

T.O.A.D.



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ME 72ab. Engineering Design Laboratory
Instructor: Mike Mello
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3/18/15

I. Introduction

Our task for ME72ab this year was to build an amphibious robot that would compete in the Aquamania competition on March 10, 2015. We had two terms to build and test our vehicle. The competition included many 2 vs. 2 rounds of competition before the 1 vs. 1 semifinals and final. The goal for each round was to score more points than your opponent(s). Points could be scored by moving small and large balls to certain zones or goals in Millikan Pond. The vehicle also had to transition between water and land via wooden ramps and could garner extra points for entering the water autonomously and exiting the water at the end.

II. Vehicle and Strategy

We designed the final iteration of our robot to be the simplest of our ideas that would be able to compete effectively and play well with any other team we were paired with. As a result, our robot's main function was pushing balls around (with no lifting or shooting functionality). Our final design had two geared paddlewheels that doubled as our driven ground wheels, which allowed for a simple, reliable transmission. Our vehicle also had two additional ground wheels (for support only since we didn't need them for ground) and a chicken wire plow for pushing balls (both large and small). The hull of our vehicle was made of a piece of molded thermoplastic hot glued and acrylic welded to another piece of thermoplastic. All of these components (as well as the small ball holder, motors, and electronics housing) were attached to the main plate of our robot, which was made of acrylic, which had good strength and rigidity for its weight.

Our strategy for the competition varied depending on our partner and opponents. We used a combination of defense (pushing opponents' balls out of scoring zones and blocking opponents) and offense (pushing large/small balls to scoring zones 2 and 3), deciding which of these to focus on based on the strengths and weaknesses of the allied and opposing teams. We also used the autonomy portion when possible to gain bonus points for entering the water, and when we were able to do this, we capitalized on the bonus points for exiting the water towards the end of the round as well.



III. Design Process

Our primary goal with our design was to create the simplest design possible that would be able to win the competition. The main functionalities that were absolutely necessary for the competition were: ball handling, mobility in water, mobility on land, and some sort of autonomy (not completely necessary, but something that would definitely be worth the time investment).

Here are the ideas we first came up with and our thoughts on them:

Ball handling:

- 1) Shooting - Collect a ball and shoot or collect multiple and shoot them. This would in theory decrease the amount of movement necessary, especially if you can shoot from zone 1 to zone 3.
- 2) Pushing - Don't ever "hold" balls, just push them around to different areas. This would require a lot more movement but would reduce the complexity of the vehicle, allowing for more reliability.
- 3) Lifting - Collect balls and then carry them to the goal and deposit them there. This would allow us to take advantage of the largest scoring opportunity but would be challenging to implement, especially given the size constraints.

Mobility:

- 1) Paddlewheels that double as ground wheels: Allows for fewer motors and moving parts, though it's challenging to have the paddlewheels and ground wheels at the same height given the necessary size of the pontoons because of our original estimated weight. Also limited by buoyancy constraints and the clearance of the bottom of the hull to the bottom of the wheels.
- 2) Separate paddlewheels and ground wheels: Might be more possible to implement practically than the above but would be more complicated.
- 3) Propellers in water, driven wheels on land: Similar to paddlewheels and ground wheels. Propellers might be difficult depending on where you mount them (if they poke out of pontoons/hull waterproofing may be difficult).

Flotation:

- 1) Two pontoons: Allow for space in the center of the boat for ball handling
- 2) Hull: Potentially gives more volume (and therefore buoyancy) than pontoons but doesn't allow for much in the way of ball handling unless you can lift balls
- 3) Materials: We thought about the benefits and drawbacks of using casted foam, closed-cell foam, and thermoplastic to displace water

Given these initial ideas, we decided on shooting for ball handling because we thought this would be an easy way to quickly move balls around, allowing for a lot of versatility (easy to play defense or offense and wouldn't be hindered as much if we weren't very fast). We decided on separate paddlewheels and ground wheels because, as mentioned above, we were unable to set the ground wheels and paddlewheels at the same height given how high we wanted the paddlewheels to be and how low the ground wheels needed to be. We decided on pontoons to allow space for our shooter.

We did calculations to determine the height we needed our paddlewheels to sit for maximum efficiency, the speed our boat needed to be to be able to travel what we decided was a competitive amount, the weight of our boat given the materials we proposed using, and the spring constant we'd need for the force we required for our shooter.

We later abandoned the shooter and replaced it with a plow, which we decided was more practical and useful for the competition given the difficulty of constructing something to shoot the oddly shaped balls very far and our speed (which would be able to move balls around relatively quickly by pushing them). Additionally, without the added weight of the shooter (and with the added buoyancy from switching to a hull since we no longer needed space for a shooter), the vehicle rode higher in the water, and we were able to combine the paddlewheels and ground wheels. This resulted in the final design described above.

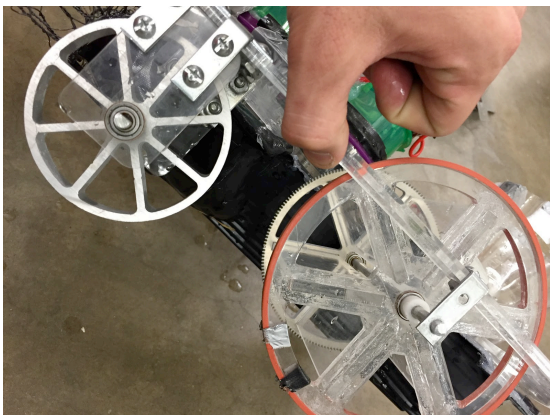
B. Final Design

1. Mechanical Design Components

Our mechanical design included many components, outlined and imaged in the following sections below:

a. Transmission

To simplify our transmission as much as possible, we used a single gear ratio between the motor gear and the paddle wheel gear (see figure to the right). The motors are waterproofed with party balloons, gorilla tape, and hot glue. They are fixed to the deck with two-bolt L-brackets and an adjustable motor mount (also pictured right). Two small hex-cap screws hold the motor to the mount and a single set-screw keeps the pinion gear attached to the motor shaft. The paddle wheels are also attached to the deck for ease of alignment. Their axles are suspended between two L-brackets which are bolted to the deck. These paddle wheels (with press-fit bearings) sit on the axle in a single orientation, so the motors could be adjusted for the best possible mesh. We attached as many components as possible to the deck so that they could all be aligned relative to one another and kept that way for long periods of time.



b. Ground wheels

Since our paddle wheels had so much torque and friction, we only used front wheels for balance and to avoid dragging the hull on the ramp. The system was designed to be compatible with front ground wheels driven with the same motors and timing belts (see CAD in section V.D below), but this design proved unnecessary. The ground wheels are suspended on D-profile axles in bearings pressed into $\frac{1}{8}$ " acrylic plates, which are mounted on the hull with the classic L-brackets, nuts, and bolts.

c. Hull and buoyancy

This hull was designed to be the appropriate volume to keep the boat above water and

the paddle wheels at the optimal height, without providing excessive drag while going forwards or backwards. It was designed in SolidWorks then chopped into ¼" vertical cross-sections which were laser-cut from MDF. Using two aluminum shafts for alignment proved useful for regular hulls and an easily reusable mold. The hull is sealed with thermoplastic, melted together with a hot glue gun. The edges are reinforced with acrylic weld, as are the bolt holes where the hull connects to the deck. To add last-minute buoyancy, we taped plastic condiment containers to the front of the hull to get it higher out of the water.



d. Plow

The plow was designed for optimal pushing of small balls without sacrificing weight or the ability to shove the large balls around. The chicken wire mesh was strong enough to stand up to collisions with other vehicles but

malleable enough to be easily moldable during the competition. The plow was held on with zip-ties and gorilla tape and was adjustable depending on the round's strategy (different configurations for large and small balls, and a different arrangement entirely for pushing other boats). In general, the sides were molded around the buckyballs and tilted upwards slightly to allow them to get better contact area on the balls.

e. Electronics box

Our electronics box is made of tupperware food storage containers sealed together with layers of hot glue. There is a protective plate in the bottom to prevent the components from sitting in water in case of leaks. The box is not quite water-tight if submerged, but no water enters the box even when it is splashed vigorously. During the competition, a combination of time and sunlight may have separated some of the glue bonds, allowing water to leak in, and that was fixed with strips of reinforcing gorilla tape.



f. Ball-holding cup

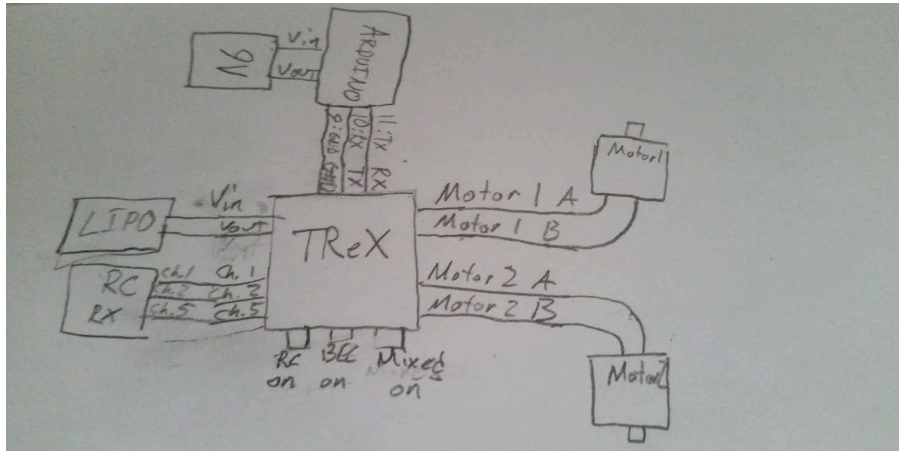
The ball-holding cup is made from strips of recycled two-liter soda bottles woven together and secured with tape. The bottle has some holes poked in the bottom for drainage. Having this bit of extra mass near the back of the boat pulled the prow up relative stern and caused the vehicle to rise noseward out of the water when accelerating, reducing drag further. It also gave us extra points at the end of the round depending on which scoring area we ended up driving to.

2. Electronics/autonomy (schematics)

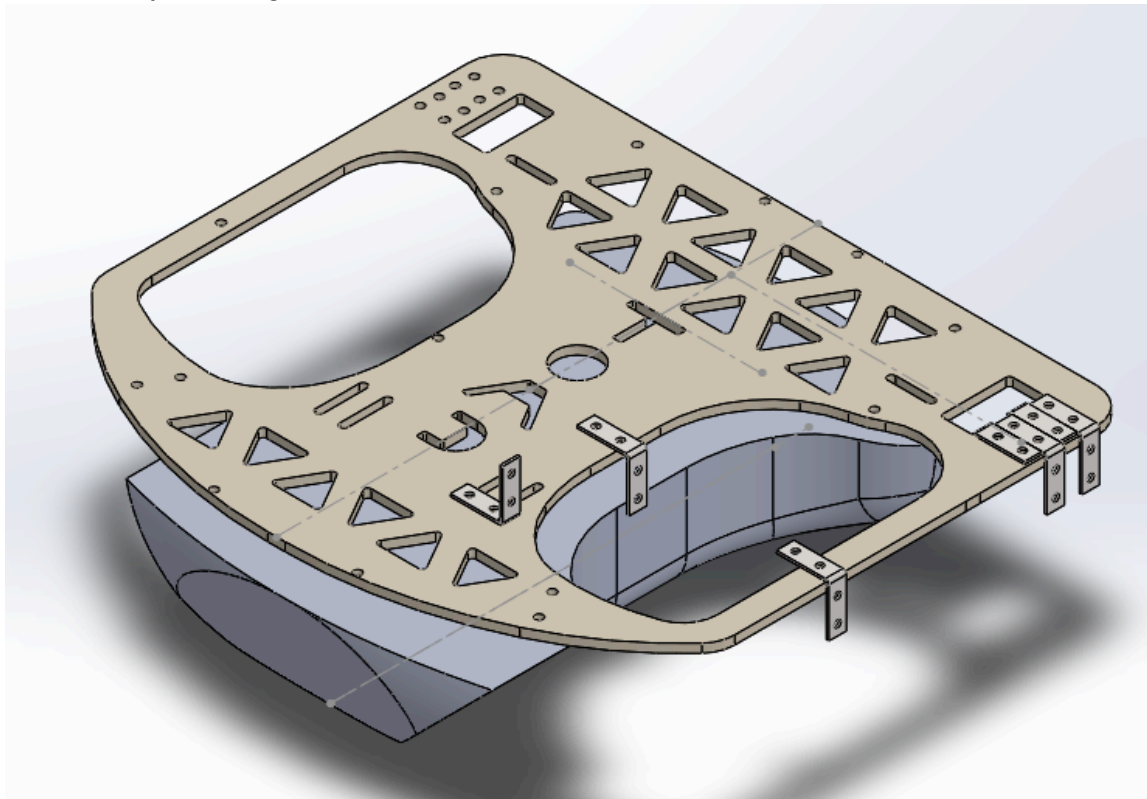
In the final iteration of our design, the external power system driving the ground wheels was removed for reliability and weight concerns. This left us with a simple TReX-Arduino system where, when serial mode (Ch. 5) was on, the Arduino sent serial codes moving the vehicle forward for ~4 seconds then stopping it. Elsewise, the two paddlewheel motors were controlled directly through Ch. 1 & 2 on the TReX, mixing the signals for ease of control.

More information about RC control on the TReX can be found [here](#).

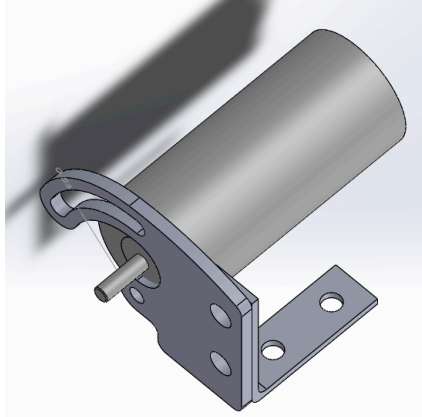
The Arduino code is attached.



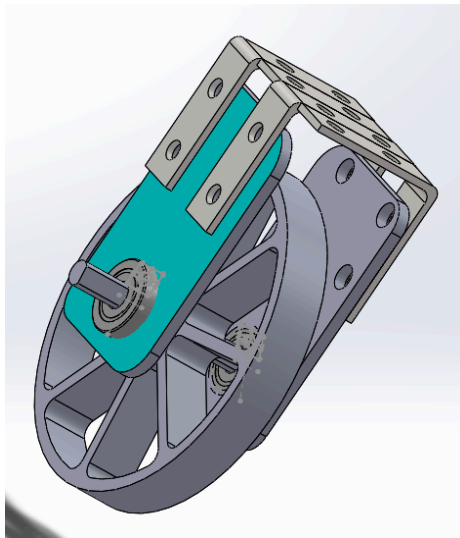
3. Assembly Drawings



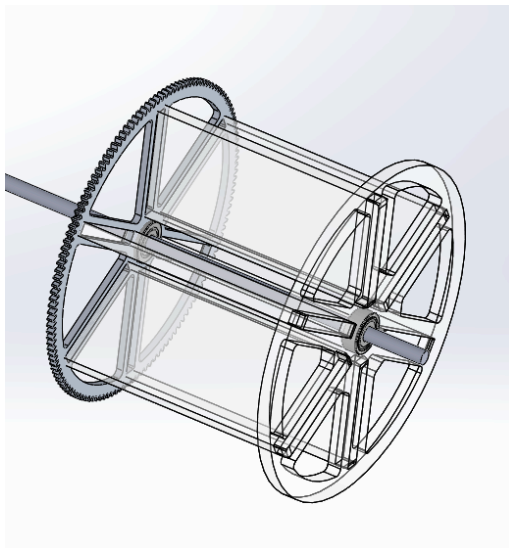
Drawing of the deck plate in relation to the hull with the attachment screw-holes and the different mechanisms assembled on top of the plate.



Motor mounted to the L-bracket in the slots up above. The mesh of the transmission is shown above.



Ground wheel mounted to four L-brackets with two plates as support.



Paddlewheel assembly. The two ends of the axle were fixed to two of the L-brackets above.

IV. Construction

A. Materials

In designing our vehicle, we used a variety of materials. In the final vehicle we used thin (3/16") aluminum for the gears, and acrylic sheet for the other major components. Although acrylic is about twice as expensive as aluminum per volume, it is about half the density. That allowed us to make thicker, more rigid components without sacrificing weight. We used cheap bearings from ebay that had consistent 0.247" inner diameters. John managed to find some undersized shaft that fit the bearings perfectly, averting catastrophe. We used brushed DC motors for maximum power transfer and coupled these to the paddle wheels with pinion gears, giving us a gear ratio greater than 12. In our second version, we used timing belts and timing belt pulley (GR = 6) to drive our ground wheels. This was quite successful, but proved unnecessary with the power of the side-mounted paddlewheels. For the hull we tested various thicknesses of thermoplastic and sealed the seams with a combination of hot glue, acrylic weld, and gorilla tape. The chicken wire plow was made from scrap wire found on campus. As always, we used an abundance of duct tape, gorilla tape, and zip ties to patch leaks and ad hoc hold bits together.

B. Machining

At the beginning of the process, we designed our vehicle to be easy to construct, but we quickly ran into trouble because we didn't think on a small enough scale. We forgot to thoroughly consider the 80/20 connectors, and our MDF cast for vacuum forming was too thin and kept collapsing. In our second iteration, we got rid of many of these issues by designing primarily for 2D components connected with bearings, axles, L-brackets, nuts, and bolts. This simpler design, coupled with our experience on the vacuum former made it much easier to fabricate the second robot. The third robot took advantage of the 2D fabrication from the second and some new techniques like stacking laser-cut MDF to make molds. We used manual machines only when necessary - to turn down shafts, cut washers, trim and ream out L-brackets, and drill extra alignment holes in the acrylic deck.

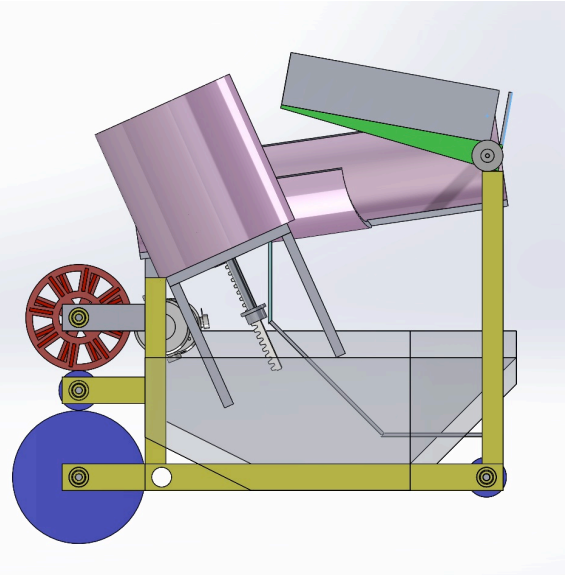
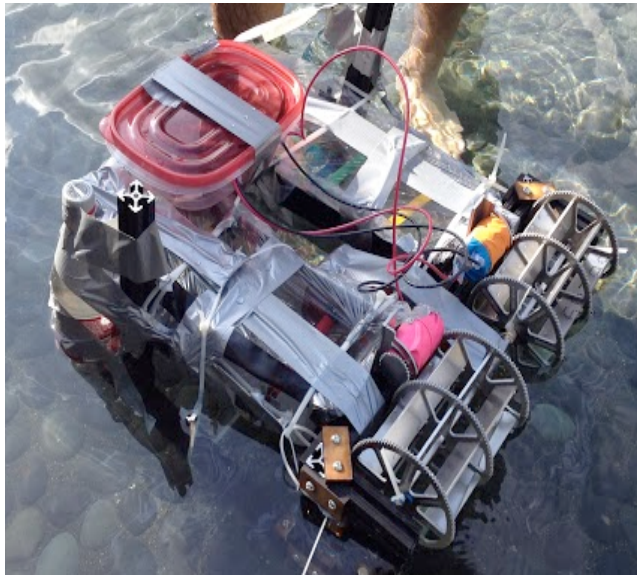
V. Testing

We spent the final week of the term testing different aspects of our design. We adjusted the plow to best turn while holding small balls, without sacrificing the ability to push large balls. We tested our water mobility by slaloming around the fountains in the Gene Pool and driving around Avery to test ground control. We spent a few hours shifting our electronics box from side to side to get the best possible buoyant position. Once the course was set up in the Millikan pond, Dan and combinations of the rest of us spent sessions there testing our ability to climb and descend the ramps and timing our speed between various parts of the course to determine optimal strategy. Finally, Jalani spent days testing and tweaking the autonomous Arduino code to make sure we could drive straight straight. Since one of the paddlewheels had more frictional resistance than the other, driving the motors with the same input pulse widths led to the vehicle constantly veering left. Jalani had to take this into account when writing the autonomy code and getting it right required a lot of testing and calibration. We did very little but test and tweak for the last week leading up to the competition.

VI. Initial Performance

A. Mobility Demo Stage

At the mobility demo, the first iteration of our robot was able to float and maneuver with rear-mounted paddle wheels. It was cobbled together with duct tape, zip ties and an all-nighter. Our performance was adequate; we added extra weight and rode low in the water to simulate our robot loaded down with motors and springs for our planned ball-capture mechanisms. Although our paddle wheel design worked well for propulsion, the rear-mounting caused the robot to be extremely back-heavy and unable to drive backwards. In the mobility demo, we used a heavy frame made from 80/20, which we later scrapped because of its weight and size. Just before the demo, our ground wheels snapped off, leading us to reevaluate our transmission design leading into the critical design review. See images below for CAD model and photo of TOAD_mark1.



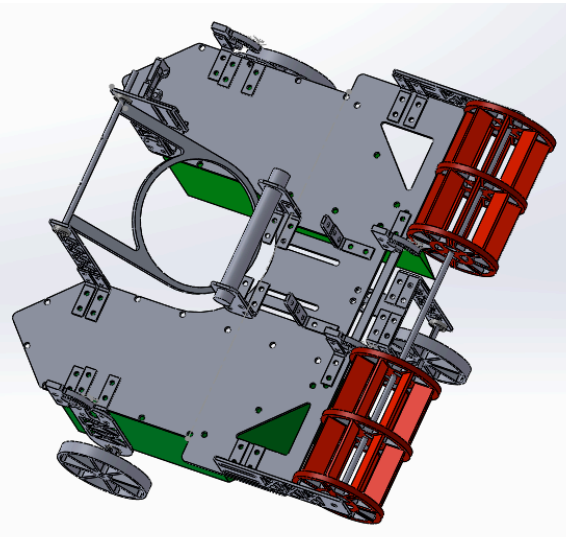
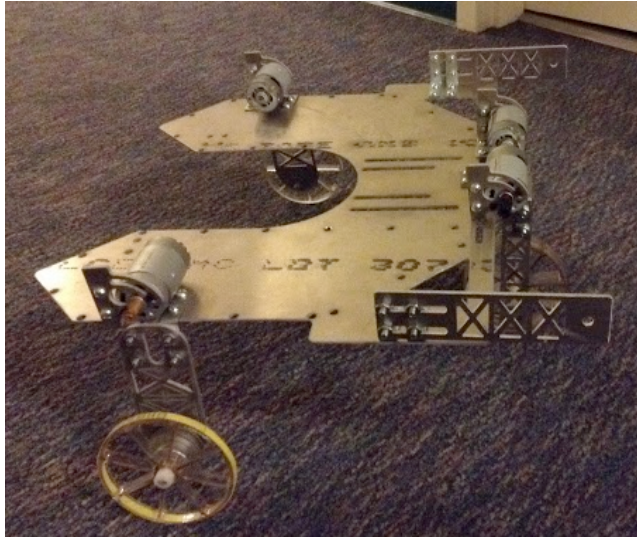
B. Critical Design Review stage

After the mobility demo, we realized we had a few major changes to make to the vehicle. We redesigned our pontoons out of stiffer plastic, got rid of the 80/20 frame, attached all of our components to a deck plate (since the buoyancy force pushes the pontoons upwards), and redesigned our ground wheel transmission system. We did not redesign our paddlewheels but, unfortunately, did design a complex ball capture and launch mechanism. Over the first few weeks of winter term, we constructed this second robot and tested in preparation for the scoring/handling demo. It worked relatively well (despite being heavy, lumbering, and slow) and we had control over both ground and water mobility with timing-belt-driven front ground wheels. This design was more balanced, with four brushed DC motors, but still required us to attach lead weights to the front to keep the bow down.

C. Scoring/Handling Demo Stage

We brought this second robot to the scoring/handling demo, but while testing a few minutes before the demo, a set-screw coupling a motor axle to its pinion gear came loose. While trying to retighten the screw, we stripped it, rendering the motor useless. We were unable to move (other than in circles) for the handling demo, so we did not participate. The pinion gear in question was the incorrect inner diameter, mistakenly, so it failed to couple properly with the motor shaft. Due to the weeklong headache caused by our failure to put our robot in the water

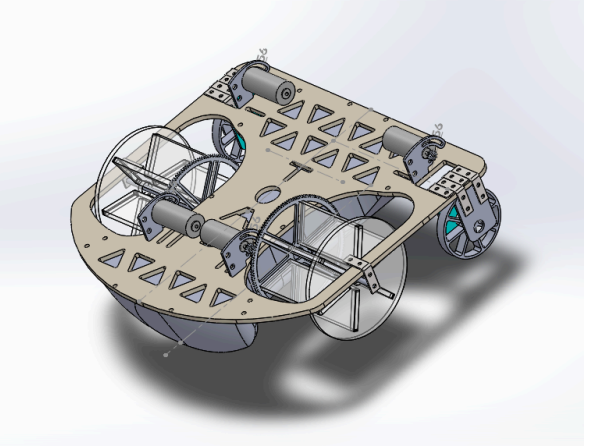
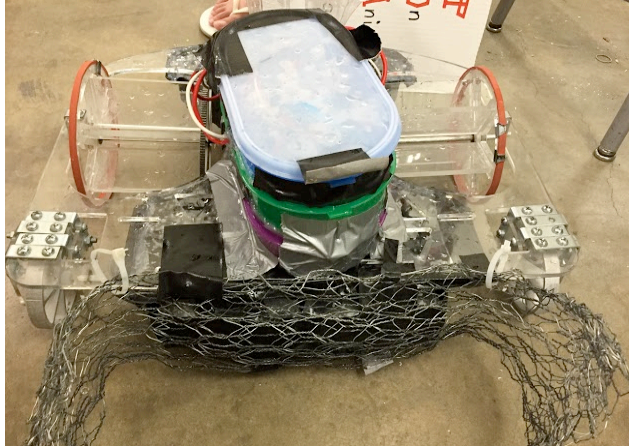
during the scoring demo, it is unlikely any of us will ever forget to double-check the fit of shafts and their receptacles again. See images below for CAD model and TOAD_mark2.



D. Final Design and Assembly Stage

After wasting almost a week dealing with the repercussions of the scoring/handling demo, we did a whole system overhaul. Since the rear-mounted paddle wheels were wreaking havoc on our balance, we switched to side-mounted paddle wheels. We kept our ground wheels front mounted, but had so much power with the paddle wheels that we removed the front two motors for simplicity in electronics and for reduction of weight. With just one of our two motors we had enough torque to get up the ramps. This reduced our robot's weight to under eight pounds. To accommodate the side-mounted paddle wheels (that double as ground wheels) we reformatted our flotation from pontoons to a hull and allowed the paddle wheels to extend outwards horizontally to be clear of hull interference. We also shortened the boat to put a chicken-wire plow on the front and scrapped more complex ideas of ball manipulation.

This third iteration of our robot went ideas on a whiteboard to a prototype in the water in just eleven days. This version was significantly lighter, better balanced, and easier to control on both land and sea than either of our previous two robots. We had some waterproofing issues with the hull which we fixed with a mixture of acrylic weld, hot-glue melting thermoplastic, and a drainage hole sealed with gorilla tape, and of course, an all-nighter. By the time we repeated our handling demo, our robot was a few tweaks and hours of driving practice away from the final competition. See the images below for a CAD model and photograph of TOAD_mark3.



VII. Final Performance

In the final competition, we performed as well as we could have hoped. In the first round, our partnership with KATS worked well. We lost by a single point to Axolotl and Sea Bears over a misunderstanding of the rules. We ended the round on our own platform holding a ball, but we awarded no points for it because we had failed to enter the water during the autonomous period. Had we stayed in zones 2 or 3, however, while holding the ball, we would have won the round.

After a successful round paired with Axolotl, our radio receiver got damp and malfunctioned. We switched receivers (thanks to quick action by Justin Koch and John Van Deusen) and controllers. Unfortunately, the new controller was broken, so we were forced to rebind our old controller to the new receiver. These technical difficulties kept us out of two rounds, leading to losses against the Sea Bears and the Millikan Ballerz. However, once we fixed the controller/receiver issues, we rebounded with two strong wins, one with the Koopas (the highest scoring match) and one with the Shipping Flits. Although our robot was ready for action and showed a strong performance, we'd missed two rounds completely and so our 30 points were nudged out of contention for a semi-final spot by the Flits' score of 33.

In the games that we did play, our robot was quick and maneuverable in the water. We only lost a single round and that was due to a misunderstanding of the rules. Not only were we one of the fastest boats in the water, we were able to navigate the land obstacles forwards and backwards and able to move small and large balls quickly. We played effective offense (scoring balls in zones 2 and 3 and bringing balls up our own ramp) and defense (blocking the ramp and protecting our balls in zone 2 and moving balls of the opposition back into zone 1). Our boat was so resilient that when the Koopas were rushed into making a mistake while fixing their robot, we lent them ours to compete against Shipping Flits in the semi-finals. Although this move got the Koopas disqualified from the match, it gave the audience and announcers some excitement. It also showcased the value of a sturdy boat and a quality driver; Joaquin's control over TOAD was excellent, and had the round been counted, Koopas would have won handily even after a two-minute handicap. Overall, we are very satisfied with how our vehicle performed over the course of the competition.

Arduino Code:

```
/*
Code for autonomous control of T.O.A.D.'s vehicle in the 2015 ME72 competition.

*/

#include <SoftwareSerial.h>

SoftwareSerial mySerial(10, 11); // RX, TX

void setup()
{

    pinMode(9, OUTPUT); //set pin mode to output for GND pin
    mySerial.begin(19200); //set computer side baud rate
    digitalWrite(9, LOW); //set pin low for GND connection

}

void loop()
{

    int loop_time = 1;    // Wait time for a loop, so it doesn't go too fast.
    delay(loop_time*1000); // delay(millisecods)

    mySerial.write(0x83);    // Ask the TReX if the serial controls the motors.
    int we_control1 = mySerial.read(); // If 1 then it's we control the motors; if 0, then not.

    if ( we_control1 == 1)
    {
        // Serial mode was ON.

        option1(100); // Characteristic "stutter" to let you know you're in choice mode.

        int option_time = 3; // This is the time you have to input an option, in seconds.
        delay(option_time*1000);

        int run_time1 = 4;
        option1(run_time1*1000);
    }
}
```

```

}

while ( we_control1 == 1 )
{
    // Wait until Serial mode is turned off.
    mySerial.write(0x83); // Check if we're controlling still.
    we_control1 = mySerial.read() ;
    delay(4*1000);
}
}

void option1(int drive_time_in_ms)
{
    // Now we move forward.

    uint8_t motor1_off[2] = {0xC6,0x00};
    uint8_t motor2_off[2] = {0xCE, 0x00};

    // Motor 1
    delay(1);
    mySerial.write(0xC6); // Set motor 1 forward.
    mySerial.write(0x18); // Set speed = 24 (on a scale from 0-127)
    delay(1);
    // Motor 2
    // Set motor 2 forward.
    mySerial.write(0xCE); // Set motor 1 forward.
    mySerial.write(0x2A); // Set speed = 42.

    delay(drive_time_in_ms);

    // Now we turn off our motors.
    // Motor 1
    mySerial.write( motor1_off, sizeof(motor1_off) );
    delay(1);
    // Motor 2
    mySerial.write( motor2_off, sizeof(motor2_off) ); // Set motor 2 forward.; // Set speed = 0
    delay(1);
}

```

Item	Description	Quantity	Price Per Unit	Total Spent	Date Purchased	Purchaser	Link	
Motor	12V, 4A	1	\$3.49	14.37	11/2/2014	Aaron	http://www.jameco.com/1/1/28167-md5-2070-r-12vdc-motor-dc-direct-drive.html http://www.jameco.com/Jameco/Products/ProdDS/232040.pdf	These provide a stall torque of 0.028 Nm or a max velocity of ~2.2 m/s
Gorilla Tape		35 yd	\$12.99	\$12.99		margaret		
Water Seal			\$8.99	\$8.99		margaret		
Rubber Cement			\$3.19	\$27.44		margaret		
Balloons			\$2.45	\$2.67		margaret		
10.7" Jumpers		2 packs	\$5.99	\$13.06		margaret		
80/20				\$42.26		aaron		
Cheap-o bearings				\$17.76		aaron		
Small Motors				\$11.26		aaron		
JB Weld				\$11.70		aaron		
Large Motors				\$21.50		aaron		
1/8" Aluminum Sheet				\$60		aaron - me72 account		
MDF				\$10		aaron - me72 account		
Plastic from John				\$30		given by John		
More large motors				\$46.50		aaron		
Timing Belts and pulleys				\$58.82		aaron		
Rice				\$5.00		aaron		
0.247" Shaft				\$5.00		Given by John		
1/4" aluminum shaft				\$4.29		aaron		
Cable tie 14" loop				\$12.49		aaron		
Alligator clips				\$1.49		aaron		
60 yds wire				\$7.99		aaron		
Screw rod				\$4.49		aaron		
nuts				\$3.19		aaron		
general purpose wire				\$3.99		aaron		
thin wire				\$10.08		aaron		
fuse holder		2	\$2.49	\$4.98		margaret		
fuse	15amp	1	\$3.99	\$3.99		margaret		
zener diode	16volts		\$1.69	\$11.62		margaret		
nuts		1	\$3.19	\$3.19		margaret		
bolts			\$4.49	\$8.37		margaret		
L-brackets			\$8.98	\$9.63		margaret		
Aluminum Sheet	1/16"			\$12.39		aaron		
Aluminum Sheet	1/8"			\$52.47		aaron		
Aluminum Sheet	1/4"			\$16.34		aaron		
Aluminum Sheet	1/2"			11.44		aaron		
Worm and Worm Gear		1 each		77.8		aaron		
Pinion gears	32 pitch			14.97		aaron		
Pinion gears	24 pitch			30.96		aaron		
More timing belts	mcmaster			17.28		aaron		
Spring Rebate	McMaster	1	-\$48.77	-\$48.77		aaron		
Worm gear rebate	SPD-SI	1	-\$62.34	-\$62.34		aaron		
Acrylic	1/4" 2'x2'	2		\$65.66		aaron - me72 account		
Acrylic	1/8" 2'x2'	1		\$21.48		jalani - me72 account		
Traction pads	3' by 1/2"	2	10.26	20.52		aaron		
MDF	1/4"	a couple of sheets		\$3.16		aaron - me72 account	this stuff is so cheap!	
Aluminum sheet	1/2"			\$26.11		aaron - me72 account		
Hollow Aluminum Tube	1/2" Diam, 6" length	1	\$0.89	\$0.89		aaron - me72 account		
Aluminum shaft	1/4" diam, 2'	1	\$3.04	\$3.04		aaron - me72 account		
Aluminum sheet	1/8" 2'x2'	1	\$12.35	\$12.35		aaron - me72 account		
Arduino Mega	Used, Jalani had one	1	\$11.75	\$11.75		jalani	http://www.ebay.com/itm/NEW-ATmega2560-16AU-CH340G-MEGA-2560-R3-Board-Free-USB-Cable-For-Arduino-/151303481964?pt=LH_DefaultDomain_0&hash=item233a63ea6c	
Grand Total Spent:				776.61				