Beach Cities Robotics
2004 Robot Build

One Mentor's Perspective

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Rick Wagner is an employee of Northrop Grumman Space Technology in Redondo Beach, Calif. Northrop Grumman is the major sponsor of Beach Cities Robotics, a *For Inspiration and Recognition for Science and Technology* (FIRST) Robotics high school competitive team, made up of students from Redondo Union High School (RUHS, Redondo Beach, Calif.) and Mira Costa High School (MCHS, Manhattan Beach, Calif.).

2004 Robotics Competition Kickoff

We had been speculating on the 2004 game design since the 2003 competition in which we had won the Engineering Inspiration Award at the Phoenix regional competition and the silver medal at the LA regional. The 2003 "Stack Attack" game utilized some classic robotics behaviors of pushing and stacking boxes. There is a long robotics research history on pushing and stacking algorithms, for example Marvin Minsky's 1960s "Blocks World" at the Massachusetts Institute of Technology. My own research at the University of Southern California (USC) involved pushing algorithms for part orientation in manufacturing. So I had been hoping that the 2004 game would involve boxes again. That way, a lot of the problem solutions we had come up with in 2003 could be applied to 2004. Other mentors liked the manipulation of balls of earlier competitions.

Figure 1: The team watches the kickoff broadcast on the NASA channel at the RUHS Futures Academy. The photographs in this article are shown in chronological order.

Mentor Mark Miller and I met at USC on Saturday morning, January 9, to watch the kickoff and pick up the parts kit. USC is the distribution center for Southern California. The other mentors and students stayed at RUHS to watch the kickoff on NASA TV. Every year the new game is unveiled for all teams simultaneously across North America. When Mark and I returned to RUHS, the team was ready for brainstorming a robot design.

Figure 2: Students watch intently as the new competition game is revealed.

This year's game turned out to be a ball game with inflated balls. The smaller ones were 13 inches in diameter, and the larger ones were 34 inches in diameter. Called "First Frenzy," it was a game of cooperation between robots and humans and between allied pairs of teams against opposing alliances. A plan view of the playing field is shown below in Figure 3.

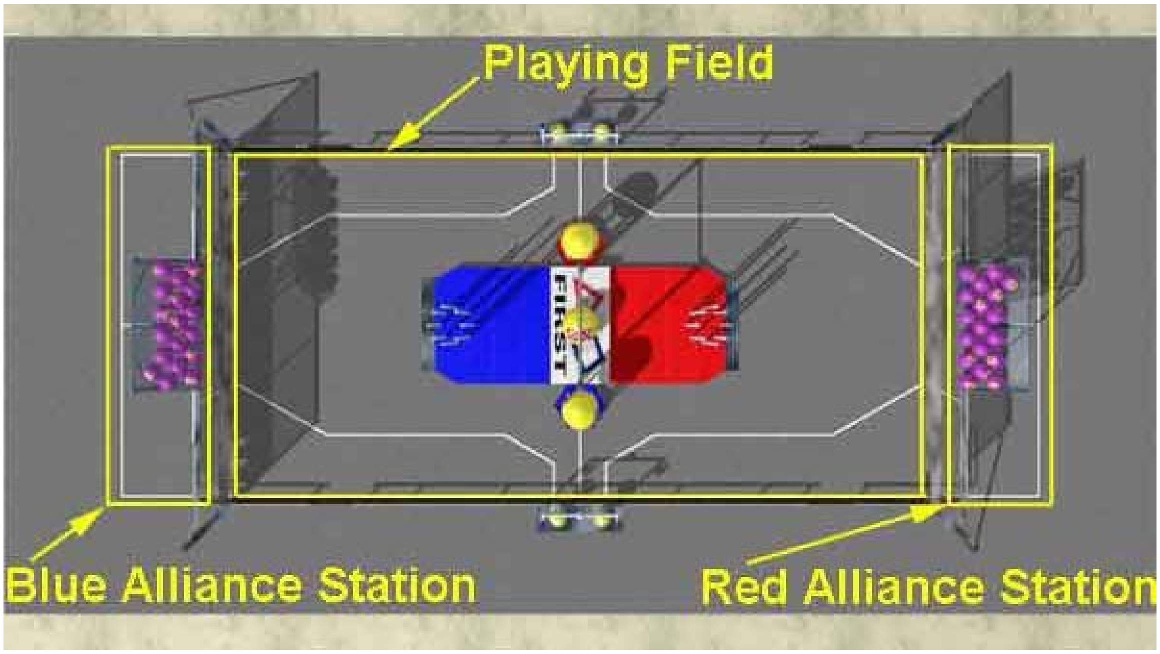

Figure 3: Plan view of the First Frenzy playing field.

Only the human players could shoot balls into two types of goals, a fixed goal and a mobile goal that had a 30 inch capping ball that had to be removed before scoring balls could be put into it. The mobile goals could be brought closer to the human players. Only the robots could be on the field to obtain scoring balls to pass to the human players through rectangular ports in the end-field safety barriers. A perspective view of the playing field is shown below in Figure 4.

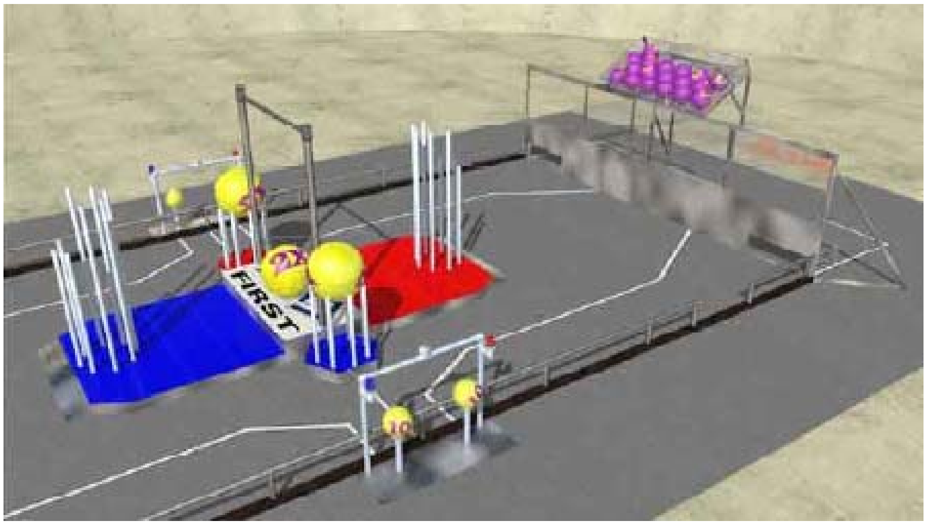

Figure 4: Perspective view of the First Frenzy playing field.

In addition to scoring with balls in goals (and scores in goals could be doubled by having a robot place a 30 inch capping ball on the goal), robots could score points by being suspended (hanging) from an overhead horizontal bar in the center of the field at the end of play.

As National Champions in 2001, we regard ourselves as one of the top teams and act as examples for other teams, providing help to any team that asks for it, and mentoring new teams. Therefore, we strive in our design ideas to produce a robot capable of winning a national championship and we approach the design problem with the intent of producing a robot that can “do it all.” This idea is somewhat of a point of contention. Some on the team believe that we tend to end up biting off more than we can chew that way, and that a smarter approach would be to design for only a good subset of game playing features. However, optimism tends to prevail, and it’s always possible to delete design features that we don’t have time to implement, so we tend to have fairly ambitious robot designs.

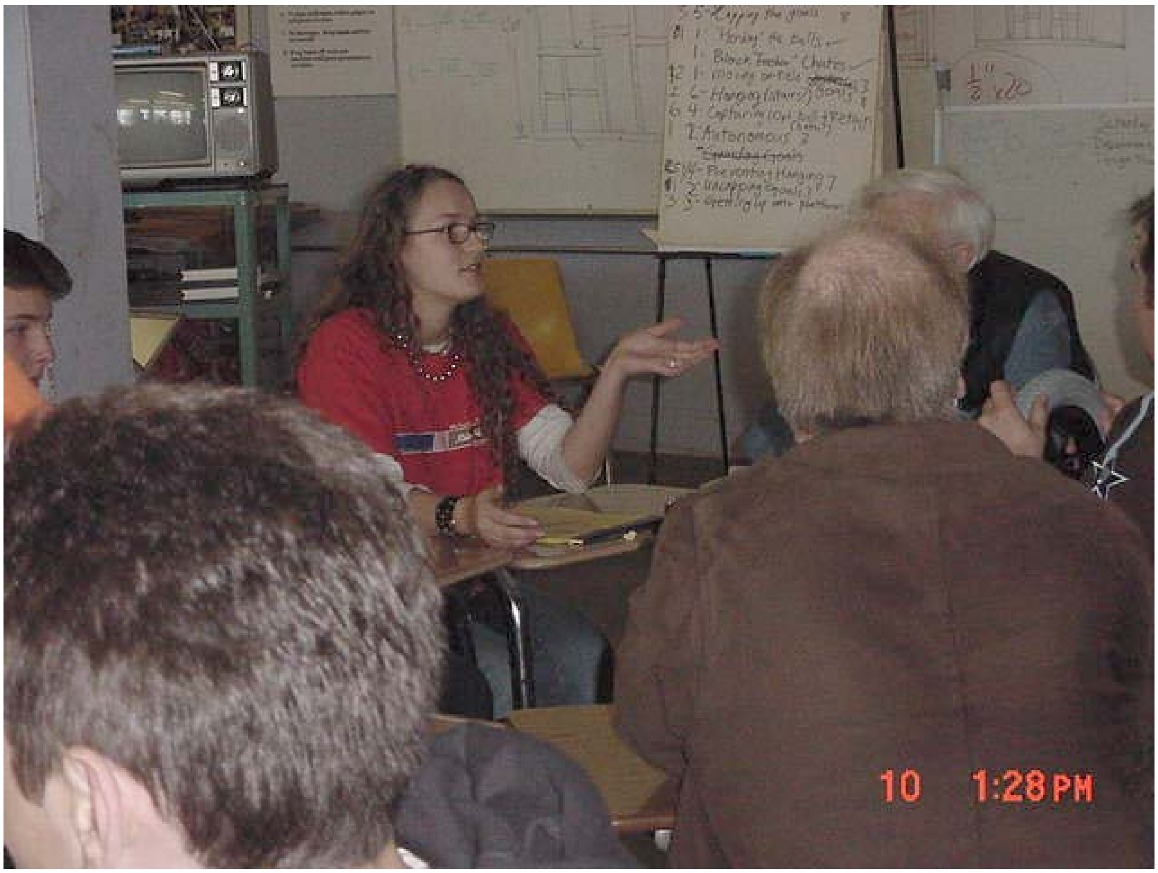

Figure 5: After the game is revealed in the kickoff broadcast, the students and mentors brainstorm the robot design requirements.

This year we came up with a design that could perform all imaginable necessary functions: ball herding, goal grabbing, doubler ball manipulation, autonomous ball drop triggering, step climbing, and pull-up bar winching. It was a tall order, so we divided up into balanced mechanical design and fabrication subteams. We had a subteam for the robot drive base (the most difficult and important task) mentored by LeRoy Nelson, who is currently self-employed, formerly a researcher at Xerox’s Palo Alto Research Center (PARC), a subteam for the manipulator arm mentored by Mark Miller (with sponsor Rent.Com), and a subteam for the miscellaneous mechanisms (goal grabbers, ball herders, and winch), called the peripherals team, mentored by me. We also had the usual subteams for programming and the control board. Each subteam had a student leader who had overall responsibility for the team's performance. We want to maximize student involvement, so the mentors try to resist the temptation to "take charge" and produce an optimal robot by engineering fiat. It's really all about the learning experiences of the students.

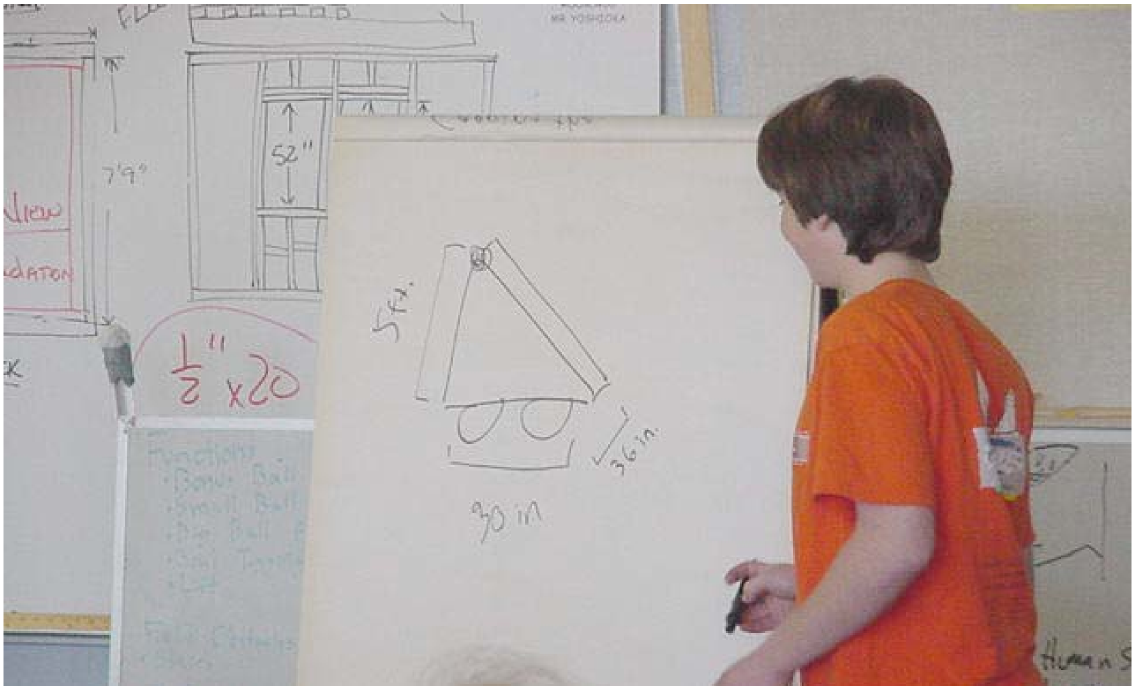

Figure 6: Brainstorm ideas are presented by students. Here Jared Niemiec explains a concept.

Building the Robot

Even though we once again had a "do it all" robot design, we had much less deadline trouble than last year for two reasons. First, LeRoy and the drive base subteam learned a lot from last year's build and focused early on a simple robust design so that we had the drive base parts in fabrication within two weeks of the kickoff. Second, Mark Miller asked team 60, the Bionic Bulldogs, for a copy of their 2001 ball manipulation arm design that was very successful. Team 60 graciously complied and, with a few of Mark's team's modifications such as adding a turret (a third, vertical, axis of rotation), the arm parts were also quickly in fabrication.

Figure 7: Drive base team at work on a design.

In spite of a very ambitious robot design, the team worked better together and things went smoother, producing a much better robot than last year’s. Even though we won the silver at Los Angeles in 2003, there was a lot more friction and frustration in getting our robot fielded that year.

Figure 8: Robot arm team, led by Jared Niemiec. Mentors Jon Will of Northrop Grumman (seated), Scott Tupper of American Aircraft Products (standing, left), and Gary Robinson, of Boeing Satellite Systems, participate.

On the peripherals subteam that I mentored, I resisted the temptation to produce the designs myself, but encouraged the students to brainstorm and come up with their own designs. I taught them how to produce 3-view orthographic projections of their part ideas, and had them produce scale drawings on paper.

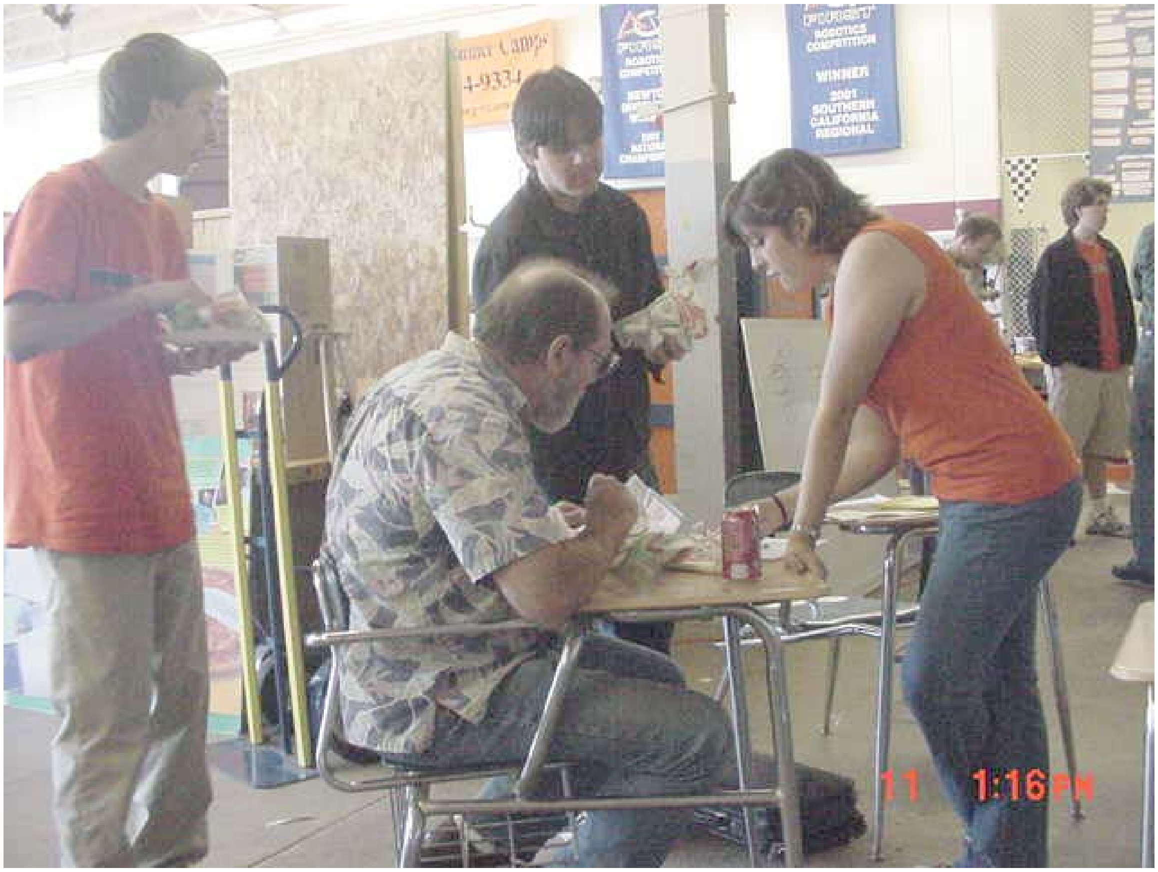

Figure 9: Peripherals team, responsible for goal grabbers, ball herders, and the robot lifting winch.

For the pneumatically actuated peripherals, the goal grabbers and ball herders, team members computed the pneumatic cylinder stroke required, and verified forces for given pressures and cylinder diameters. Doing these computational activities lets the students appreciate the relevance of their mathematics and sciences courses in school.

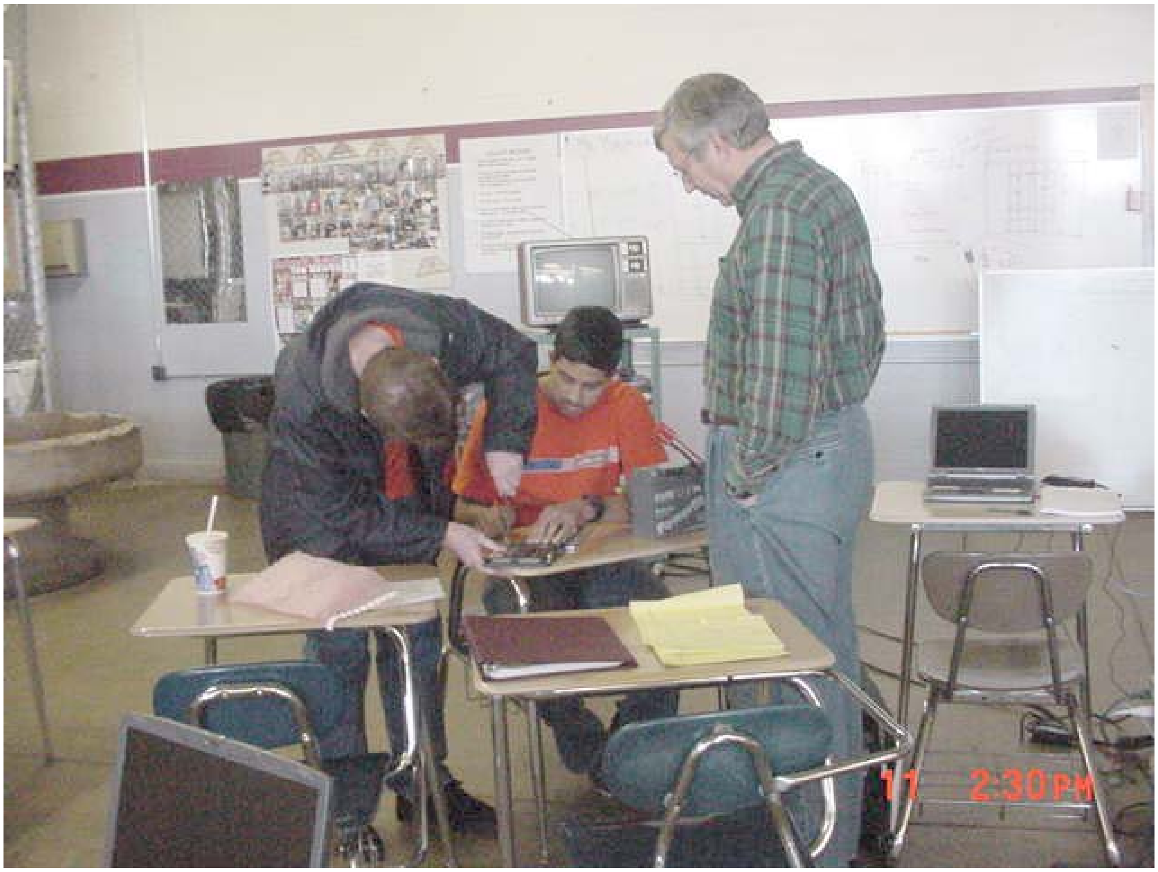

Figure 10: Programming team, with Bill Kunz (Raytheon, retired).

For the winch motor, the students took the motor specifications and converted torque from international system (SI) units to United States customary system (USCS) units and confirmed that the torque was sufficient to lift the robot off the ground. Motor specifications show torque in Newton-meters and game rules specify robot mass in pounds and dimensions in inches.

Later, when the winch was assembled, we tested it to verify that it had enough pull. Tests like these are always fun, and give mentors a chance to discuss safety precautions with the students. Many tests require significant forces or quantities of stored energy, and tests need to be carefully planned to they don’t endanger the testers or bystanders.

Figure 11: Greg Robinson works on a design.

Once we had designs for our peripherals, students were assigned various fabrication tasks including cutting on the bandsaw, drilling, tapping, and welding. Last year, Marygrace Barron was our only student welder, but this year we had several students trained.

We were also fortunate enough again this year to have a tungsten inert gas (TIG) welder lent to us by a sponsor. TIG welding is required for aluminum, which oxidizes rapidly in the oxygen of the atmosphere. A TIG welder has an annular orifice around the tungsten electrode and a continuous flow of argon (an inert gas) keeps the oxygen away from the weldment (the melted aluminum from both the welding rod and the parent material).

Figure 12: Many sponsors donated lunches and dinners for the team.

The six-week robot build period required many weekends and evenings. Team Mom Cheryl Miller worked with local restaurants and fast food outlets to obtain donations so that we always had lunches and dinners available for the team. Team parents also donated food.

Figure 13: Students help each other. Here Greg Robinson teaches David Tsao about drilling and tapping.

More mature teams have several advantages over newly formed teams. The first advantage is that more senior students are able to pass on their knowledge to the freshman and younger students. This helps lighten the teaching load on the mentors. Another advantage is that more mature teams have parts, batteries, and whole robots left over from earlier competitions. With autonomy programming, having a robot testbed is important for debugging algorithms in parallel with the robot build.

Figure 14: Bryan Campbell takes the AutoDesk Inventor tutorial.

A computer aided design (CAD) tool is essential to rapid and accurate design. Building a virtual robot as a solid model assembly lets the designer modify and improve his design quickly and produce accurate part fabrication drawings easily. Fortunately, Autodesk, makers of AutoCAD software, include Inventor, an easy-to-use solid model CAD package in the FIRST kits. All of the students are encouraged to take the tutorial, upon the completion of which the student is ready to begin assisting the design process. This year, several students were able to make major solid modeling design contributions. As a result, we had a complete robot model in software. We hope to have even more students CAD-literate next year. One student, RUHS sophomore Daniel Brim, worked extensively to produce our CAD models. This is what Daniel said about his experience this year:

> “To me, the design process was the hardest part of the building of the robot. I was on the 3D design subteam and I did most of the CAD work. I enjoyed this assignment mostly because I like to work with computers, and it was a nice challenge. My greatest accomplishment was finishing the entire robot in Autodesk Inventor and submitting the design for the Autodesk Inventor Award. The process was frustrating at times, because I did not have time for anything else, but it was worth it and I plan to do it again next year.”

Figure 15: Safety glasses are worn when using power tools.

All of the students are asked to assist with part fabrication and robot assembly tasks. For some new students, this was the first time they have used simple hand and power tools for metal fabrication. Students learn valuable skills such as maintaining safety in the shop, selecting drill sizes, and identifying thread and tap sizes.

At one point in the build period, the team took a field trip to tour sponsor American Aircraft Products' manufacturing plant. Students got to see machines in use for water jet cutting, sheet metal shearing and bending, and other tasks.

Figure 16: The team toured sponsor American Aircraft Products manufacturing facility.

This year's game, like last year's, required a 15-second autonomous period at the start, adding a challenge to the programming. However, unlike last year's robot, this year's processor was programmed in C. Programming was also required for the radio controlled features of the robot. For example, if a manual mode command is given to move an arm joint to a given position, an algorithm is required to compare the current position to the commanded position and change the motor current to reduce the difference.

Figure 17: Student programmer Aaron Miller and Northrop Grumman engineer mentor Dale Hall work on the software using robots from previous years as testbeds.

Programming progress was slower than anticipated and resulted in a high level of frustration for the programming team. I think a lesson to be learned for next year is that programming efforts should start early, be given a high priority, and progress should be monitored closely. We should also establish a testbed with last year's processor so that algorithms can be checked out early.

Figure 18: Peripherals team discussing design options.

The peripherals were not on the "critical path" of the robot build, so the peripherals team members weren't under as much pressure as with some of the other teams. I was able to take the time to teach the students about some of the engineering aspects such as force and pressure calculations and engineering drawings.

Figure 19: Artistic talent is required for many tasks. Breanne Munoz paints the shipping container.

In addition to the robot build tasks, there are other tasks that need to be accomplished, such as building the practice field and shipping container. Every student participated in both robot tasks and non-robot tasks.

Figure 20: The team is busy fabricating parts. Mentor LeRoy Nelson explains technique.

Safety is always a major concern when working in the shop, especially with the power tools. We had a two-man rule for working with rotating machinery such as the mill, lathe, and drill presses. One person would be able to turn the machine off if the operator got caught in the machine. We were both vigilant and fortunate and nobody was injured.

Figure 21: Jared Niemiec works on the accumulator assembly for the peripherals pneumatic system.

The older students are able to work without supervision on many tasks. The younger students generally need to be monitored, especially with regard to proper fastener tightening and wire crimping.

Figure 22: The winch assembly is tested to make sure it has enough force to lift the robot. A student on a swing acts as our weight.

We often do some simple tests to prove out concepts before committing them to hardware. Last year it was suggested that metal coil springs be used for hold-down tension in our box stacker, so some of the students learned how to measure spring rates by hanging weights on springs and measuring deflections.

In that test, we found that the springs didn't have sufficient extension for our purpose, but would yield (remain deformed after the load was removed) so we changed the design to use the latex rubber tubing that comes in the robot kit.

This year we wanted to be sure a winch design would have enough lifting power before installing it in our robot. We rigged up a quick test using a student on a swing as our weight. A larger student stood with him to help him land on his feet in case the apparatus should fail.

The proper use of verification tests is an important lesson for the students. Theory is good, but theoretical models should be grounded in reality by test when there is missing data for a complete theoretical understanding.

Figure 23: Team captain Marygrace Barron using the mill.

We now have several of our students trained in welding and mill operation. These kinds of capabilities give our team greater design flexibility. Designing within our fabrication capabilities is an important topic the students learn about the design process.

Figure 24: Drive team captain Richard Mills and Veronica Newman working on the drive base.

Mentor Scott Tupper with sponsor American Aircraft Products assisted with a significant amount of fabrication this year, making our rather sophisticated design possible. Scott was able to have custom sprockets cut on the water jet machines, and other parts fabricated as well. The drive base frame parts were welded by sophomore Marygrace.

Figure 25: Some parts for the robot arm arrive from sponsor American Aircraft Products.

The professionally fabricated parts gave a very sophisticated look to our robot this year, and the mechanical performance and reliability were quite good.

Figure 26: Seventh grader Katie Winslow learned all the machines. Here she is setting up the horizontal band saw.

While BCR is a high school team, the team membership is not tightly restricted. We have had students from high schools other than the two main ones, Redondo Union and Mira Costa. We have also had a few elementary and middle school students.

Figure 27: The robot arm is coming together.

This year's robot arm was to perform several functions. First it was to be the instrument for knocking the ball-drop trigger ball from its pedestal in autonomous mode. Second it was to grasp the large diameter doubler balls for uncapping mobile goals and capping either fixed or mobile goals. Third, it was to be used to attach a hook to the pull-up bar for winching the robot off the playing surface.

Figure 28: The robot drive base takes shape.

While all those features were incorporated into the design, and the mechanical aspects were fabricated and assembled, the complexity of the design and the need to adjust and calibrate the control feedback potentiometers resulted in a late fielding of full arm capability. The arm wasn't used at all in the Chatsworth High School preliminary competition, nor in the Phoenix regional. It was first used in the LA regional, and again in the national competition.

Figure 29: Peripherals team members pose with goal catchers and ball herders.

All of the parts for the peripherals, goal grabbers, ball herders, and the winch were fabricated in our own shop at RUHS by the students, who were very proud of their handiwork. The goal grabbers worked quite well, but in their first use in competition were damaged and later upgraded to thicker material. The herding arms functioned well in the competitions.

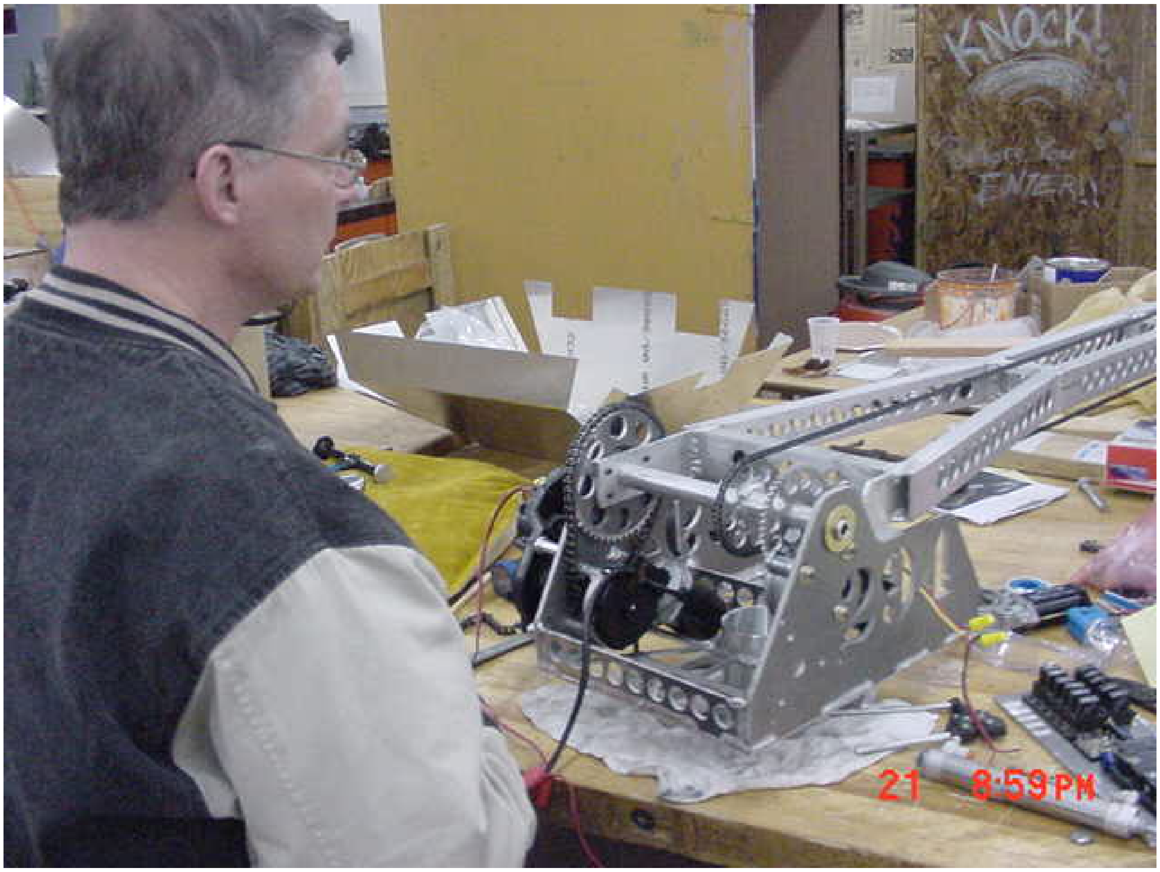

Figure 30: Mentor LeRoy Nelson studies the robot arm.

The manipulator arm had three motor-driven rotational axes plus a pneumatically actuated grasp. The three rotational joints were called “shoulder,” “elbow,” and “wrist.” The shoulder joint, also called a turret, was at the base of the arm and had a vertical axis. It was a feature of the design that the goal grabbers had to be extended in order for the shoulder joint to move. In order for the goal grabbers to be retracted, the shoulder joint had to be in its starting (zero angle) configuration. It was planned to do this appendage coordination in software, but we never actually used the shoulder joint rotation capability in competition.

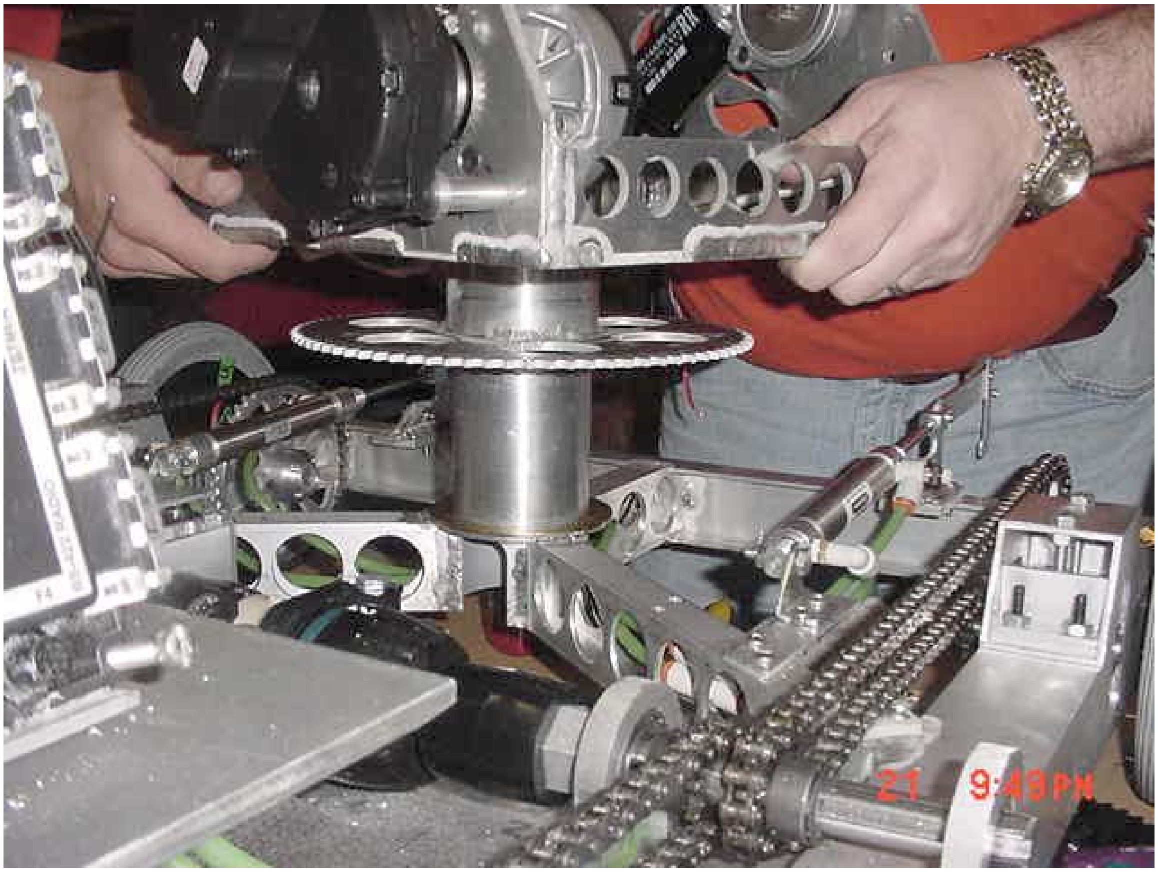

Figure 31: The arm assembly is installed for a fit check.

Last year, packing the shipping container was difficult with all the things we needed to pack, such as spare parts, battery chargers, etc., so this year Mark had the great idea of fastening the robot to the top of the box so it would hang upside down. That would free up container floor space for other things.

Figure 32: LeRoy Nelson and Richard Mills testing the upside-down shipping position for the robot in the crate, interior design by Breanne.

Before the robot was totally completed, we practiced installing it in the box to check out the idea. It worked quite well. We cut some 2 x 4 wooden posts to help support the robot while the suspension straps were tightened.

Robot Competition

We shipped the robot on time via FedEx, which has donated shipping services for all FIRST robotics competitions. The shipping container was sent to the stadium in Phoenix with all the other competing teams' robots, where it would wait until the first day of practice. All the teams arrive in the morning of the first day and open their containers at the same time.

Figure 33: In the pits at the Phoenix regional competition.

At the Phoenix regional (March 11-14) we drove our robot in practice and stayed late in the pits the first night getting the robot ready to pass inspection. The pneumatics system pressure gauge was facing toward the floor and had to be moved to a more easily visible location.

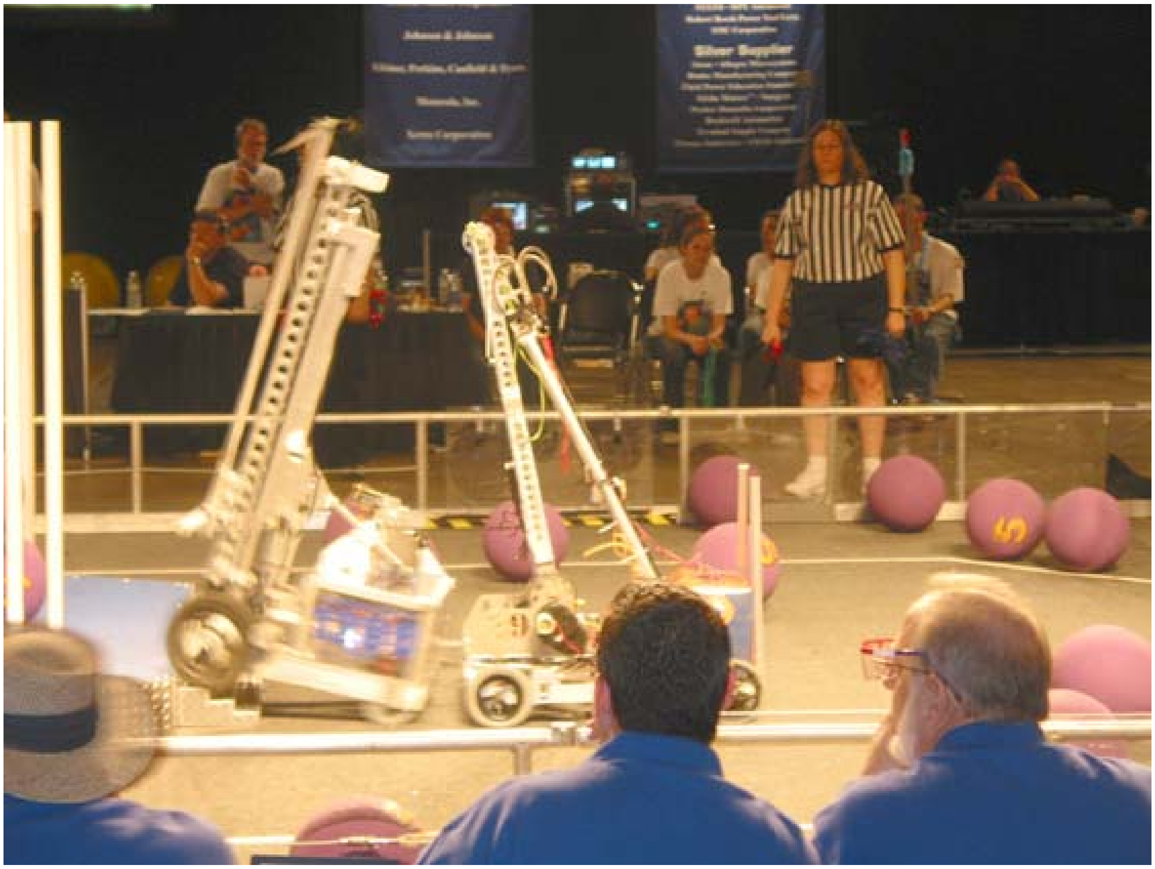

Figure 34: In competition at the Phoenix regional.

We finished about mid-way in the rankings, but weren't selected to compete in the finals. However, all the students enjoyed the experience, and we were awarded the gracious professionalism award from Team 60, the Bionic Bulldogs. This award was an actual working steam engine mounted on a plaque.

We went on to the LA Southern California regional competition (March 25-29) where we won the Chairman's Award, FIRST's highest regional honor. MCHS junior George Chen, who is our Webmaster (see BCR's Website at http://www.bcrobotics.org/), organized our Chairman's Award submission. Our robot and team performed well, running in seven of seven elimination matches, winning four of them, and qualifying 20th out of 57 teams.

Figure 35: Driver MCHS freshman Andrew Cole, co-driver MCHS junior Jared Niemiec, and drive team coach and mentor Scott Tupper prepare to start a match at the LA regional competition.

At the national competition in Atlanta, Ga., (April 15-18) we contended for the national Chairman's Award, and the team had a wonderful time there. We drove in four of six assigned practice matches (in two of three practice sessions). Our drive team competed with the robot in the Newton Division in six out of seven qualifying matches, winning one of them, the sixth. Nearly 400 FIRST Robotics teams from all over North America competed at the event.

We had a design for a robot that could "do it all," we built and shipped it on time, we won the regional Chairman's Award at Los Angeles, and we competed successfully in two regional competitions and at the national competition. As a learning experience for the students, it was among the best. In all, it was a highly successful build and competition season for Beach Cities Robotics.