to "aim" the kick with the kicker.

Drivetrain

- How hard is it to cross the bumps?
- How hard is it to turn on the bumps?
- How hard is it to drive through the tunnel with a 28" wide robot?
- What drivetrain geometry will cross the bumps?
- Is it necessary to have a drivetrain that can move sideways?
    - When manipulating balls?
    - When playing through defense?
    - When aiming shots?
- Can we adopt the Nonadrive to cross the bumps?
- How does the robot interact with balls on the field?
- How does the robot interact with the goal ramps?
- How does the robot perform while plowing a ball up the goal ramp?
- How fast do we need the robot to go?

Day 2:
No meeting today. Everyone is meditating independently. I'm summarizing our meeting from yesterday in my Design Process log. Mr. Francis is purchasing field components so we can build our field Monday.

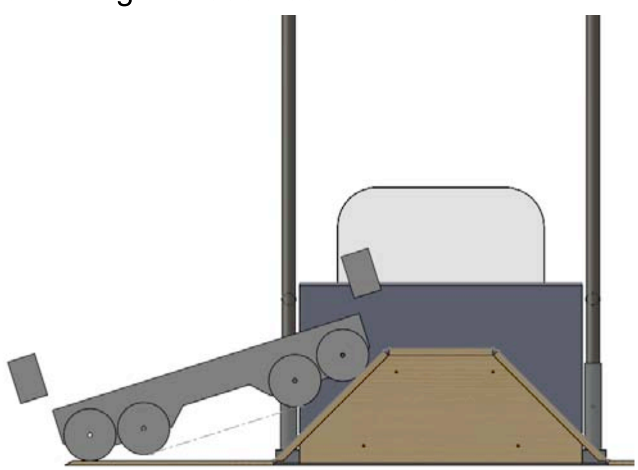
We're lucky to have space in the IFI warehouse for a full field. We're also lucky to have some parents and mentors who spend a lot of time building us our playing field each year. I don't have anything to do with the field construction except to tell them "this year we need the entire home alliance station, two full bumps, one full tower, and one full ball return." Our parent who headed up the build for 2009 and 2010 is Jim Francis.

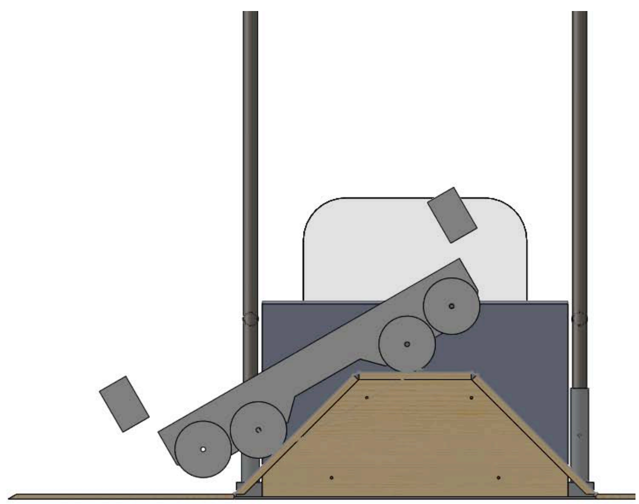
I told Jim sometime during week 1: "*Jim, I don't think you can possibly understand how much I appreciate what you do. If I had to choose between my current job as lead engineer and what you do, I'd keep my current job.*"

I don't envy anyone who must decipher those field drawings. There are a lot of things I'd rather do than that.

Day 3:
Field is coming along well, those ramps look pretty intimidating. Parker finished the Crayola CAD for the drivetrain. Prototyping groups are kicking butt: one successful proof of concept to be detailed tomorrow, one awesome napkin sketch to be prototyped tomorrow, and a third group is 50% of the way done with ...a jig we can use to figure out the design details of a major system.

We were concerned about how "violent" driving over the bumps would be. Our goal was to find some wheel geometry that would allow for a smooth transition. We were also worried about how big the cutout in the center of the robot would need to be to prevent getting high-centered on the bump. Our team also really liked the features of our pre-season Nonadrive prototype. We felt the Nonadrive would be extremely useful in this game. These were all parameters we needed to take into account when figuring out the drivetrain geometry. We challenged one of our Senior HS students, Parker Francis, with solving this problem. He built a quick parametric Crayola CAD model in Solidworks and tweaked it until he came up with something that seemed to work.





The jig I refer to is something that a group of students rigged up to test kickers. We knew we wanted to be able to kick from all three zones, and we suspected (based on our experiences from 2008) that a spring-tensioned kicker would work well for this. We wanted to be able to play with several variables to determine the best configuration. The jig built by our students would allow us to change kicker weight, kick angle, leg length, pivot height, spring tension, kicker pull-back distance, and more. We quickly learned how changing these variables individually would affect the distance of the kick and the ball trajectory.

Unplanned Collaboration

At this point in the season, team 148 starts to compare notes with our friends on team 217, the Thunderchickens to get another perspective on the game. Sometimes if our teams are thinking along the same lines on some aspect of the robot, we make the decision to collaborate on its design. In our experience collaboration doesn't work as well when it is pre-planned, the best collaborations come from two teams whose plans converge. We never force it.

This year, team 217, the Thunderchickens, came to some of the same conclusions we did. Since both teams had the same concept for the robot, and were determining the same things from their initial prototyping, the team leaders made the decision to do a full collaboration.

Each team continued to prototype independently. Lessons learned were shared during nightly design calls. Design and CAD work was balanced between both teams with SolidWorks files being passed back and forth each night; both teams had a fully updated set of models.

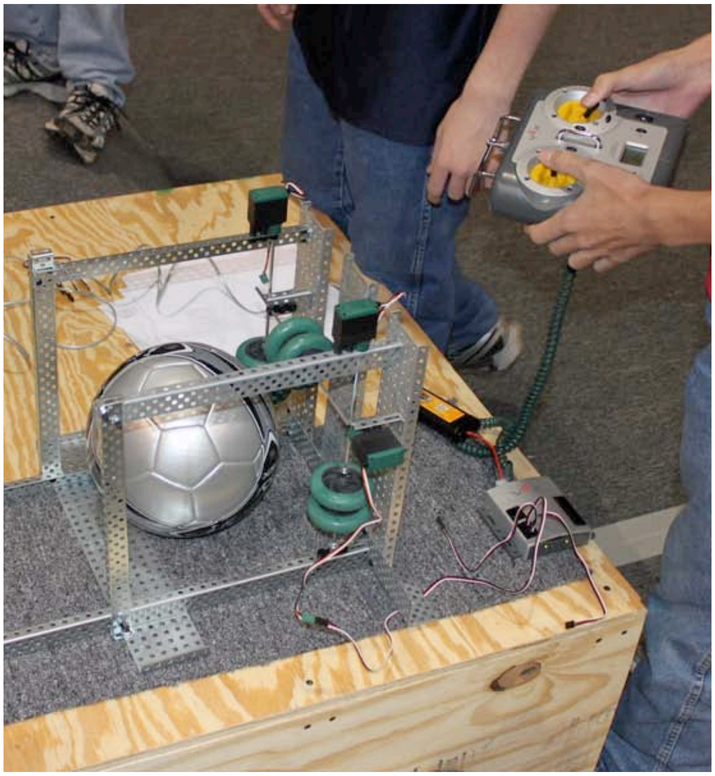
Day 4:
Great meeting, field is almost done, should be finished on Day 5. Charlie and Connor finished a critical prototype proof of concept, everyone is in great spirits. I earlier promised to hug Charlie if it worked, and had to pay up.

We tested the kicker for the first time and it cleared both bumps. Everyone was happy. I had to hug Charles (the student leading our kicker prototyping team.) We finished our first goal on this night and began taking shots on it from around the field with the prototype while tweaking the parameters (see above).

Day 5:
We "improved" one of the prototypes so much it didn't work anymore. Spent 2 hours getting it back to previous state. No hug tonight. Design is an iterative process. The other groups did great work, feeling really good about where we're at even as we celebrate another failure.

We began to tweak the kicker such that it would clear both bumps and score in the goal from all three zones with only one “kick setting” all while minimizing the space the kicker takes up in the robot. Unfortunately we tweaked it so much it stopped working. I’m proud to say that we really do celebrate failure on this team. We made a list of the lessons we’d learned, and went back to work. It is easier to celebrate failure when it is only day 5.

While all the fun with the kicker was going on, we had two groups working on ball-magnets, and one group working on a hanging mechanism. Each group came up with several concepts and began experimenting. The detailed design work of the drivetrain was also in process. Using Parker’s Crayola CAD and the fall prototype Nonadrive design as the basis, it was possible to begin work on the 2010 drivetrain.



Day 6:
Field is DONE. There is even enough memory foam left to make a little bed under my desk. The "real size" design of one subsystem is almost finished. Another subsystem is progressing nicely, lots of iterations already under our belt, lots of lessons learned.

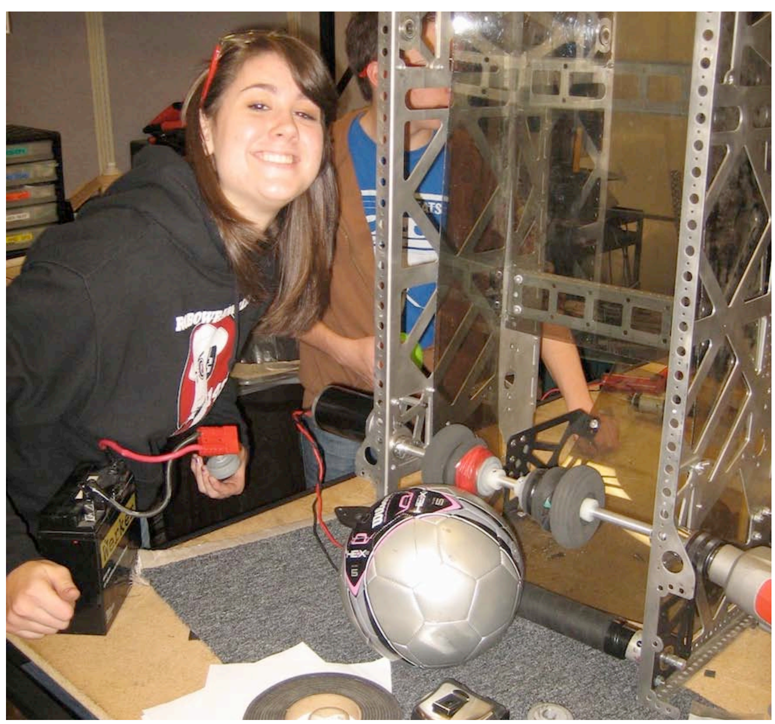
The “real-size” system I’m talking about is the kicker. After learning enough lessons about the kicker parameters our prototyping group attempted to build one that was less than 16” tall, so it would package nicely within the robot. Despite their objections they listened to me when I said, “Leave the one we have working exactly as it is, build the new one as a totally separate unit.”

We sketched a concept for a cam-tensioned, spring-loaded kicker very early in the process. We liked the cam design because it seemed simple compared to some type of engage/disengage style tensioning system (i.e. a winch back then release system). The major downside of the cam system was its inability to create variable spring tensions (varying kick distances.) Someone came up with the idea of using a pneumatic cylinder to add/remove tension from the elastic tubing if we wanted to vary the shot. We weren’t sure how many tensions we would require, but we suspected we only need two at the most, and could probably get by with one. This “search for a sweet spot” is one of the major things our kicker prototype group worked on.

The other subsystem I reference in the above status is the ball magnet. It is funny to look back at how optimistic I was about this one on Day 6. We had a lot of great concepts, and we’d throw out a lot of failures. At this point we were still experimenting with “dribbling” the ball by keeping it rolling backwards and slipping on the ground. It seemed promising enough when we just had a kid with a drill and a piece of pipe. We had multiple groups attacking this one at once.

Day 7: *<This Facebook post was just a picture of a glass of beer, with no other notes>*

All teams have their own schedules. On 148, we meet every weeknight, except for Friday, from 6:30PM until 9:30PM (the parents take turns bringing food for the engineers at 6PM every night so they can eat before the students arrive). On Saturdays we meet from 1:00PM until 6:00PM. We get Fridays off and Sundays off; typically, a lot of work gets done on these days anyway. Eventually we stop taking days off...



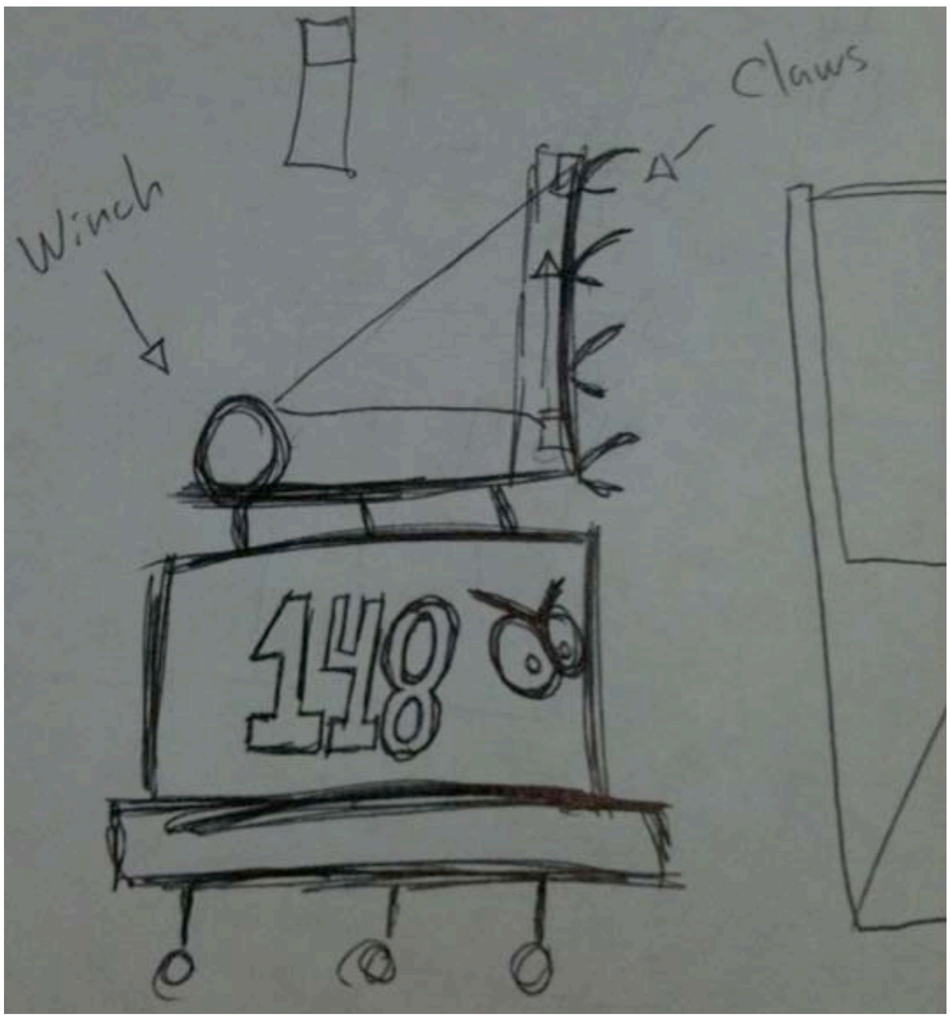
Robot Specifications

This year, several members of our design team wrote a set of robot specifications. Our team does not always do this, as we are typically less formal than that. These were written sometime during week 1. They don't necessarily match the final robot functionality, or even the final expectations the team has for a "good" robot, but they do show what the designers were originally attempting. See Appendix A for the list of robot specifications.

Day 8:
Had a huge debate as a team whether this is day 7 or 8... I wish I was joking. Another very successful prototyping day. Since prototyping is all about learning from failures, it is easy to be successful. We have the geometry finished on one of the main systems and can now move on to CAD design. The other two systems aren't close behind. Goal: finish CAD of the entire robot by next Sunday night.

I really wish I were joking about our argument; the entire team had a fight about what number day it was. Our new team motto: "Join the Robowranglers, you don't even need to know how to count!"

The kicker geometry was finalized on this day (we found a "sweet spot" we were comfortable with). Our team at this point felt it wasn't important to score in the goals from far away, but only kick the ball into the home zone; balls in the home zone would then be scored later in an independent action. This philosophy would evolve as the season went on; we would later see how accurately the robot could kick from the mid and far zones.



The only two remaining prototypes were the hanger and the ball-magnet. The hanger concept was determined very early on, as inspired by the 217 and 148 robots from 1999. Both teams felt that the mechanism to hang from the vertical pole would be much simpler, lighter, and lower CG than one to hang from the high horizontal bar. Both teams worked hard to prototype gate-latch mechanisms, hanging claws, and to determine the arm geometry (height of pivot point, size of claw, etc.).

Day 9:
No meetings on Sunday for 148... at least not this early in the season.

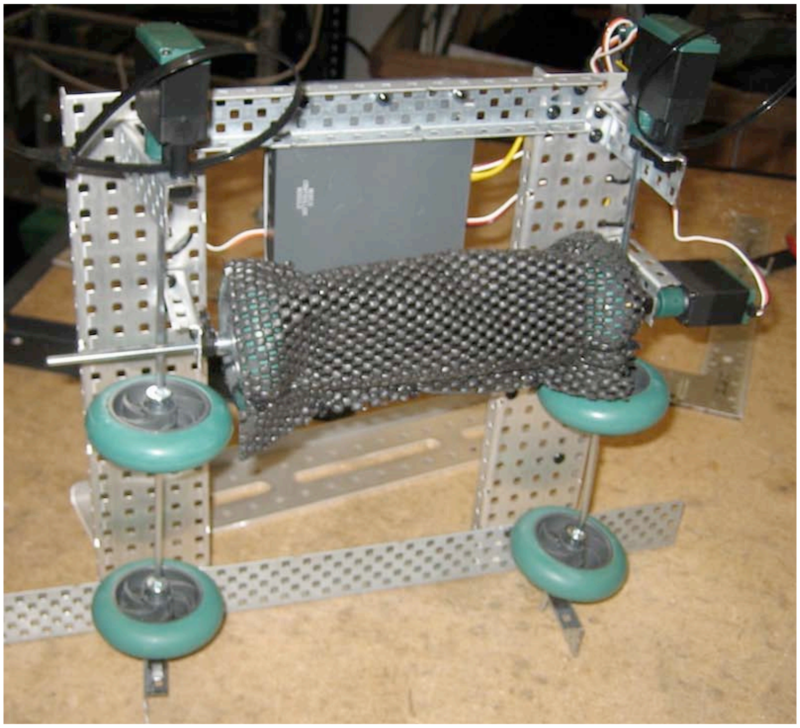
Day 10:
Begin detailed design on 4/5 of the robot! Paul is heading up that group of students while I scratch my head and try to get a finalized prototype for the remaining 1/5...

The only remaining prototype that neither team could get working was the ball intake. Paul led the Robowrangler design team while also coordinating with the Thunderchicken students and engineers. The members of both prototyping groups would now put ALL of their effort into working on the ball manipulator.

Both teams worked to refine the hanging mechanism; in particular they worked to perfect the geometry of the gate latch such that it would successfully engage on the bar without significant adjustment by the driver. Mockups placed on prototype drivebases proved successful, and this system was deemed “complete.”

Day 11:
Charlie does GREAT work on CAD details. We have reached the baaaaare minimum acceptable functionality for the remaining system. I think we're closing in on a solution. Great work by all the Robowrangler students. It is awesome to see how many answered my call for "new ideas" tonight.

This is another example of me “hiding” the collaboration in my Facebook posts. At the start of Day 11 both teams started with a clean-slate and all members were challenged with coming up with some new ideas for the ball manipulator. This call for fresh ideas was at the same time both exciting and frustrating. I’m proud at the way both teams handled their failures and continued to work using their lessons learned. At one point during the meeting on Day 11 team 148 had 5 different groups prototyping ball manipulator ideas. By the end of the meeting we had one prototype that seemed “good enough” for competition; although, I’m proud that no one on either team was ready to settle for “good enough.” This prototype was the first version of the top roller / bottom roller design which would appear on the completed robot.



“What are drawing boards for? They’re for going back to.”

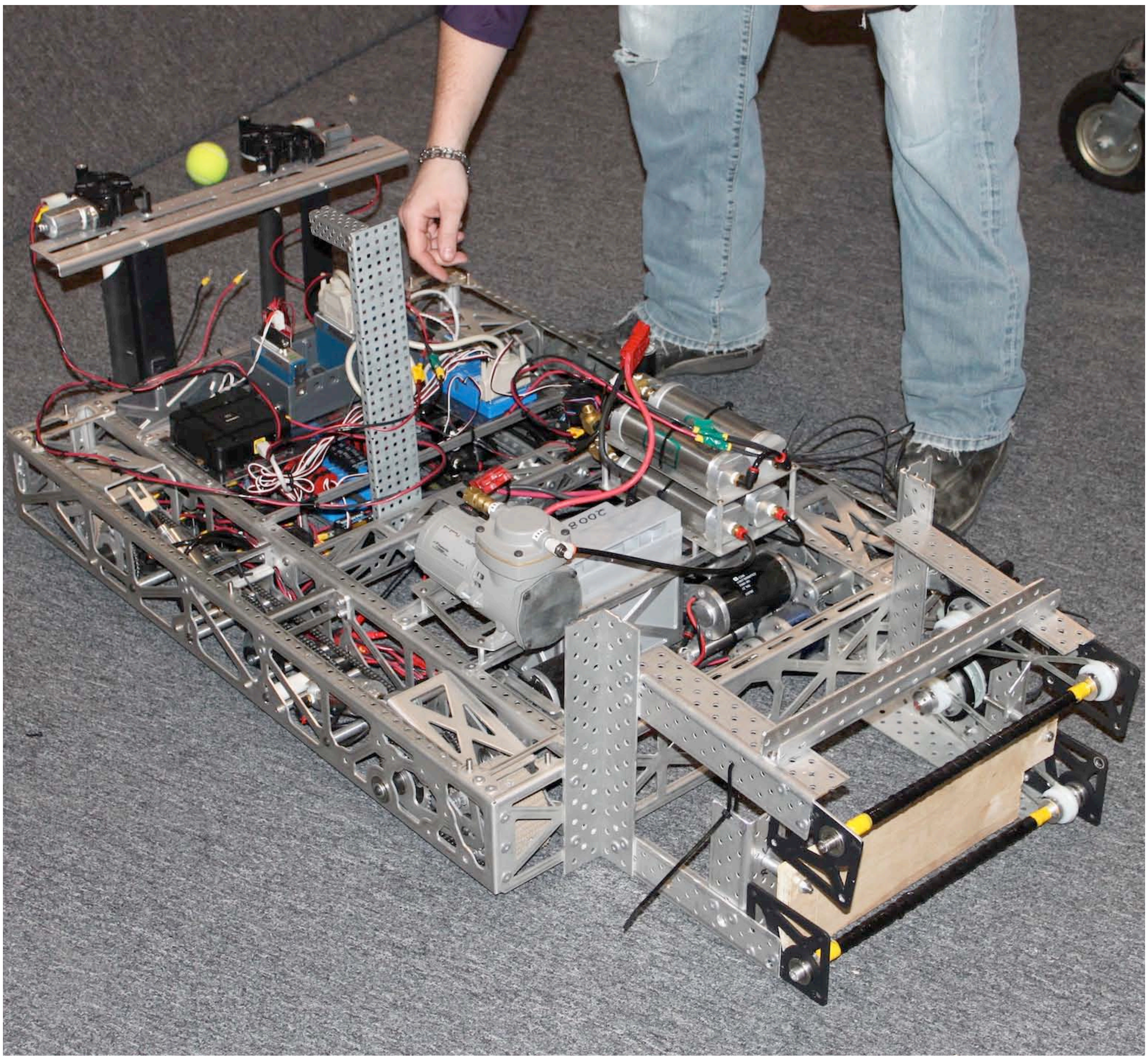
Day 12:
Our breakthrough from yesterday violated a design requirement because we didn't notice something (the devil is in the details). Taking the lessons learned and moving on. This 1/5 may be more difficult than I imagined. I don't think we're the only one struggling, but maybe we're just being picky.

The prototype roller system created on Day 11 had a pulley that was not taken into account when the designers measured to see how far into the robot the ball would enter when grabbed. As a result of this the promising results from the night before were partially negated, as the system did not perform as well with proper intake depth.

This is a very critical stage in our process. We did not have a prototype that met our desired functionality, but we did have a prototype that worked "good enough." Unfortunately this subsystem was extremely integrated into the overall robot, and much of the detailed design for the rest of the robot could not be finalized until the ball manipulator was finalized. Many members of both teams (myself included) believed we should finalize the design as it was and move onto fabrication of the robot. However there was a group (including Paul Copioli) who wanted to continue prototyping until we could find a ball manipulator capable of holding onto the ball even during a "death spin." The current system could not move backwards and turn at the same time without losing the ball.

Day 13:
Two very successful prototypes for the missing 1/5 of the robot. I think both of them show promise. We will spend Saturday trying to improve/finalize them. Each has pros/cons in different areas. I hope they BOTH succeed. It should be a fun exercise to pick which one to use on the final robot.

This meeting didn't have any results, just students working to further refine their prototypes. One was a new improvement on the horizontal roller system and the other was a prototype involving two vertical rollers. It was cool to see both of these mounted on the fall Nonadrive prototype; one on the front, one on the back.



Day 14:
Paul and I had one of our argu-discussions today about system number 5. No meeting tonight, back at it again tomorrow morning.

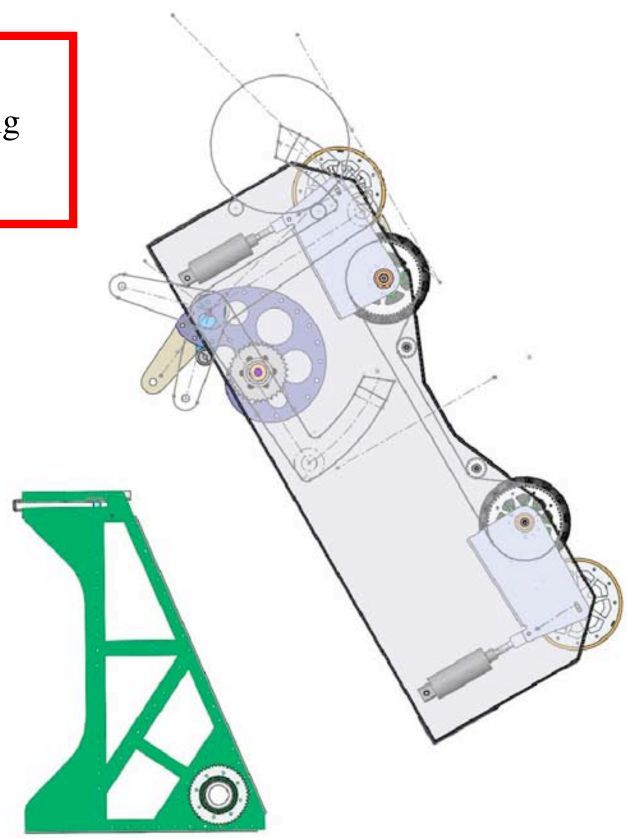
There was no meeting on Day 14. Paul and I had a long argument/discussion about the ball manipulator during lunch. We let one of our students listen to us fight, and he may never be the same. Paul and I were debating how to proceed with the development. Part of the discussion was focused around whether we should do more investigation into suction. Several of our friend teams reported success with it. We believed that suction would hold the ball very well, but were worried about how difficult it would be to actually grab the ball...

Day 15:
Another day at the robot factory.
Two steps forward, one step back. The prototypes for "the 5th system" are getting more and more detailed as we slowly close in on an elegant solution that meets all our criteria and fits within our constraints. What a fun challenge; I'm so proud of our students for keeping their cool while attacking this problem and continuing to work so hard.

Yep... we kept working. The only progress we made on Day 15 was measured in failures. I put up this great uplifting status, but really all I wanted was for the thing to work. We were all starting to second-guess our progress, and began wondering if we were the only team who hadn't "figured it out."

Day 16:
No FRC meeting this Sunday. I spent the day catching up on my real job.

Don't you hate it when work gets in the way of robotics?



Day 17:
5/5 done! Everyone is psyched that we kept going. Everyone sees now why it is important not to settle. Now it is all about detailed design. Robot parts by the end of next week? Probably. I'm optimistic about the schedule from here because of how much prototyping we did... it SHOULD just drop together.

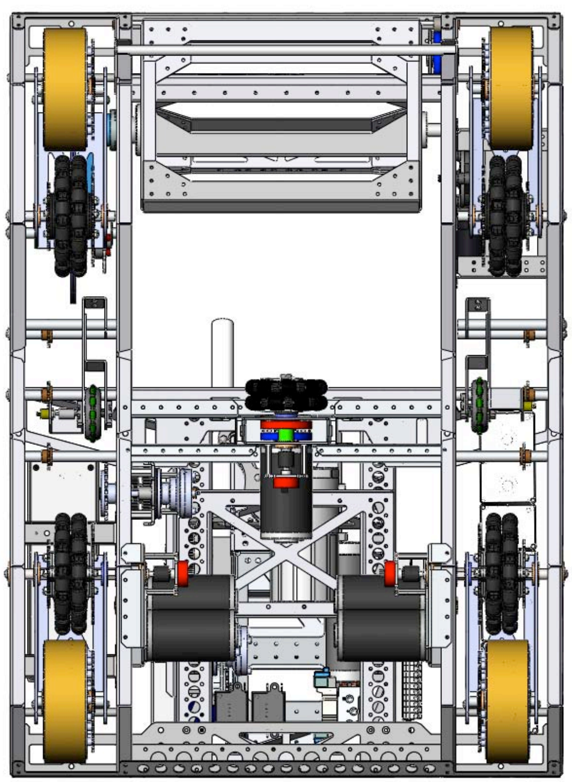
Today the prototype drivebase with a LEGAL prototype intake grabbed a ball on the fly, backed up while turning, and then did a death-spin without losing the ball. Everyone was very happy with the result. Of course when someone looked at the calendar, pointed out it was Day 17 and we were about a week behind schedule, most of the smiles went away.

Day 18:
I had to go to a business dinner tonight so I missed most of the meeting. The CAD elves are doing their dirty business...

Day 19:
The CAD elves are both hard at work. We need to be careful not to give them any clothing until the robot is done. Prototypers combined the mockups for systems 4 and 5 to make sure they work well together when integrated -- success. More tuning tomorrow. Late nights babysitting the CAD elves, but strangely enough I haven't actually CADded a single part yet...

The prototyping groups passed along the final intake geometry to the design teams. The 217 and 148 design students worked together on the CAD models. My involvement in the CAD goes up and down depending on the year; this season we had so many dedicated students I was less involved than usual. At this point in the season I hadn't yet done any design work.

In order to see how the new intake affected the kicker subsystem our prototyping group integrated our kicker prototype with our intake prototype. When the ball is held in the intake, it reduces the distance of the kick, however, increasing the amount of surgical tubing used brought the kick back to the "sweet spot." The prototyping team reported "all systems go."



Tip:
Don't do any "cosmetic" design or detailed design until the entire system is complete in a rough stage. One of our designers learned the hard way that if you draw your lightening pattern onto the part before you've figured out EVERYTHING that is mounting to that part, you're just going to end up redoing it later...

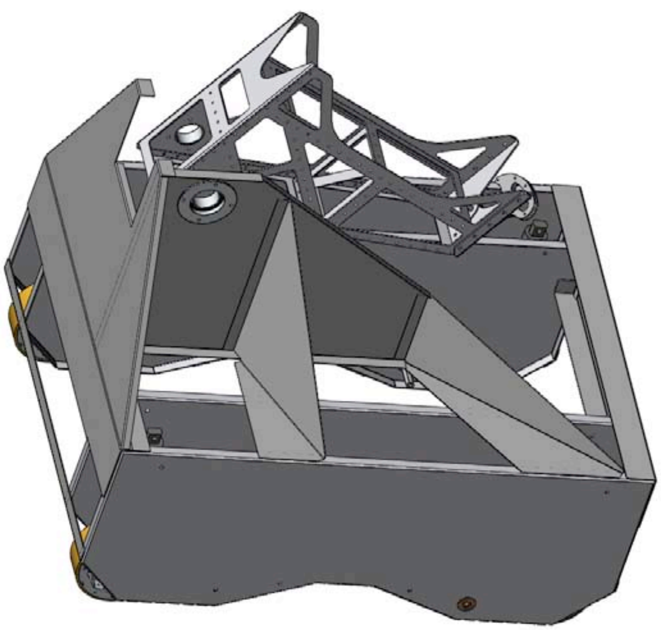
Day 20:
I missed the meeting because I'm in Arkansas on business. I assume the prototypers continued playing with systems 4/5, the CAD guys continued on the detailed design, and the SparkE's played with the fall prototype. Hopefully both Robowrangler shop rules were enforced in my absence.

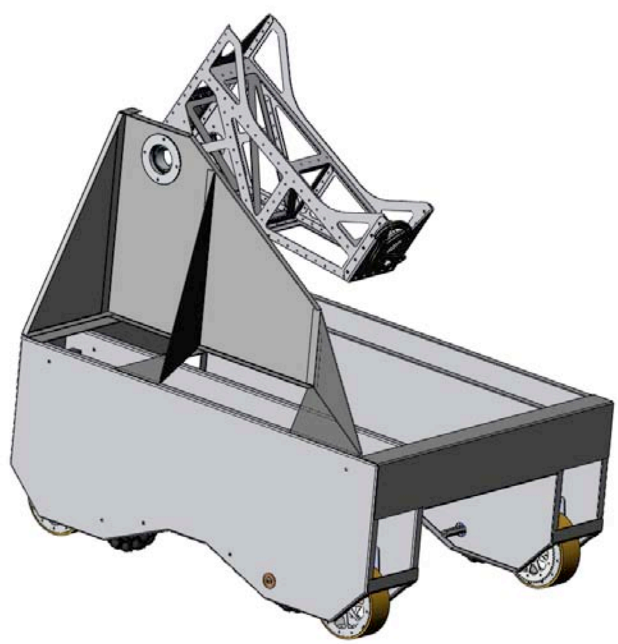
The two Robowrangler shop rules:
Rule 1 – "Don't be an idiot." (If you need to ask, you're probably being an idiot...)
Rule 2 – "Only AC/DC music is allowed."

It is a little known fact that AC/DC is the most effective "secret for success" in robotics.

Day 21:
No meeting tonight. I'm still in Arkansas. I've been providing feedback on CAD drawings via email. The CAD continues...

The magic of technology... even while sitting in meetings a student can still send me CAD renders to review. This is the phase of the year when everyone on the team starts to look at the calendar and wonder when the design team will finish. In response, the design team starts to feel the pressure and begins doubling their efforts. This is why on a Friday night with no official team meeting, several design students camped out at IFI to work on the CAD detail work.





The 217-prototyping kids were working on the hanging mechanism; building a proof of concept mockup. They learned that the hanging claw design did not exert enough force on the bar to hold the robot in place. They ran the calculations and determined that shortening the claw would result in the robot holding; a revised mockup verified their calculations.

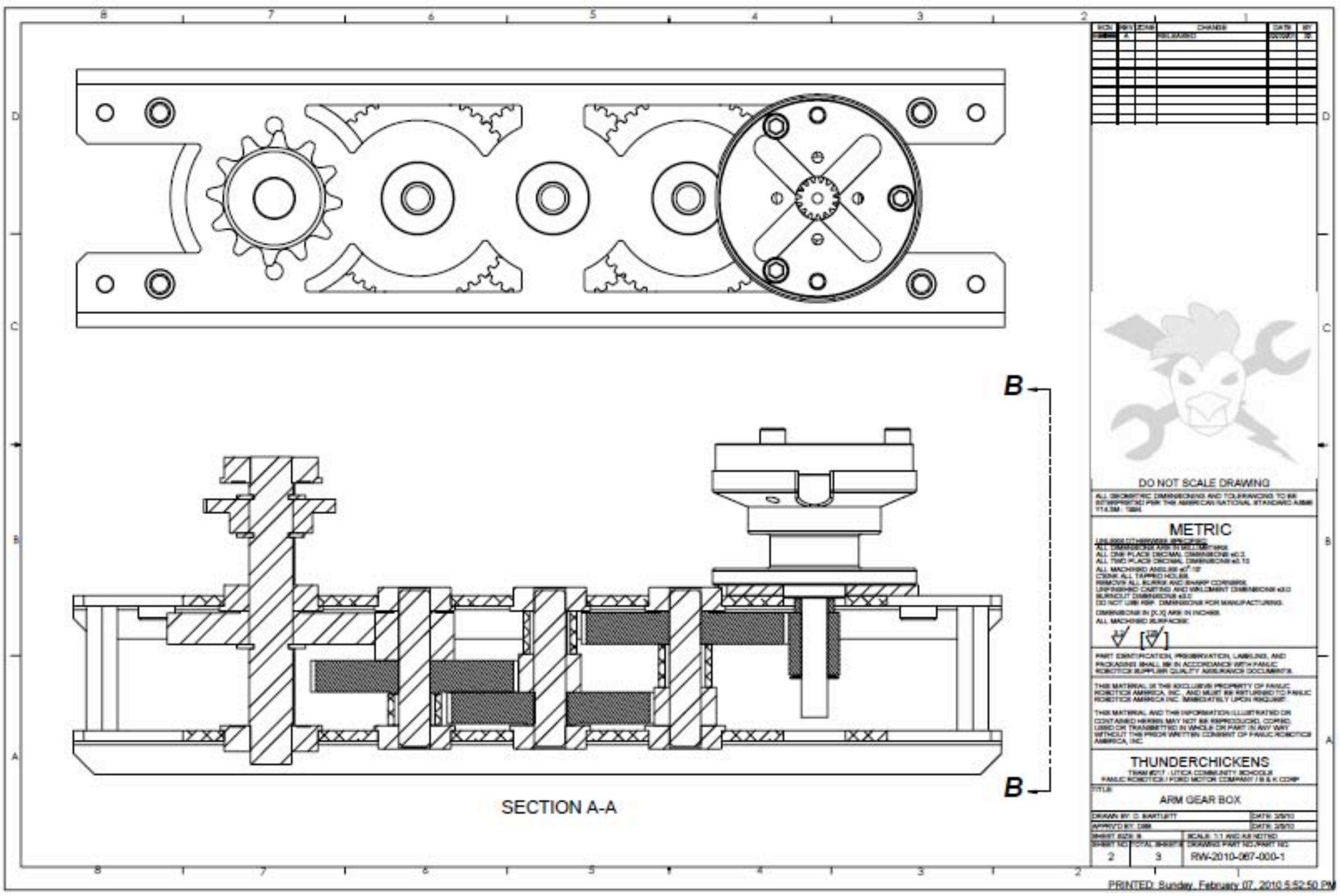
Day 22:
Spent the meeting playing with prototypes. Now the design team works late into the night trying to finish the primary sheetmetal design so we can get parts made this week.

While the design team kept chugging on the CAD models, a prototyping group played with the dual intake/kicker prototype to learn more about our kick. This session allowed us to experiment with scoring from all three zones, and determining where the sweet-spots on the field are that our robot can score from. The results of this experiment were extremely promising, but until the robot was completed we would have no way to be sure how successful we would be at scoring.

Day 23:
No official team meeting today. The design team (minus presidentioli) is meeting because we're so far behind on CAD. So much for my goal of not touching a CAD mouse this year. Truss truss truss truss truss truss...

I had to shake the rust off and start CADding. Though I'm sure the design team would have done just as well without me involved, many hands makes for light work. Those pretty trussed lightening patterns take a looooooong time to draw in.

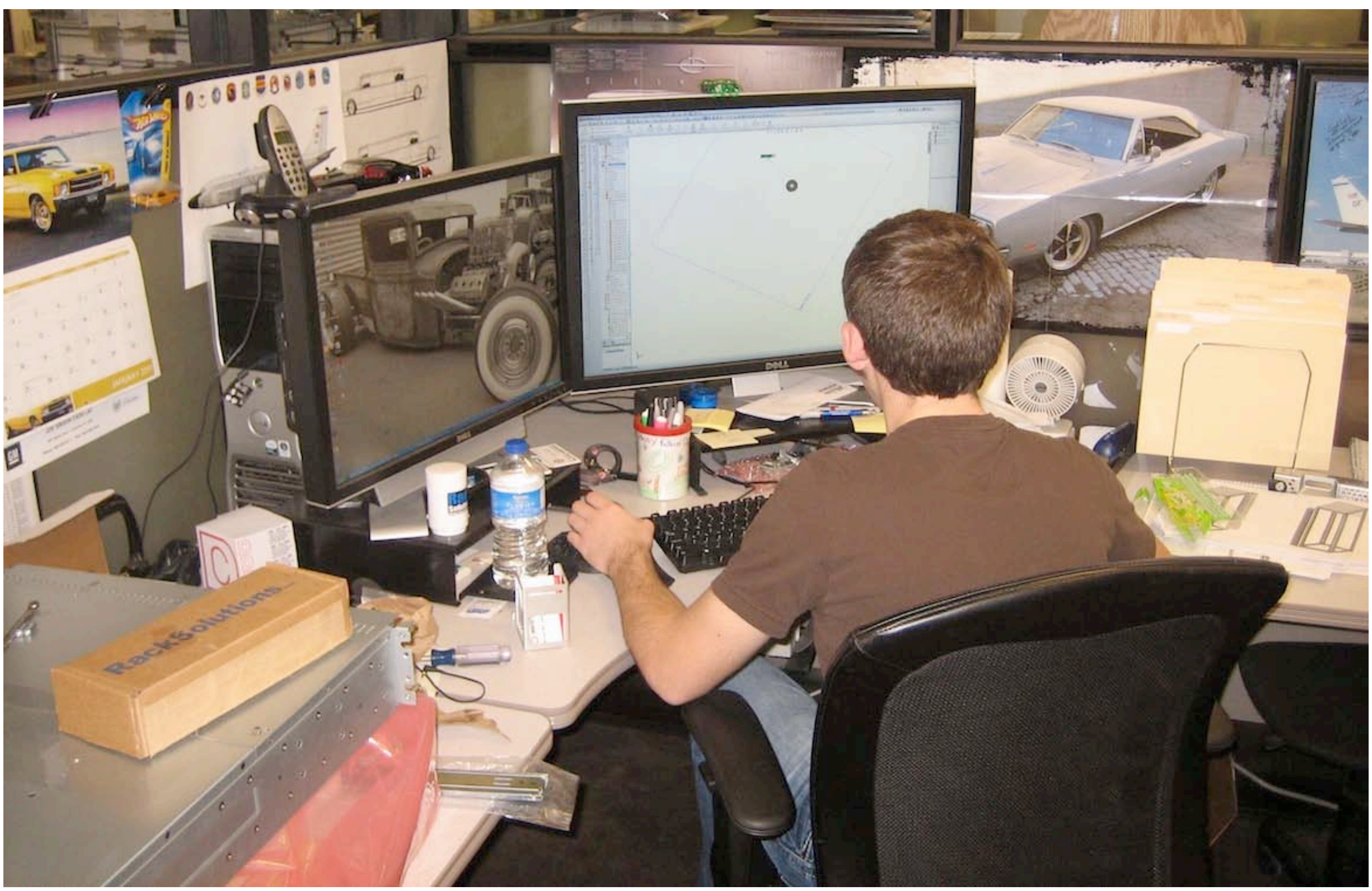
At this point in the process, the Thunderchicken designers began working on assembly drawings for all the subsystems.



Day 24:
I don't even know what happened at the meeting because I was CADding all night.... and I'm still CADding... drawings to the shop by Wednesday morning, parts by Friday.

Day 25 / 26:
I've been awake for 37 hours. Thanks to the hard work of all members of the design team I sent 75 (yes, seventy five) different parts to the sheet metal shop (that doesn't account for multiples of the same part.) This is going to be the most complex and hopefully impressive robot I've ever worked on. I'm thankful to be on a team with such incredible people. Parts are arriving Friday...

When everyone is waiting on the design team, the design team picks up the pace. It takes a great deal of time and effort to detail out the entire robot, and our team has learned just how important this is. This is where people new to our team start to get nervous. Almost four weeks have gone by and our team hasn't manufactured a single part or installed a single screw. Our friends on The Cheesy Poofs have been CNCing almost non-stop since kickoff and they usually remind us how far behind we are...

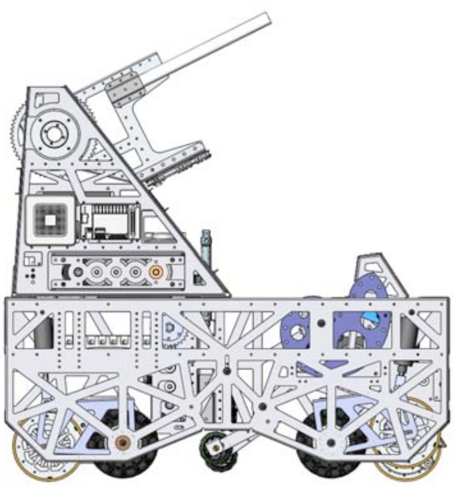


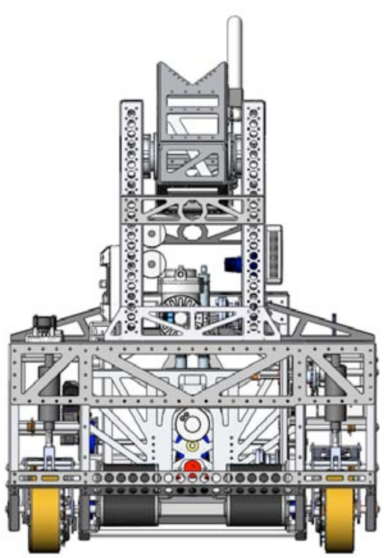
Day 27:
I spent most of the meeting dubbing a YouTube video with @Brandon Martus, and several Wrangler students. Manufacturing of some of the small lathed parts was started tonight (CAD elf = lathe elf?). I went over to the shop today and checked out the sheetmetal... beautiful stuff so far. The next 4 days will determine whether our build will be painful or easy.

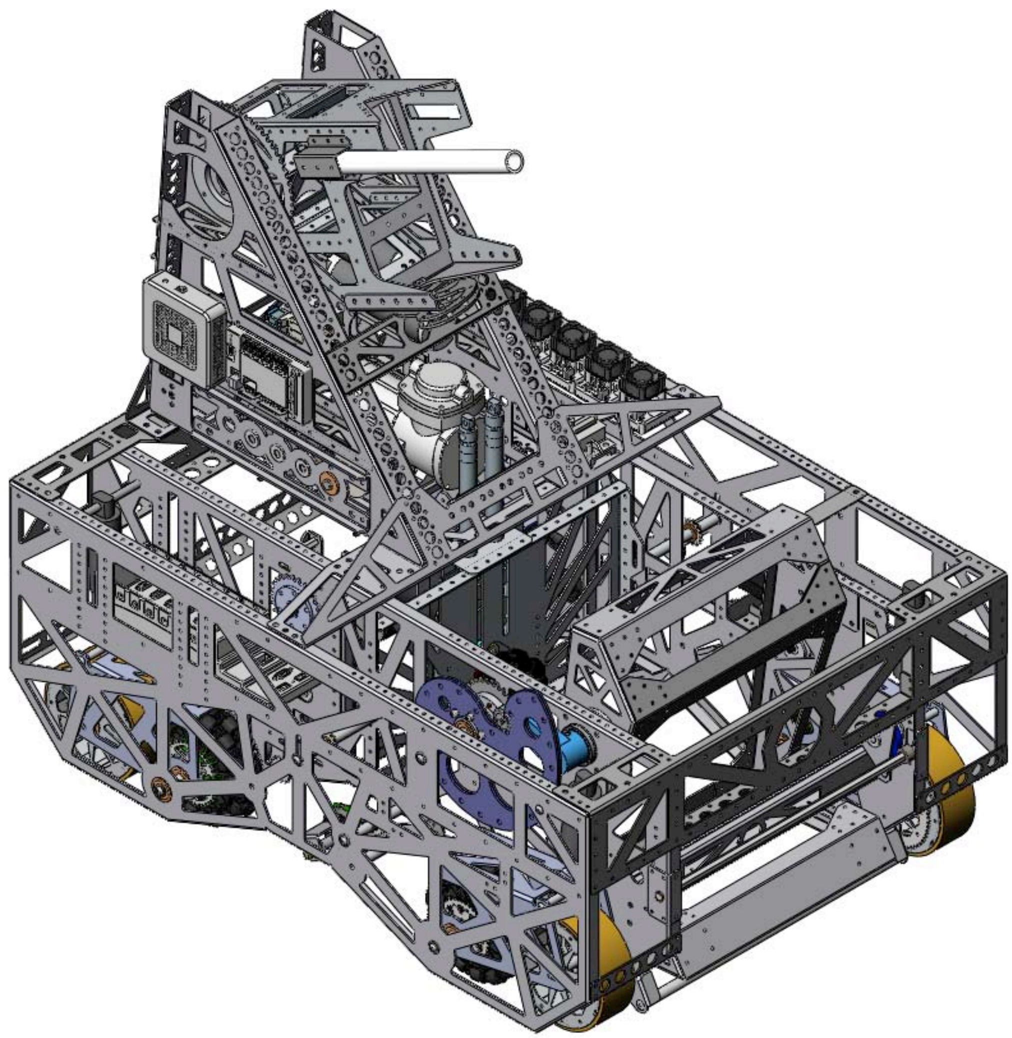
Our team gets incredible turn-around times from the shop. Usually if drawings are delivered in the morning, the parts are done by the end of the day. However with 75 distinct parts this year, it took a little longer for them to finish. We're lucky to have so much support from our sponsoring company and sponsor shop.

There has been a lot of interest from other teams about how our sheet metal is manufactured. The members of both the Robowranglers and the Thunderchickens spend a lot of time at competition talking about how our process works and how our parts are manufactured. To help explain this to the community, we made a video outlining "How It's Made."

Check out the Robowrangler/Thunderchicken 2010 *How It's Made* video at:
http://www.youtube.com/robowranglers/







Day 28:
Sheet metal is here!!!

Several pallets of metal were delivered from the shop. Due to economies of scale, once the parts are programmed, it is just as easy to manufacture multiple copies of parts, as it is to make one. The shop provided enough parts for each team to have a competition robot, a practice robot, as well as a set of spare replacement parts. We divided everything up and sent 1/2 to Michigan for 217. Using the Thunderchicken exploded drawings, our students began the robot assembly process. On 148 we have a saying that "Every Wrangler is a Riveter;" this means that every student puts their time in during the assembly process with no exceptions.

Day 29:
All the practice robot sheet metal is assembled. The competition robot sheetmetal is about 80% assembled and is now on its way to the powdercoaters. Gearboxes are lagging behind because we're waiting on parts. Once we get all the gears and shafts done we'll be good to go for a preliminary assembly. Hopefully she drops together nice... If the sheet metal is any indicator, we're in great shape.

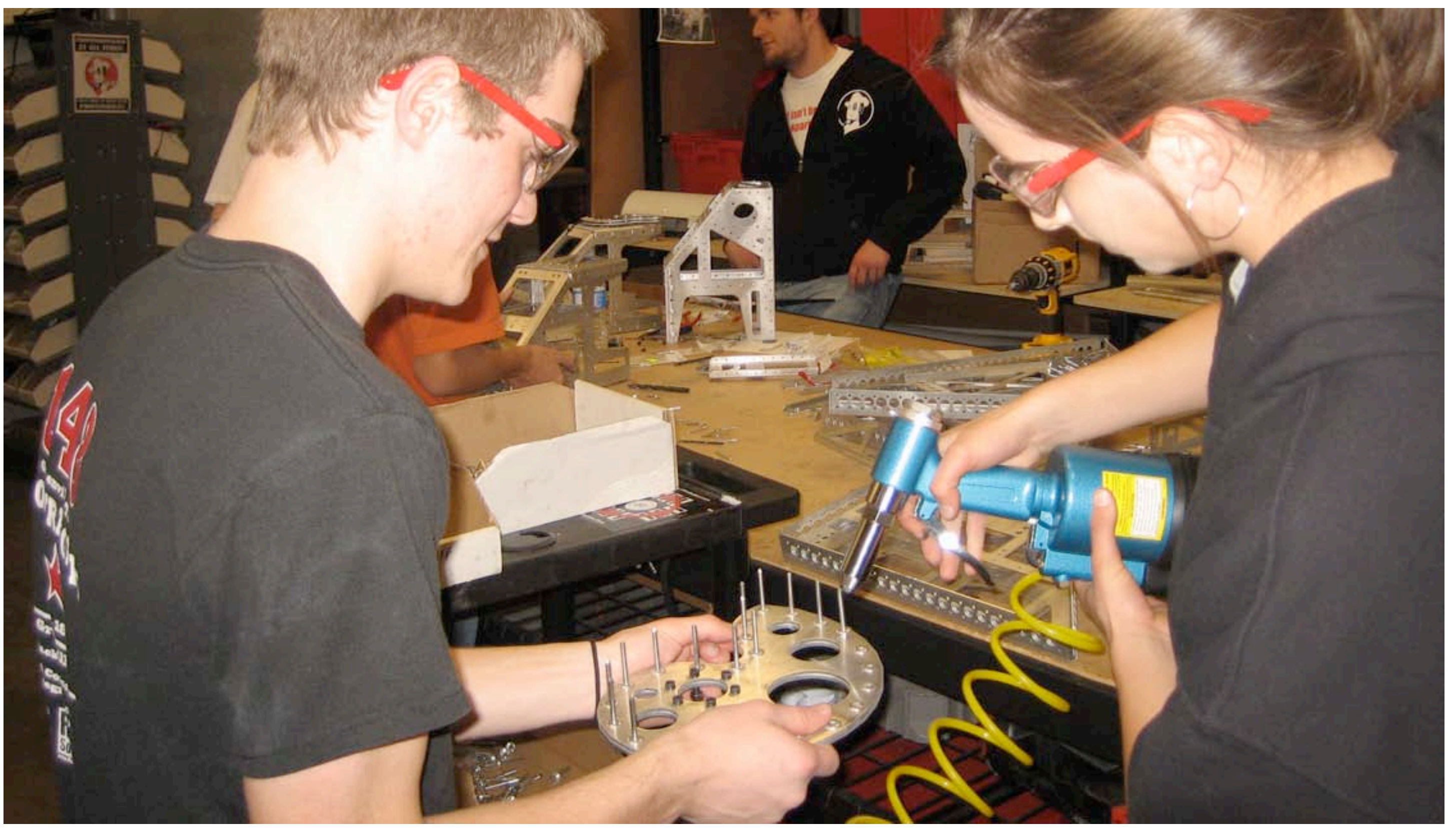
The sheet metal is done and almost entirely assembled, but most of the motion parts are still in work. We've been ordering COTS components throughout the build season (as soon as they are finalized in the design). The Thunderchickens have access to manual machining resources that the Robowranglers do not, so they manufacture almost all of the lathe turned and milled components for both teams. Many people understand the sheet metal components that are made in Texas and sent to Michigan, but few people know the huge number of lathed parts made in Michigan that are sent to Texas.

The sheet metal went together very smoothly without significant "fit at assembly" work. In 2009 the Robowrangler robot was designed much faster and the assembly process was begun much earlier in the year. The 2009 robot then went through significant "tweaking" after assembly. Since there was substantially more prototyping done on the 2010 robot before assembly, there was much less tweaking to be done afterwards. We had no idea of this at the time though, and everyone was starting to worry about schedule. Luckily, as this post optimistically mentions, the entire robot dropped together just as neatly as the sheet metal.

Day 30:
No meeting today. Spent the morning figuring out what the upper shields look like. Superbowl tonight...

I usually need to fight some sort of design crisis and end up missing the Superbowl. The fact that I got to watch the game is a good sign for how our season was going...

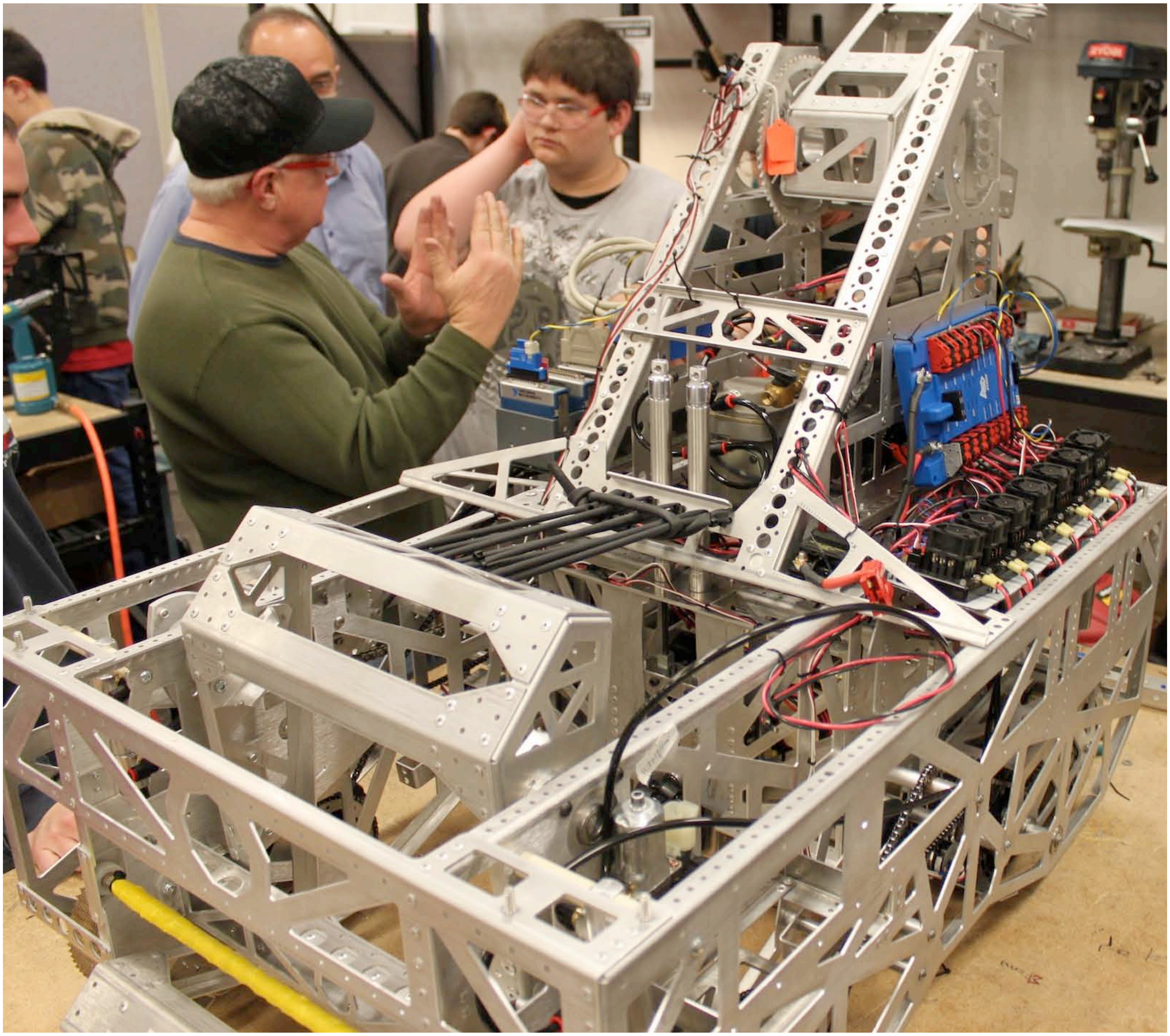
Day 31:
Wiring as much as we can. The motion parts should be here tomorrow. The powdercoated sheetmetal should be back tomorrow too. Big week followed by a bigger weekend. This Friday and Sunday will have optional meetings. We're not leaving on Sunday until we score.



Day 32:

Robot? Getting closer... there is a powdercoated robot assembly sitting on the 148 workbench. Students are going above and beyond. We feel like we're behind, and aren't even close to some of the teams posting videos... but hopefully she's worth the wait...

Day 33:
Practice Robot - All systems nearing completion. First functional test, estimated Friday night. Competition Robot - Mechanical systems 20% complete. Wiring, not started. First functional test, estimated Tuesday night. The goal line is in sight!



Day 34:
I'm home sick today, and tonight's meeting was cancelled due to snow. Hopefully the weather (and my head cold) clears up in time for us to hit things hard this weekend.

Day 35:
Since GISD had no school today (due to snow) there was no meeting tonight. I'm kind of wishing this was one of the years we had a simple robot and finished in week 3 or 4.

All the Mid-Atlantic teams are crying for us, I can tell...
(Some of these teams lost almost two full weeks of build time this season due to weather.)

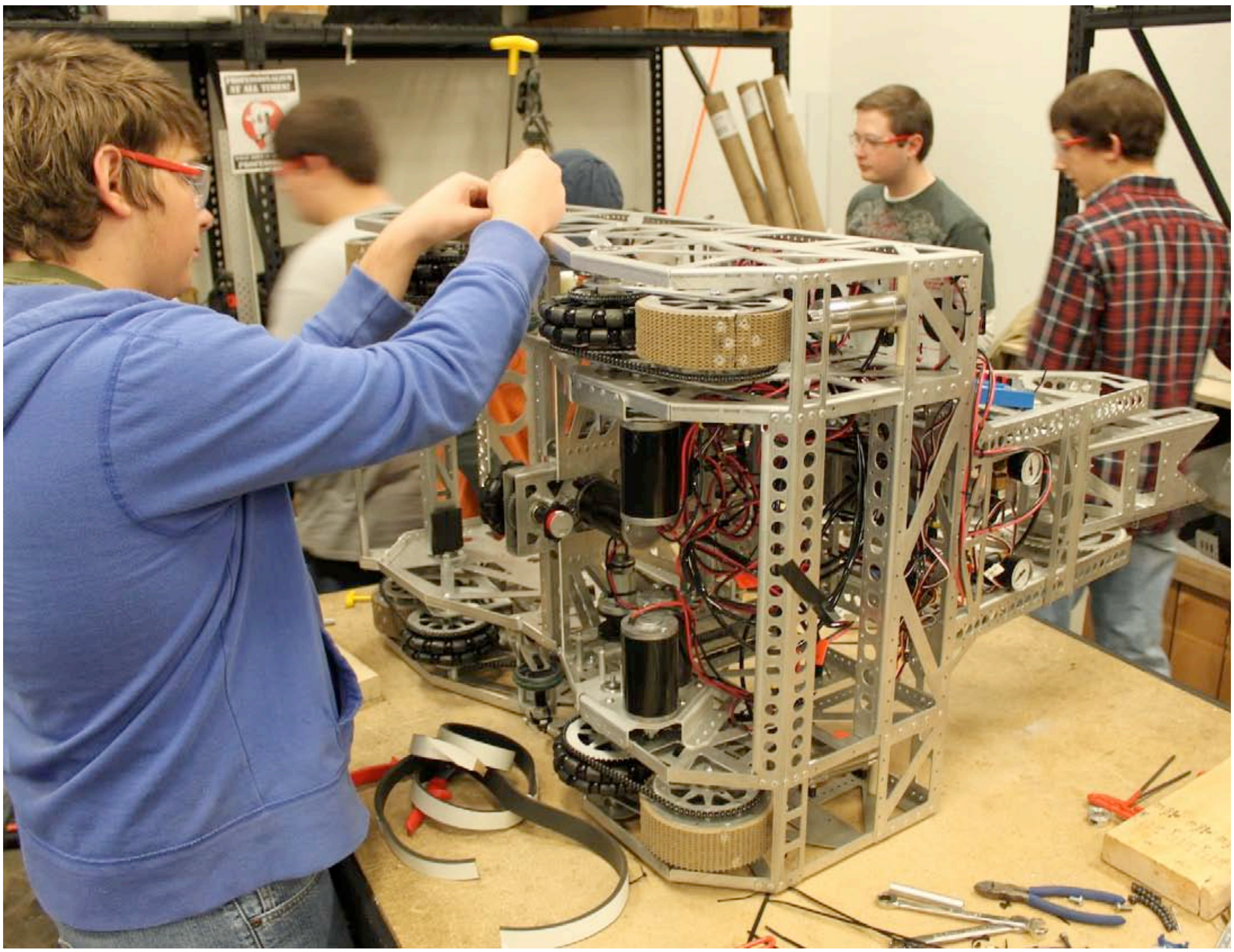
Day 36:
Today the team got to learn about torsional failure. So... let's go to steel on that one? Yeah. Practice robot is "done" pending some new parts to fix the lessons we learned today and some tuning. Competition bot is stalled out waiting on new parts. New ETA on competition bot is Tuesday night.

We use the same gearbox for the hanging mechanism and the kicking mechanism. Our initial design called for an aluminum output shaft. We knew this was "on the line" for failure, and we figured we could replace them with steel shafts if necessary. The kicker shaft failed in pure torsion, while the hanger shaft failed under combined loading of torsion and bending. In order to eliminate this bending load we modified the design to support the end of the shaft on this gearbox.

Though I hate it when we fail a shaft (this is not the first time, and it won't be the last) I enjoy the opportunity to showcase these to our students. These failures become opportunities for learning.

Day 37:
Practice robot is finished* (note the asterix). We have a list of changes a 1/2 mile long and 7 days to implement them. New sheetmetal drawings going to the shop tomorrow morning, so we'll have parts back from powdercoat on Tuesday. New motion parts should be finished just about then. Behind schedule, but doing okay...

List of changes 1/2 mile long? Check. Continuous improvement can be a real pain. I love it when outsiders tell me how “easy” our process is and accuse our students of not doing anything. Sheesh.



Day 38:
Two steps forward, one step back. CG is way too far back. Durability issues with part of the drivetrain. Everyone is working hard and knocking down problems one at a time. Tonight we fixed our short-game and shifted the CG quite a bit. The competition robot is catching up to the practice robot fast. Hoping for the "ah-ha" moment that solves our remaining issues...

Design is an Iterative Process...

The kicker mechanism took up a lot of space in the front/bottom of the robot. As a result, when we mounted the major robot components, they were placed primarily in the back of the robot. This resulted in the robot CG being too far back, causing the robot to have problems crossing the bumps. We made some modifications to shift the CG forward. The most notable modification was moving the compressor from inside the tower to the very front edge of the robot (tucked inside the kicker).

Due to the position of the lower-jaw of our ball intake, the robot was having trouble climbing up the goal ramps with our traction wheels up. To help facilitate the robot going up the ramp we added some plastic skids to the lower-jaw.

The traction wheels used were custom designed “super light” versions of the IFI wheels. These wheels were NOT strong enough for this year’s game. When the robot crossed the bumps, these wheels would sometimes slam down onto the ground. After we destroyed two of these wheels we made the decision to swap them out for the standard IFI traction wheels and have not had any problems since.

The U-brackets that held the traction wheels were not stiff enough. These brackets were bending and throwing the chains that connect the omni wheels to the traction wheels. There was no easy way to solve this problem without a significant redesign of the drivebase. We changed the #25 chain to #35 to make it more forgiving to misalignment. We also added plastic skids on the sides of these U-brackets such that any side-load would be transferred directly into the robot chassis.

The chassis itself was bending in some places. Additional bracketry was added to help reinforce the chassis structure. Specifically the outer side plates and inner side plates were connected at their bottoms, and the two inner side plates were connected together across the bottom of the chassis.

The “Ah-Ha” moment wouldn’t come until the weekend before ship date...

Day 39:
We're in the phase where we start to question some of our decisions and begin to consider "cop-out" solutions to our problems. Paul and I are waffling as opposing sine-waves so we cancel each other out and prevent rash (bad) decisions. Stay the course... If we had to compete with the robot as is, we'd probably be fine... Is fine good enough? At 3AM it sure seems like it...

I believe it is natural for a designer to question the decisions and especially the assumptions that were made earlier in the process. When confronted by a problem with no obvious simple solution, it is necessary to look for more difficult solutions. However, it is also important not to make hasty decisions in the face of failure. Sometimes you just need to stare at a problem for a little longer before the simple solution reveals itself. One of the best things about my friendship with Paul is the way we bounce ideas off each other. When I start to panic at this point in the season and suggest a drastic change, he will talk me off the ledge. I also get the opportunity to return the favor. This year's "panic" involved the drivetrain and a potential major redesign. At one point I was in favor of redoing the entire drive (at the Dallas regional in the pits if necessary) and Paul talked me out of it. Then later on, he would start to consider redoing the drivetrain and I would talk him out of it. In the end, we found the simpler solutions which got everything running well without any major modifications.

During this stage the Thunderchickens were doing similar testing and tweaking. It was great having both teams doing this work. We helped each other work through "gotchas" and GREATLY decreased the final "tweak" time. I don't like making the same mistake twice, so why would I want to make the same mistake our sister team made a few hours earlier?

Day 40:
The practice robot sees the light at the end of the tunnel. Lesson learned tonight, 8-32 screws do not have sufficient strength to act as a turnbuckle to tension #35 chain on our hanging mechanism.

The chain for the hanging mechanism was to be tensioned by some sort of turnbuckle. However, in our laziness we never designed the turnbuckle itself. I think everyone assumed it wouldn't be that difficult to figure out. Only later on did someone say "Hey... How much force is going through that chain anyway?" Needless to say, our initial turnbuckle attempts were... less than optimal.

What is the major lesson here? Design every aspect of the robot. It is always the little thing you didn't take the time to fully design that gets you. The devil is always in the details! You would think I would have learned this lesson by now, but I still get bitten by this every year.

We also probably spent a lot of time tuning the robot at this meeting, but that isn't nearly as exciting and memorable as an exploding turnbuckle causing the robot to crash to the ground.

Day 41:
Practice robot is fully functional. Durability problems solved... Minor tuning required. Competition robot is still in pieces, but should go together fast. I'm worried how long it will take to wire/plumb the competition robot.

I was right to be worried. We have a FANTASTIC electrical team on 148. Since I've joined the team we have yet to have a "wiring related problem" at competition. This is an awesome thing to be able to say (especially since I've done regional tech support in the past and have seen 1,000,000,000 ways robots can die on the field). So – you can't rush perfection (but you can pace angrily and ask "are you done yet?" so many times they just start lying to you).

Day 42:
Competition robot is mechanically complete and 98% wired. Just needs some last second loving, and she'll be fully functional sometime tomorrow afternoon.

The competition robot "just lacks finishing." Translation: "We will spend a full day getting it ready to run." Tomorrow afternoon = Tomorrow at midnight? We got her running in time for a late night video shoot then learned a lot of lessons during this testing...

"I love deadlines. I love the whooshing sound they make as they fly by." – Douglas Adams

Day 43:
Competition robot completed. Video shoot done. Considering a MAJOR redesign to emphasize certain features and fix perceived reliability problems. The robot unveiled to the world next week, and the robot that competes in Dallas may be very different... ... ...

Wow, what an ominous post! What could I possibly have been referring to?

This is where we decided we wanted to pull off the hanger to improve the robot's performance as a "baller." We asked ourselves one major question: "If we pull off the hanger, will it help our robot score more than 2 more balls a match?" We believe the answer was 100% yes, and are happy with our decision. At the time, this was a tough decision. It was almost unanimous among the Robowranglers. Most people held the same opinion: "I want to keep the hanger because it is so darn cool, but I agree that taking it off is the right decision."

What is funny is that we made this decision almost immediately following our video shoot that was done with the hanger intact. We knew the robot we unveiled in our video would not be the one we put in the crate. The video robot would hang; the robot in the crate would be better at crossing the bumps, more durable, and better at scoring. We really enjoy releasing the videos, so we decided to put it out there anyway.

I believe the decision to remove the hanging arm was our "ah-ha" moment for this year. As soon as we made that decision, I felt as though a huge weight was lifted off my shoulders. I did not want to spend the entire season "fighting" a robot and was excited at the concept of a more durable, reliable version with some extra weight to play with for improvements (this weight would come in handy.) This was the defining moment in our season. I'm extremely proud of every Robowrangler for the way we handled this as a team.

Day 44:
Armadillo... *<linked to video>*

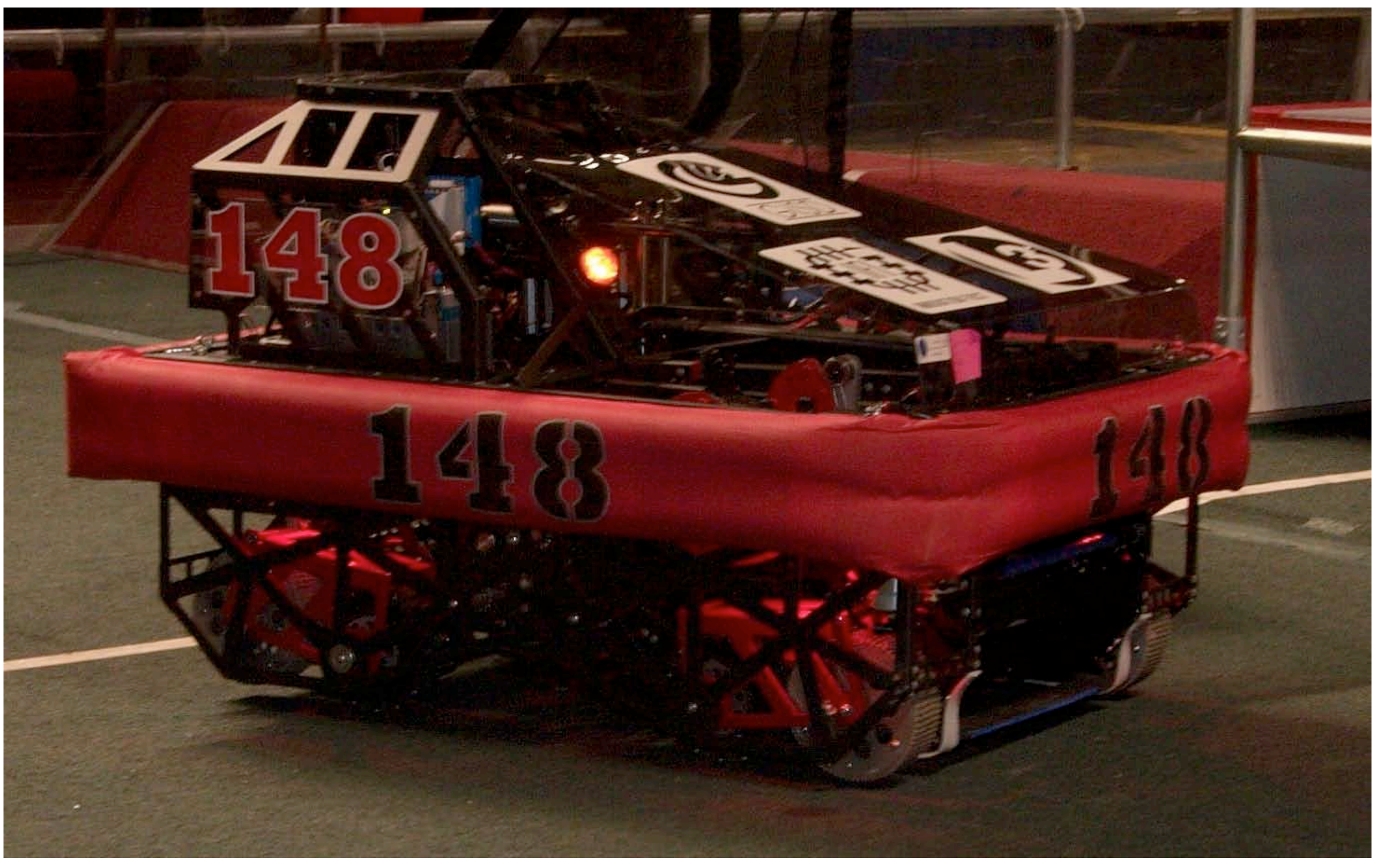
On day 44 we unveiled the video to the public. To see Armadillo's unveiling video go to: http://www.youtube.com/robowranglers/

We also spent day 44 feverishly modifying the robot to incorporate all the lessons learned from the night of the video shoot. My most distinct memory from this day is taking one of the spare towers out into the IFI parking lot with two HS students and sawzalling off the top 6 inches of it. We left that night with the competition robot still not totally rebuilt and not capable of running.

Day 45:
The last 2 days have involved a major design change resulting in a MAJOR (imho) performance gain. I'm so proud of all the Robowranglers for never doubting this gutsy decision and for their hard work in making it happen. We had a great open house for our community tonight, and I'm proud to see Armadillo in the crate...

Our team has a tremendous amount of support from our team parents, our sponsors, our school district, and the community. Every year sometime around ship date we have a big open house where we invite everyone to come out to IFI and see the robot. It seems like we've been getting bigger and bigger turnouts. It is awesome to see so many people from the area come out to give our robots a big send-off, and congratulate our students on making it through build season. This is one of my favorite nights of the year, because I get to watch the students showing their parents what parts of the robot they worked on.

This year, I was a little more stressed than usual because the robot was finished literally just after the parents arrived. The first time we tested the reinforced drivetrain without the tower was in front of a crowd of people. Luckily, everything ran great. Our students all stepped up their game for one last big push, and the result showed.



Day 46:
The robot was crated last night at 5AM. I spent the day catching up on my real job (after giving a tour of IFI to 47 middle-schoolers on a field trip). We'll start practice on Thursday. Less than a month until Dallas... "Will you be able to say at the end of the season that you tried everything possible? That you held nothing back?"

Crated and gone. Does that mean we can rest? Not on 148. The quote about "trying everything possible" is one of my favorites. I'm amazed by the students on 148 and by the culture that has developed here. We have positive peer pressure, where students are encouraging each other to be more professional and to work harder. We took 2 days off after ship date, and then got back to work prepping for the Dallas regional and working on the practice robot.

Removing the Hanger – Public Announcement

The Thunderchickens were originally going to try to keep their hanging mechanism, but shortly before they competed at the 2010 Finger Lakes Regional, they made the decision to remove it. Just as they took the field in Rochester, I put the following post on Chief Delphi and announced our justification for removing the hanging arm:

03-04-2010, 04:31 PM #196

UFH 03
Aug 1-15

John V-Neun
Registered User
FRC #0148 (Robowranglers)
Team Role: Engineer

Join Date: May 2001
Rookie Year: 2000
Location: Greenville, Tx
Posts: 2,630

Re: pic: Team 148 - Robowranglers 2010 - Armadillo

Since Armadillo's twin Mia is competing this weekend and word will probably be out soon anyways, I thought I'd take a minute to discuss a somewhat "controversial" change we made to the robot...

Here is the rough timeline:
Our video was shot on the Saturday before ship, the video itself was edited during the day Sunday and released that Sunday evening...
On Monday evening the Robowranglers held an open-house for the Greenville community, then put the robot in the crate late that night (early the next morning).

After the video shoot on Saturday night we (in typical "continuous improvement" fashion) began to discuss what we needed to improve.

We were concerned about the durability of the drivetrain, but didn't have any weight to spare to reinforce it. We were also disappointed at the way the robot traversed the bumps and felt lowering the CG would greatly improve the robots performance.

Early on in our game analysis (day of kickoff) we were trying to do cost-benefit analysis to determine how much those 2-points for hanging would really be worth. At the time we couldn't really tell, because we had no idea how hard it would be to score and had no "easy" way to simulate it. Playing with the actual robot gave us more of an idea of how many balls a match a robot could score.

At the start of our meeting Sunday, we made the decision to remove the hanging mechanism. We would use that weight to reinforce the drivetrain, and lower the CG. By the time the video was posted on Sunday night, the new "baller" Armadillo was up and running. She goes over the bumps smooth as silk forward and backwards, and the drivetrain has been significantly reinforced.

I know some people will question our decision to give up the hanging. I see it as a "no-brainer". When the decision was made, it was like a weight was lifted from my shoulders.

The Thunderchickens went through a similar analysis and made the same decision. Neither robot will be hanging for 2 points this year.

So thank you for all the compliments on our hanging, but you won't ever see Armadillo or Mia do that in competition. Instead you'll see a new-and-improved version of the drivetrain, on a lean, mean, soccer-ball scoring machine.

-John

John Vielkind-Neun
Team 20 | Alumni | 2000-2001 | Shenendehowa HS
Team 229 | Alumni | 2002-2005 | Clarkson University
Team 148 | Lead Engineer | Since 2007 | Innovation First International

Post Ship - Leading up to Competition

The continuous improvement process doesn't stop just because the robot ships. Our team is lucky enough to build two robots, so we can continue to test and tweak all the way through the competition season. This year we were pretty happy with the functionality of the robot we shipped. As a result, most of our improvements were centralized around problems we found on the practice robot.

After a few practice sessions, we noticed that the brackets holding the lower ball manipulator roller were bending. Not only were the brackets themselves deflecting, but the inner chassis plate was bending as well. After bending the practice bot back into shape for the tenth time we decided to design a new lower jaw for the intake. The new version was reinforced and integrated into the side plate such that forces would better transfer up into the chassis.

Other points of failure were similarly identified and repaired on the practice robot. Each of these repairs was documented such that they could be repeated on the competition robot.

Another improvement added to the practice robot after ship date was a variable tensioner for the kicker. We added a pneumatic cylinder which, when actuated, would tension some additional strands of surgical tubing for a longer kick distance. This allowed us to further tune our kick distance for scoring; we had one tension for scoring from the near and middle zone, and an "overdrive" tension for scoring from the far zone.

The Thunderchickens were following a similar testing plan and competed Week 1 at FLR and Week 2 at Cass Tech. The Thunderchickens compiled a list of all their improvements and sent it to the Robowranglers. This meant that by the time the Robowranglers competed at the Dallas regional we had two competitions worth of lessons learned. This resulted in a much better robot in Dallas. It also resulted in a much more difficult Thursday in Dallas with a mile long list of repairs to make.

Conclusion

Our team takes pride in our “continuous improvement” process. The rapid manufacturing capabilities we have allow us to spend more time on design, prototyping, and iteration while spending less time on fabrication and manufacturing. As you read through my build journal you can see numerous examples of failure. What makes our process work is that the students and mentors on 148 (and 217) are capable of learning from their failures, iterating their concepts, and improving their results. Anyone can implement a continuous improvement design process; the only secret is to remember that “done” is a 4-letter word.

Appendix A – 2010 Robot Specifications – Week 1
LEGEND – (D) *Demand*, (P) *Preferred*, (W) *Wish*
Specifications - Design Constraints:

1. (D) Robot must meet all requirements and restrictions presented in the 2010 FRC Manual. Key restrictions include:
   - Robot starting size
   - Robot maximum size
   - Robot weight
   - Parts & materials usage
   - Available robot power
   - Motor usage
   - Ball interaction restrictions
2. (D) Robot must be able to be fabricated using the methods available to our team including the following:
   - Sheet metal components that meet the manufacturing capabilities of our sponsor: the "Metal Solutions" shop.
   - COTS items within the team's "robot" budget.
   - Parts manufactured using our team's shop tools (bench-top lathe, drill press, band saw, hand tools).
     1. Additional tools may be purchased if their cost is within the team's "engineering" budget.

Specifications - Functional Requirements:

Drivetrain:

1. (D) Robot has a top speed of no less than 6 ft/sec.
2. (P) Robot has a top speed of no less than 8 ft/sec.
3. (W) Robot has a top speed of no less than 10 ft/sec.
4. (D) Robot can accelerate to top speed in a distance less than 10 ft.
5. (P) Robot can accelerate to top speed in a distance less than 7 ft.
6. (W) Robot can accelerate to top speed in a distance less than 4 ft.
7. (D) Robot has an overall coefficient of friction of no less than (0.8) = 118.4 lbs pushing force.
8. (P) Robot has an overall coefficient of friction of no less than (1.0) = 148.0 lbs pushing force.
9. (W) Robot has an overall coefficient of friction of no less than (1.2) = 177.6 lbs pushing force.
10. (D) Robot can turn about a point inside its footprint (zero turn radius).
11. (P) Robot can move in any direction regardless of its orientation.
12. (W) Robot can rotate about a given point outside its footprint at a fixed radius (spin around a ball).
13. (D) Robot can drive over the "bumps" on the playing field.
14. (P) Robot can smoothly transition over the "bumps" on the playing field without any drastic shift of robot CG (no flop-overs).
15. (W) Robot can drive over the "bumps" on the playing field without any significant loss of forward speed.
16. (D) Drivetrain turn rate is greater than 120 degrees / second.
17. (P) Drivetrain turn rate is greater than 180 degrees / second.
18. (W) Drivetrain turn rate is greater than 360 degrees / second.
19. (D) Drivetrain can be aimed by driver without excessive over-steering.

Ball Control:

1. (D) Robot can possess and control a ball such that it is held in a fixed position relative to the robot while the robot is immobile.
2. (P) Robot can possess and control a ball such that it is held in a fixed position relative to the robot while the robot is turning.
3. (W) Robot can possess and control a ball such that it is held in a fixed position relative to the robot regardless of robot drive motion.
4. (W) Robot can possess and control a ball such that it is not dislodged from our gripper during normal game play.
5. (P) Robot can gain control of a ball as soon as it contacts the front edge of the robot without requiring any driver action.
6. (D) Robot ball control mechanism "input" is at least 10" wide.
7. (P) Robot ball control mechanism "input" is at least 20" wide.
8. (W) Robot ball control mechanism "input" is at least 28" wide.
9. (D) Robot can plow through a pile of balls without getting jammed up.
10. (P) Robot can push a pile of balls in the direction of the robot's motion without them scattering (herd multiple balls without possession).

Ball Shooter:

1. (D) Robot can shoot a ball over both "bumps" the full length of the field.
2. (D) Robot can shoot a ball over 1 "bump" half the length of the field.
3. (P) Robot can toggle the distance the ball is shot between two presets (mid-field vs full court)
4. (D) Robot can shoot balls repeat ably and accurately.
5. (D) Robot shoots the ball upwards such that it clears a 12" tall "bump" if it is more than 4 feet away.
6. (D) Robot shoots the ball in a consistent direction relative to the robot orientation regardless of ball placement within the shooter mechanism.
7. (P) Shooter mechanism functions such that the ball can be anywhere within the center 20" of the front face of the robot and fire correctly.
8. (D) Shooter mechanism fires at least once every four seconds.
9. (D) Shooter mechanism can be "cocked" and fired at a moments notice without any significant delay.

Robot Hanger

1. (D) Robot can raise itself above the height of the platform less than 10 seconds after engaging with the tower.
2. (P) Robot can raise itself above the height of the platform less than 5 seconds after engaging with the tower.
3. (W) Robot can raise itself above the height of the platform less than 2 seconds after engaging with the tower.
4. (D) Robot can go from touching the driver station to hanging in less than 20 seconds.
5. (P) Robot can go from touching the driver station to hanging in less than 10 seconds.
6. (W) Robot can go from touching the driver station to hanging in less than 5 seconds.
7. (D) Robot latching mechanism does not require precision alignment by the driver to engage.
8. (W) Robot has a mechanism which will allow a partner robot to hang off of us after we are fully hung, this mechanism is designed similar to the field tower such that most "standard" hanging mechanisms can utilize it.

Electrical

1. (D) Robot electrical system is designed and implemented robustly enough such that inspection and maintenance is only required once a day.
2. (P) Robot electrical system is designed and implemented robustly enough such that inspection and maintenance is required only once at the beginning of each competition.
3. (W) Robot electrical system is designed and implemented robustly enough such that no maintenance is required during the season.
4. (D) Electrical components are designed for easy replacement - any component can be replaced in less than 10 minutes.
5. (P) Electrical components are designed for easy replacement - any component can be replaced in less than 5 minutes.
6. (W) Electrical components are designed for easy replacement - any component can be replaced in less than 2 minutes.
7. (P) Electrical components and connectors are easily accessible to assist in troubleshooting and testing.
8. (P) Electrical wiring is clean and organized such that it is easy to visually follow a wire from its source to destination.

Programming & Autonomous

1. (D) Robot can use a camera to find the vision target and identify when it is pointed at the goal.
2. (P) Robot can use a camera to find the vision target and identify how far it must be adjusted to point at the goal.
3. (W) Robot can use a camera to find the vision target and automatically adjust itself so it is pointed at the goal.
4. (D) Robot does not cross the center field line during autonomous mode.
5. (W) Robot can identify the center line and stop itself from crossing it during autonomous mode if it comes near it.
6. (P) Robot can shoot 3 balls from the far zone into the home zone during autonomous mode.
7. (W) Robot can score 3 balls from the far zone into the goal during autonomous mode.
8. (P) Robot can shoot 2 balls from the middle zone into the home zone during autonomous mode.
9. (W) Robot can score 2 balls from the middle zone into the goal during autonomous mode.
10. (D) Robot controls are ergonomically designed such that the robot can be intuitively controlled by 2 student drivers.
11. (W) Robot controls are ergonomically designed such that the robot can be intuitively controlled by any two outsiders with minimal training.
12. (D) Robot meets all functionality described in the separate software specifications.

Overall:

1. (D) Robot is designed such that it cannot "carry" balls at any time. Any balls landing on top of the robot roll off.
2. (D) Robot CG is within 6" of the center of the robot in the x-y direction.
3. (D) Robot CG is no more than 12" off the ground.
4. (P) Robot CG is no more than 8" off the ground.
5. (W) Robot CG is no more than 4" off the ground.
6. (W) Robot top is shaped such that it can "deflect" falling balls from the return track back toward the home zone.
7. (P) Robot can return itself to its wheels from any other stable configuration (self-right from flip).
8. (W) Robot can return a partner to its wheels from any other stable configuration.
9. (P) Robot is large enough to effectively block shots on a goal.
10. (P) Robot is shielded such that nothing larger than 1/2" can penetrate the outer layer.
11. (P) Robot matches the "Robowrangler Aesthetic" and looks professional in fabrication and design.
12. (P) Robot is physically robust and can survive the rigors of "Breakaway" with NO damage.
13. (D) Robot is physically robust and can survive the rigors of "Breakaway" with no damage that cannot be repaired in a 5 minute period.