ME 250 Redesign

ME 450 – Section 3 – Team 6
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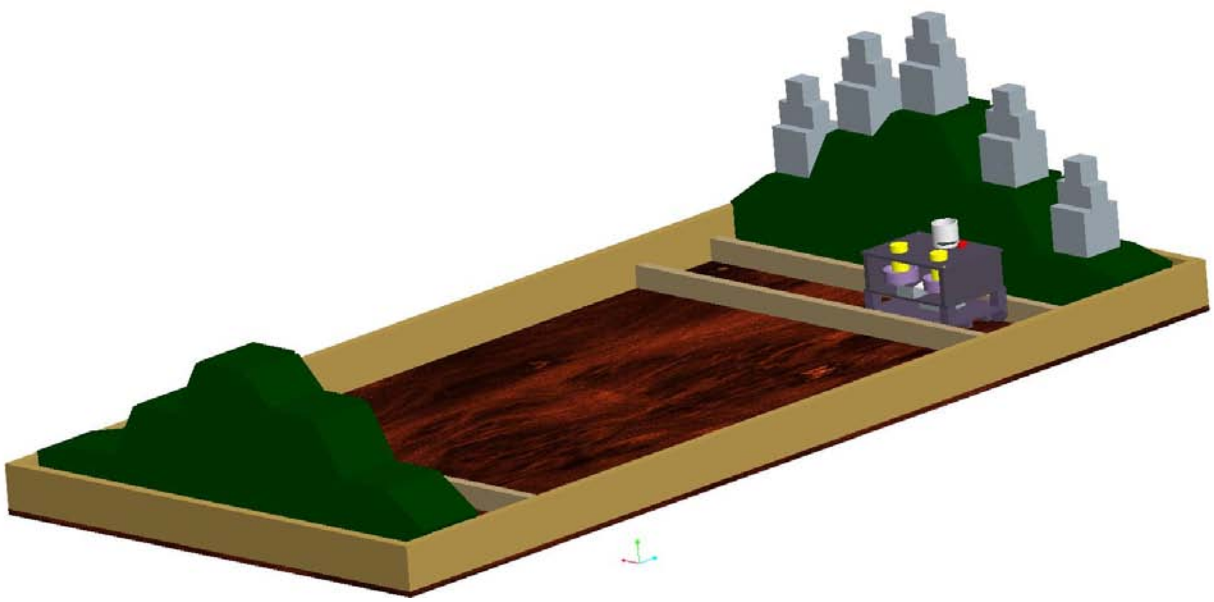

The purpose of this project is to redesign the sophomore level mechanical engineering course and design project to allow students to utilize their classroom knowledge and creativity to manufacture a prototype. The team worked with Professor John Hart to establish a team project that incorporates various design and manufacturing methods, offers more creativity, and utilizes various materials and moving mechanical components. The team created two prototypes, equipment for the end of semester contest, and relevant lecture materials. This project will affect the future Mechanical Engineering (ME) design and manufacturing curriculum, and positively impact over 250 ME students each year.

EXECUTIVE SUMMARY

ME 250 (Design and Manufacturing I) has come to a point where the course needs to be redesigned. The lectures and materials do not directly relate to the project, and the project itself should be improved. Michigan's sophomore design course is inferior to comparable courses at peer institutions (MIT, Cal Tech, Houston, and Villanova). Their sophomore level design and manufacturing courses intensely focus on successfully prototyping a robotic device that can compete in an end of semester competition. This method results in engaged and excited students, tailoring their prototype in an attempt to have the winning device. Based on the examples provided by these schools, the lectures should focus on the "big picture" and the class should include a more complicated project involving moving parts.

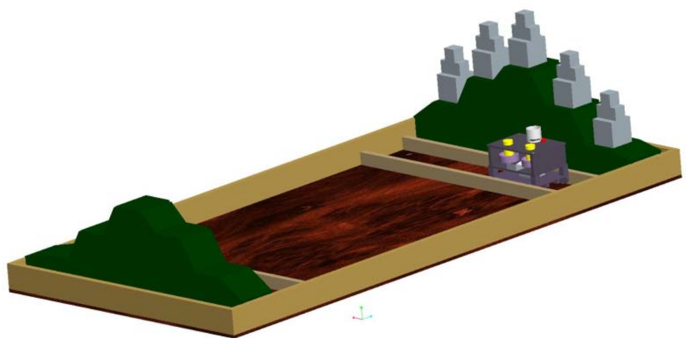

Figure 1: Battlefield with an example tank prototype

The top five customer requirements that were considered when designing our course were:

1. Ensuring the safety of each student.
2. Allotting a reasonable amount of time for completion of the project.
3. Allowing for students to express creativity when designing prototypes.
4. Creating a challenging environment for the students.
5. Including moving parts (gears, bearings, etc.)

The project that we decided on is called Tank Wars. Student teams will design, manufacture, and program a tank capable of firing a foam ball to destroy their opponent's buildings made of stacked balsa wood blocks. The students' tank prototype must include the mechanical components, motors, and programming needed to fire the foam ball. Teams will attach their tank prototype to the provided tank platform which will include the Arduino control system and the motors needed to drive within the road barriers. Teams are provided a material kit, a budget that they can spend on additional components, competition rules, and specifications that their tank prototype must meet.

The competition places the tank prototypes in the battlefield. The tanks will sit within a road barrier that will allow the tanks to move from side to side on the battlefield. Each end of the battlefield has a hill with horizontal platforms at a variety of heights. Each platform holds a building made of stacked balsa wood blocks. The battlefield also includes a short wall around the perimeter and a net to contain the foam balls.

We designed and manufactured two example tank prototypes. The first prototype uses stored energy by compressing a spring with a rack and sector gear. The second prototype is similar to an automatic pitching machine; the ball develops a velocity as it is fed between two rapidly rotating wheels.

We develope a sophomore level mechanical engineering course and design project that effectively allows students to utilize their classroom knowledge and creativity to manufacture a prototype. We manufactured the battlefield, two tank platforms, and two example tank prototypes. We also created a supporting document describing Tank Wars and its requirements to student teams and lecture and lab schedules.

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INTRODUCTION

ME 250 (Design and Manufacturing I) is the sophomore level design and manufacturing course at the University of Michigan (UM). The class has three hours of lecture and two hours of lab each week with prerequisites of Calculus II (Math 116) and Introduction to Computers and Programming (ENGR 101). It currently covers engineering and CAD drawings, basic mechanical elements and materials, and industrial manufacturing methods. Also, there is a team project due at the end of the semester. In previous semesters, this project has consisted of designing and manufacturing a product such as a CD case or iPod dock as shown in Figure 1. These products do not integrate moving parts, limiting a student's ability to apply technical knowledge to analyze his design. Additionally there is not an end of semester competition to motivate students to create the most successful design. This class is not equivalent to similar sophomore design classes at peer universities; therefore, ME 250 should be redesigned.

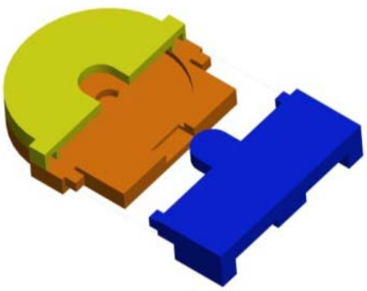
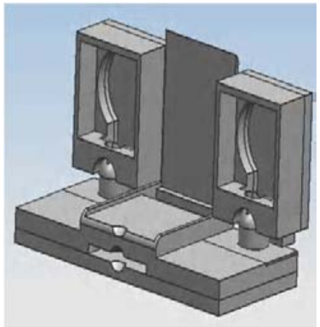



Figure 1: Previous ME 250 projects (CD Case and iPod Dock)

The sponsor for the project is Professor John Hart, an Assistant Professor of Mechanical Engineering at UM. After meeting with him, we believed that the ME 250 class could be taught differently and should include a more complicated project. Thus, the goal of this project was to completely redesign ME 250. Professor Hart wanted us to create everything from the lecture and lab schedules to the semester-long project. More specifically, we needed to design and manufacture two prototypes, the equipment for the end of semester competition, and include plans for all relevant lecture material.

This project directly affects mechanical engineering professors, graduate student instructors (GSI), and over 250 mechanical engineering students per year. Creating a project for ME 250 that involves a competition will engage students and motivate them to continue their education in mechanical engineering. Also, the project allows students to develop a creative design that utilizes a variety of materials, tools, and moving parts. A complicated project shows students the connection between their theoretical engineering knowledge and real world applications as they analyze their designs. Overall, the changes to ME 250 will revolutionize the way mechanical engineering is taught at the University of Michigan, and keep this program competitive with peer universities.

INFORMATION SOURCES

This section will discuss in detail the results of our literature review regarding engineering design education and sophomore level design courses at other universities.

Research into Engineering Education

Research into curriculum development at a variety of universities has shown the benefits of introducing design courses early in a student's engineering coursework. Professors at Columbia University developed a design course for first year students, in which student teams create a design as part of community focused service projects [1]. The university found that this course helped reassure students of their choice to be engineers; therefore, after implementation of the design class, fewer students changed their major from engineering.

Professors of Mechanical Engineering Technology at Pennsylvania State University Hazleton (PSU) also introduced design-based courses to first and second year engineering students [2]. In this case, the design course was targeted to Mechanical Engineering Technology students. PSU found that students benefited from this class in a variety of ways. As was the case at Columbia, this course increased students' interest in mechanical engineering and their motivation to follow this career path. In addition, PSU used a technically difficult design project by focusing heavily on engineering aspects, while UM currently focuses largely on the aesthetics of the project. Because of this, they saw an increase in students' ability to connect what they learned in each of their academic courses and see the "bigger picture" of mechanical engineering. PSU's experience justifies making the design project at the UM more complex and technical. Both Columbia University and PSU provide support for continuing to offer the sophomore level design course at UM because this course will capture students' interests early in the mechanical engineering curriculum, and provides a real engineering experience. However, they also show that the course needs to be updated.

Based on their experiences teaching project-based design courses, professors at Rowan University developed a variety of theories regarding teaching design to engineering students [3]. First, the professors found that working on design projects was insufficient to develop strong design skills. Many students found it difficult to be analytical and creative at the same time. Project teams brainstormed concepts and chose a final design without analysis to support their decision resulting in over- or under-designed projects, rather than projects designed for the given situation. The professors solved this problem in two ways. First, they required students to document creativity and analysis throughout the design process. This concept should be implemented in freshman engineering classes at UM, with subsequent classes (such as ME 250) reinforcing and expanding the concept. Second, Rowan professors constructed a sequence of design projects that become longer and more complex as students progress through the curriculum. This allows students to master portions of the design process early, and use these concepts in later projects. This is the same approach that UM takes by requiring sophomore, junior, and senior design courses that increase in difficulty.

Dr. Richard Bannerot of University of Houston found that his engineering design students were benefited by situations where they had to work with students with different learning styles and different cultural backgrounds [4]. He had engineering students work with art students because it "brings two different groups of students with different backgrounds and perspectives together on the design process" [4]. He believes that art students are better than engineering students are at evaluating qualitative information and avoiding tunnel vision while working. Later in the semester, he pairs engineering students from his class with engineering students in Japan. Bannerot provides his students with both of these opportunities because he believes that "non-technical issues can not only provide the basis for design constraints and goals, but they can even dominate the technical considerations for a design to be successful" [4]. He found that instructors obtain new methods and tools for teaching, while students increase their knowledge of design concepts and theories in other countries and markets. Different learning styles and cultural backgrounds are addressed very briefly in ME 250. A lecture on these topics should be added to the class Bannerot found that students can greatly benefit by understanding how their teammates think and work.

Research into Existing Sophomore Design Courses at Other Universities

UM ME 250: Michigan's Winter 2009 ME 250 course has 26 lectures (two each week) with two 1-hour lab sections each week. Students have two exams, lecture homework, lab homework, and a semester-long project. The project focuses on designing a prototype using CAD software and manufacturing this design with CNC machines. Students work in teams of four or five, and are required to deliver a prototype, 2-

minute video clip, and a final report. Safety is emphasized throughout the lectures, labs, and project. See Appendix A.1 and A.2 for further details on the course syllabus and lecture schedule respectively.

The Winter 2009 semester project involves creating a self-propelled miniature vehicle that can drive up an inclined plane (See Appendix A.3). Figure 2 illustrates the course for the vehicles. The goal of this project is to design an aesthetically pleasing vehicle that can climb the farthest up the course at the steepest angle. In addition, more points are awarded to teams who can climb the course the fastest.

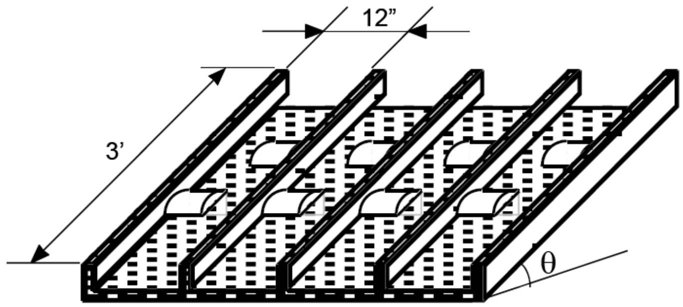


Figure 2: Obstacle course used to test the self-propelled miniature vehicles.

Teams are provided with a gearbox, DC motor, and a two AA battery holder with switch and must incorporate these parts into the device. Teams are also given epoxy, wax blocks, and PVC stock along with a budget of $40 to spend on additional materials such as metal, wood, and plastic.

We contacted the professor of the course as well as one of the head graduate student instructors (GSIs) and were given access to the course website which we used to obtain lecture, lab, and project details.

MIT-2.007 Design and Manufacturing I: MIT-2.007 is a 12 week project-based course that focuses on the design process and touches on a variety of topics related directly to the given project (See Appendix B.1). The prerequisites for this course are Mechanical Engineering Tools (MIT-2.670) and Mechanics and Materials I (MIT-2.001). Students work through the entire design and manufacturing process for a robotic device taking into consideration design, cost, time management, and safety. Grades are based on the students' design notebook, a closed book mid-term exam, their final prototype, personal website, and final report. The lectures, homework, and labs are geared to directly assist in achieving the final project goals. See Appendix B.1 and B.2 for a full course syllabus and schedule.

For the Spring 2008 project (see Appendix B.3), students were required to design a robot that could find, feed, house, and protect their "beaver baby" family. More specifically, each student created their own robotic device, but was assisted with concept generation by three other students. They were provided with a list of parts including a planetary gearbox, a motor, and a variety of other materials (see Appendix B.4 for a complete list) that could be used as needed. At the end of the 12 weeks, students competed in a tournament against one another on a predesigned course as shown in Figure 3.

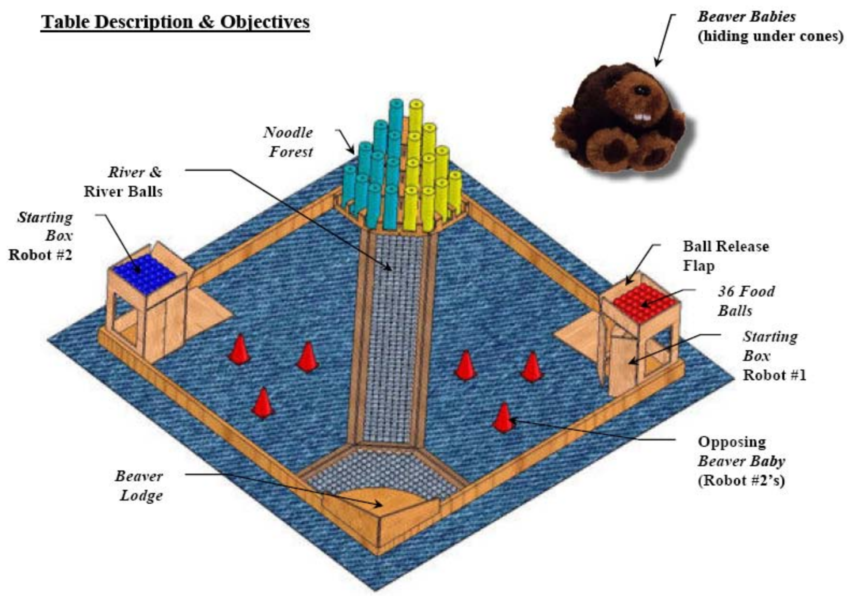


Figure 3: Competition setup for MIT 2.007 Project

MIT-2.007 has its own website that includes course information, contest layout and rules, equipment, additional resources, contacts, and links to related topics [5]. We obtained all of our information about the course from this website.

Cal Tech ME 72: This class occurs over a two-quarter period, lasting from late October until the end of March. The first quarter focuses on the design aspect of the project, while the second quarter focuses on manufacturing and assembling a prototype. Lecture time in this course is devoted to design issues, design methodology, and technical topics relevant to the project. Currently, this involves motor modeling, motor control, fluid dynamics, etc. [6]. See Appendix C.1 and C.2 for more details about the course and its schedule.

The current project for this course is to design and manufacture an amphibious device that enters a fountain, picks up and relocates balls, and exits the fountain as shown in Figure 4 (see Appendix C.3 for complete rules). Each group of two or three students is provided with a material kit including a radio control kit, servo motors, and DC motors (see Appendix C.4 for all materials). The class incorporates several evaluations during the manufacturing process to ensure that all groups are on schedule. The class concludes with a competition between the teams to determine which device best navigates the competition course.

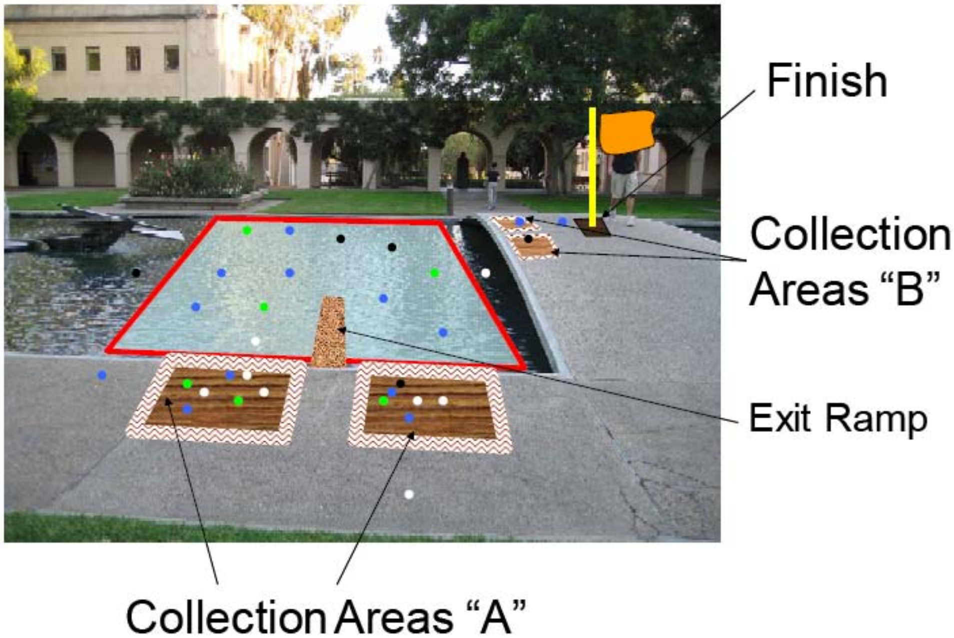


Figure 4: Cal Tech ME 72 Competition Setup

Professor Joe Shepherd provided us with information on the lecture schedule, project, and other course materials. He also referred us to the course website for additional information.

University of Houston MECE 2361: University of Houston's MECE 2361 Mechanical Design I class consists of a 2-hour lecture and a 3-hour lab each week. Students have two closed book exams, eight individual homework assignments, one individual project, and a team project completed by teams of four students. The prerequisites for the course are Engineering Graphics and Freehand Sketching (CNST 1331) and Software Development (MECE 1331). Along with creating a prototype, teams write progress reports, have meetings with the instructor, conduct initial and final testing, write a final report, and give a final presentation. See Appendix D.1 and D.2 for a course syllabus and schedule.

For the Winter 2009 semester, teams created a device that sorts golf balls and ping pong balls out of a mixture of up to 20 balls (see Appendix D.3). The device delivers the golf balls and ping pong balls into separate containers. The project requires the device to weigh less than ten pounds, and it cannot have any external energy source. Teams are penalized if their device has excessive stored energy and are disqualified if their device is deemed unsafe. The project is very open-ended, encouraging students to explore gears, hinges, pulleys, and other moving parts.

We have obtained information regarding the lectures, labs, and project from Dr. Richard Bannerot who is the professor for the course.

Villanova ME 2505: Villanova University's sophomore level design class, ME 2505 Analysis and Design, consists of 28 lectures (two lectures per week) and a weekly 3-hour lab. The prerequisites for the course are Calculus II (MAT 1505) and Engineering Computation (EGR 1705). Students are assigned a major project with an end of semester competition, as well as several minor projects during the semester. Examples of the minor projects include: assembling a ball-launching mechanism with a dowel bar and several rubber bands, creating a rocket and rocket launcher using air pressure, taking apart several tools to observe the moving parts, taking apart and reassembling a lawn mower engine, and measuring the temperature and voltages of cell phones and laptops using Labview. Appendix E.1 and E.2 contain detailed information on the class.

The major project for the Fall 2008 class was Beetle Bots, where each team of three or four students built a robot that can destroy their opponent's robot while also surviving the obstacles in the competition arena (See Appendix E.3). Teams worked on their robots on their own time outside of lab. The arena was enclosed and contains several spinning saw and lawn mower blades. Students are aware that their robots might be destroyed and use this as motivation to be more creative in their design. The robot design is very open-ended; the only restrictions that students faced were that the robot had to be less than three pounds, could not explode or shoot fire, and any objects that would be fired must be tethered. Teams were asked to spend less than $15; however there was no penalty for exceeding this amount. The end of semester competition involves 20-25 teams (80-100 students) competing head-to-head in a double elimination tournament.

Professor Jim O'Brien, along with the Villanova University Mechanical Engineering website [7], provided us with a general description of the lectures, labs, and projects.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

After meeting with our project sponsor, our team formulated a list of customer requirements that satisfied the project description. The following is a list of these customer requirements:

1. Design a competition between prototypes at the end of the semester
2. Include moving parts (gears, bearings, etc.)
3. Use a wide variety of tools
4. Use a wide variety of materials
5. Allow students to express creativity when designing prototypes
6. Connect lecture content to the project
7. Allot a reasonable amount of time for completion of the project
8. Keep the cost for prototype creation to a minimum
9. Ensure the safety of each student
10. Provide new educational tools to help students effectively work in teams
11. Redesign class schedule to accommodate increased difficulty
12. Create a challenging environment for the students

We used our engineering knowledge and previous experience in ME 250 to translate these customer needs into engineering specifications. After increasing the complexity of the project and adding a competition, we needed to ensure the students have enough time for each phase of the project (design, build, and test). ME 250 currently provides students with six weeks in the lab to learn how to use the CNC machines, build and test their prototype, and the entire semester to design. These are the time limits for our final design. The current ME 250 course has a $3500 budget per semester. Splitting the approximately 140 students taking this course each semester into teams of four, the budget becomes roughly $100 per each student team. We limited the increase in cost of this class; however, our sponsor suggested that a cost increase is justifiable if there are educational benefits. A wide variety of materials increases project complexity because students must understand the uses and advantages of the new materials. We must balance this concern with our design, providing students with an introduction to more materials and promoting creativity. Finally, because this is a sophomore design course and the level of mechanical engineering expertise varies by student, project specific teaching is required during lectures to ensure that each student is able to effectively participate in all phases of prototype creation.

Quality Function Deployment Chart (QFD)
Each of our customer requirements was given a ranking based on its importance compared to the other customer requirements. The weighting was determined by comparing a customer need against all other customer needs. For each comparison, the need of higher importance was given a value of 1, while the lower importance received a 0. After performing these comparisons, the values were totaled for each need, and the total was used as the customer weight (see Appendix F). The needs with highest importance were student safety and a reasonable amount of time to complete the prototype. The rest of the rankings can be seen on the QFD chart in Appendix G.

To determine the correlation between the engineering specifications and the customer requirements we looked at each relationship individually and as a group. These values are represented on the QFD with 1 as a weak correlation, 3 as an average correlation, and 9 as a strong correlation. If all team members agreed upon the value, it was the value we used. If we disagreed, we discussed it and eventually came to a unified conclusion. These values were then carried through the chart and relative ranks were evaluated for the engineering specifications.

Benchmarking
The following is a comparison of the previous and Winter 2009 ME 250 courses, and the equivalent courses at MIT, Cal Tech, University of Houston and Villanova to our customer requirements.

Previous ME 250 courses: Prior to the Winter 2009 semester, the sophomore design course at UM gave students the opportunity to learn about the design process. Students were assigned a product to design and manufacture based on provided customer requirements. Previous examples of these products include flashlights, CD cases, iPod docks, and computer mice. In lecture, students were taught the basics of engineering drawings, QFD charts, and various industrial manufacturing processes. Lab sessions taught the use of CAD programs (Unigraphics NX, Pro/ENGINEER, and CATIA) for engineering drawings and 3-D models as well as the use of CNC machines.

During the manufacturing stage of the project, students were given the option to use blocks of PVC for machining or wax blocks to mold epoxy parts. A CNC mill and lathe, band saw, and drill press were available to complete their project. An area was also set-up for sanding and painting the prototypes. Throughout the manufacturing process, safety was taught and enforced. The semester culminated with the Engineering Design Expo, where each team’s prototype was displayed, but there was not any explanation for the individual designs.

We found that although the cost of this project is low, it is because of reasons that contradict other customer requirements. The cost was kept low by limiting the available parts and materials, thus limiting design complexity. The only competition at the end of the semester was a comparison of aesthetic appeal. A full comparison of how ME 250 compares to the Customer Requirements can be seen in the customer opinion survey section on the QFD chart in Appendix G.

Winter 2009 ME 250 course: The Winter 2009 semester ME 250 course provided students with an introduction to design and manufacturing methods. It included many features that previous ME 250 classes have included, but had a modified project that included an end of semester competition. ME 250 revolved around a project that introduces students to the use of motors, analysis of friction, and allows for creativity by providing a $40 budget. The project culminates in a competition of motorized vehicles climbing a hill, with the slope of the hill increasing as vehicles succeed on prior slopes. The students are provided with stock PVC and epoxy, and are encouraged to manufacture parts out of this material. However, they are able to purchase additional materials. The tools available are limited to the CNC mill and lathe, band saw, and drill press. Students are allowed six weeks in the lab to manufacture, test, redesign and rebuild as necessary. Safety is taught and enforced throughout the course.

Students are encouraged to show creativity when designing prototypes, with a focus on design analysis prior to fabrication due to the limited time available to manufacture. To help with the planning, there are several lectures that focus on teaching concepts necessary to understand the functionality of the motor and gears supplied. Students are expected to enter the class with background physics knowledge to understand friction and inclined planes.

MIT 2.007 course: MIT-2.007 describes the competition in the syllabus distributed at the beginning of the semester. The competition revolves around individually designed robots with the ability to perform a number of different tasks on a predesigned course. Furthermore, MIT-2.007 requires moving parts such as gears, bearings, and motors. Final prototypes are usually created from various metals and, aside from the moving parts, also include electronics and wiring. Thus students use a wide variety of materials.

Students are free to express creativity when designing prototypes, and are expected to focus on safety throughout the entire project, so much so that creativity and safety are two of the main course objectives. All lecture material revolves around the goal of successfully completing the project, and thus students are allotted a reasonable amount of time for completion. Various companies sponsor the class so cost for prototype creation is handled differently than at UM. In addition, MIT-2.007 provides new educational tools to help students effectively work in teams and complete the project through company-sponsored guest lectures, extensive shop training, individual toolkits for each student, and online material.

Cal Tech ME 72 course: The Winter 2009 Cal Tech sophomore design and manufacturing class has a well established competition at the end of the semester that drives the entire class. Lectures provide relevant engineering fundamentals that are needed to properly design the prototype. Additionally, the students are provided with a large selection of materials, which promotes creativity along with ensuring that the project involves moving parts. Throughout the class, safety is taught and enforced to prevent injury. The class has several milestones that ensure all teams are on task. The cost of the prototypes is not available, but based on the large material kit and electromechanical pieces the cost per prototype is expected to be larger than the Winter 2009 ME 250 class. Overall, the Cal Tech class meets many of the customer requirements, yet they do this over a longer course term (approximately 1 month more than UM), with lecture material focused heavily on teaching how to design and fabricate the final product.

University of Houston MECE 2361 course: The current University of Houston sophomore design and manufacturing class has an individual project and a team project with an end of semester competition. Teams are encouraged to use a wide variety of tools and materials while exploring different types of energy sources. This ensures creativity in both the design process and the prototype itself. Teams are advised not to spend more than $100 on their device, but are not penalized if they go over. Professors constantly emphasize safety throughout the design and manufacturing process, and they disqualify or deduct points if they determine that a prototype is unsafe.

Villanova University ME 2505 course: The current Villanova University sophomore design and manufacturing class has several minor individual projects that last only a few weeks and a semester-long major team project with a competition at the end. Lectures touch briefly on the major project with more emphasis on the minor project for that week. In addition, students are encouraged to explore the use of new materials, as well as incorporate different moving elements. For the major project, students work with their teams outside of lab. Throughout the semester, professors stress the importance of safety due to the dangerous nature of their project. Professors allow teams to spend $10-$15 on their prototypes, but do not penalize teams if they go above that amount.

CONCEPT GENERATION

This section will discuss in detail the concept generation process for the end of semester competition and lectures.

Competition

When brainstorming project concepts for the ME 250 redesign, it was our goal to come up with a diverse group of solutions. With this variety, our team combined different ideas into new concepts, fulfilling a broad range of categories. To enhance creativity and the flow of ideas, our group brainstormed in multiple locations and environments. This allowed us to experience the concept generation process in both structured and relaxed situations and contributed to the lengthy list of potential ME 250 projects.

To effectively utilize the concept generation process, we clearly defined our design problem. For the ME 250 redesign it was our goal to come up with a sophomore level mechanical engineering course and design project that effectively allows students to utilize their classroom knowledge and creativity to manufacture a prototype. To describe the logical flow of information through the ME 250 course, our team created a functional decomposition diagram (see Appendix H). This diagram combined the higher level ideas of our course including general topics to be taught to students (the design process, engineering drawings/CAD, manufacturing, etc.) with customer requirements obtained from our project sponsor. The diagram decomposed the overall functions of our projects into sub-functions and eventually connected these sub-functions to the goal of an improved ME 250 course.

With a clearly organized design goal, our team set out to create an adequate project design and course structure. After several days of brainstorming, we created 47 distinct project ideas recording every idea regardless of feasibility. These concepts fit into six different categories: multifunctional, projectile, race, strength, survival, and other. Multifunctional concepts consist of projects that require multiple tasks to be completed by a single prototype. An example of this from our concept generation was “battle bots” where robots would be created to drive around a battlefield and attempt to disarm/destroy an opposing team’s robot with other mechanisms attached to the prototype. Projectile concepts involve the use of the prototype to throw or launch an object with a goal of either accuracy or distance of the toss. The best example of this was to design a catapult device where the prototype lobs an object with the goal of hitting a target a set distance away from the prototype. Race concepts involve a contest to accomplish a task in a given amount of time. Our dragster concept involved the creation of a racecar that would cross the finish line of a straight track in the shortest amount of time. Strength concepts focused on the use of forces to accomplish a task. The karate chop competition would require students to break thin wood boards in a “karate chop” motion and find the optimal force to do so. Survival concepts were projects that require a prototype to endure a particular situation without breaking. Our cliff dive concept would require the teams to build a vehicle that could drive off a height, survive the fall, and still function afterward. The Other category became a “catch-all” for concepts that did not fit into the previous five categories.

Along with assigning categories to each of the potential projects, we described the goals of each project. This was done to ensure full understanding of each concept before any decisions were made. The goals generally corresponded to the different categories, with some overlap, and were used mainly for clarification. Examples of these project goals include: accuracy, buoyancy, force, distance, maneuverability, and speed. A full concept generation list with descriptions, categories, and goals can be seen in Appendix I.

Lecture and Lab

As discussed in the functional decomposition, there are many aspects we aimed to improve regarding the lecture portion of ME 250. The current format of the lecture focuses on engineering drawings in the first half of the class and manufacturing methods in the second half. Many of the lectures failed to relate to the project, with more time than necessary dedicated to certain topics.

We studied lecture topics and schedules from Cal Tech, University of Houston, Villanova, MIT, and the previous semesters of ME 250. Cal Tech and University of Houston have lectures heavily focused on their projects, teamwork, and require students to frequently meet with professors (see respective Appendices C.2, D.2). Villanova has highly technical lectures focused on information needed to complete the project (see Appendix E.2). MIT has a unique lecture structure in which students watch a video lecture outside of class. They use the lecture periods to ask questions about the video material (see Appendix B.2). As necessary for ME 250 projects, there have been lectures related to the technical portion of the project; however, many of the previous projects lacked the need for these lectures (Appendix A.2). We considered all of these lecture formats and our own experiences in ME 250 lectures when developing our proposal for the new ME 250 lectures.

CONCEPT SELECTION

This section will discuss in detail the concept selection process of the end of semester competition and lectures.

Competition

After extensive concept generation, it was necessary to determine the optimal concept. The first step was to slim the original list of concepts down to ten competitions. This was accomplished by looking at feasibility, the entertainment factor, and safety concerns of the project. First, we eliminated the projects that were unworkable based on budget concerns and space limitations. For example, we eliminated battle boats because the availability of a water tank would be limited during design and testing. Second, we considered the entertainment factor involved in the projects. We felt that an entertaining competition would drive the students' creativity. For example, we eliminated the hammer and nails concept because it lacked a high entertainment level. Finally, we considered the safety issues involved in the competitions, eliminating projects that would produce an unsafe environment during production or testing. This was the main factor in eliminating battle bots from consideration.

Once our concepts were reduced to ten plausible competitions, we evaluated the projects again based on entertainment value, difficulty, and further investigated feasibility. We used a combination of the criterion to further eliminate our concepts down to our final five. For example, we eliminated dragster since it would be too simple for sophomore students, and we eliminated the solar panel competition due to Michigan's unpredictable weather.

Once down to the final five concepts, we utilized a Pugh chart (Appendix J) to analyze how these concepts compare to previous ME 250 projects. The Pugh chart showed that all five concepts were capable of exceeding the Winter 2009 project in many areas. Most of the concepts had very similar results on the Pugh chart, so further analysis was performed on the concepts in several categories to determine the best project.

The first project was American Gladiators. The goal of this project was for students to create a vehicle that can travel the competition course, setting off five different platforms that are elevated atop individual ramps. Setting off the platform would require the vehicle to reach the platforms and rest atop until the sensor is set off. The competition would be judged as a race to set off all five platforms. The benefit of this project is that it uses an array of concepts for the students to apply. The prototype would require the application of motors, gearing, steering mechanisms, and an understanding of radio control for the vehicle. This project was viewed as too costly because construction of the course would require sensor mechanisms for the platforms. In addition, we determined that it was simple and less creative for the students because their main task would be designing a steering and driving mechanism, and very little engineering analysis would be needed. We felt that a project that had a higher level of difficulty for students would be superior to American Gladiators.

The second project we considered was soccer. The purpose of this project is for student teams to design a device that would drive on a simplified soccer field, as well as develop a mechanism to move the soccer ball around an opposing team's robot and into the goal. This could be accomplished by transporting the ball, or developing a kicking mechanism. The competition would be a timed match, with the winner scoring more goals than their opponent during this time. The benefits are largely due to the vast applications of engineering principles in the design of the vehicle. The vehicle would require students to apply ideas relating motors, gearing to obtain proper speed and acceleration, a steering mechanism, along with the freedom of designing a transportation or kicking mechanism. The downside to this project was that we felt the competition in itself would not be competitive. A group could just create a mechanism that is able to guard the goal, and thus it would reduce competition between the teams. Additionally, we felt that the steering issues for the robot would be too difficult for sophomore level students to accomplish. Finally, it would be difficult to design the mechanism that allows a robot to maintain control of the ball.

The third project we considered was the catapult. Groups would design a catapult mechanism, with the goal of combining distance and accuracy. The benefits of this concept are that it is entertaining, the cost would be minimal, and it would require the students to apply concepts such as projectile motion, motors, springs, stress, and strain. The downside is the safety issue when working with projectiles. The project encourages stored energy before launching a projectile, this could result in accidents should an unintentional "fire" occur. Additionally, there may be a need for failure analysis depending on the students' design. Since the class is a sophomore class, the students will not have learned failure analysis at this point in their studies. In addition, the scale of the project may require a larger area for the competition than is available.

The fourth project considered was the karate chop. This concept required students to design a mechanism that would generate a force that can break blocks of wood. The competition would determine the strongest mechanism. Advantages of this concept are the competitive level it creates, along with the use of force diagrams, motors, gears, and springs. The downside of this project was its level of safety and the generated waste. The project involved creating a high swinging force, which could cause injury. Also, the competition would produce large amounts of waste since each test may result in several broken wooden boards. Due to the safety and waste issues, we did not choose this concept.

The final project we considered was tank wars. The objective of tank wars is to create a device capable of launching soft foam balls at buildings. There were many benefits and few disadvantages that were apparent for tank wars. In regards to the customer requirements, the project meets and exceeds key factors, includes an entertaining and fun competition, a wide array of materials, and incorporates several moving components such as motors and bearings. The concept also allows for additional components and engineering principles to be applied when developing the firing mechanism. This concept also allows students to implement additional functions such as defense or two-axis aiming. The project remains safe because the projectiles are soft, foam balls. The cost has increased because of the variety and number or parts needed, but the engineering knowledge obtained from the revamped project outweighs the increased cost. There are many advantages to this project; however, it does not increase the manufacturing tools and methods available to the groups.

Lecture and Lab

After studying the lectures from Cal Tech, University of Houston, Villanova, MIT, and the previous semesters of ME 250, we determined which portions of these lectures should be incorporated in our design. We believe that the MIT video lectures would be difficult to implement because of the time needed for students to watch them. We have determined that a balance between the project oriented lectures at Cal Tech and University of Houston with the highly technical lectures at Villanova should be the model for ME 250.

We chose to develop two different lecture schedules and one lab schedule based on our customer requirements. One of the schedules involved maintaining the structure and most lectures of the ME 250 course, while making minimal improvements to support the project. We created new lectures that introduce the project, discuss concept generation, teams, customer requirements, and technical communication. Also, the lectures teach technical information related to the project such as gears, motors, bearings, springs, and project materials. To accommodate the additional lectures, we eliminated redundant lectures for both engineering drawing and manufacturing topics. For a complete list of topics and content in this lecture schedule see Appendix K.

The second lecture schedule was created using both customer requirements and the analysis of all lectures, rather than adapting the previous ME 250 lectures. This is our ideal lecture schedule for implementing this project. Each lecture relates to the project, and as a whole, the lectures cover technical and design process related information that students need to successfully complete the project. Lecture topics include design and team related lectures (teaming, design process, and technical communication), engineering drawings (orthographic and 3D views, sections, dimensions, and tolerances), project components (gears, bearings, springs, and motors), engineering analysis and testing, and manufacturing (drill press, band saw, CNC machines, and assembly). For a complete list of topics and content in this lecture schedule see Appendix L.

The lab schedule we developed is nearly identical to the previous ME 250 lab schedule. We determined that the complex project we are proposing will require additional time in the shop to manufacture and test. We included two lab sessions on developing CNC tool-paths instead of the previous four. Also, we reduced the amount of lab sessions where students learn to use the CNC lathe and mill to three, to accommodate a lab on CES Selector (see Appendix M for a full lab schedule). Additionally, we have created a lecture period geared toward specifics needed to best utilize manufacturing time.

ALPHA DESIGN

After thorough analysis of all possible ME 250 project concepts, our team decided on the project we felt best fit our customer requirements as well as the other restrictions given to us for this task. Tank Wars allows students to be creative throughout the design process and further develop their mechanical engineering skills. This section will describe in detail the initial design for the Tank Wars project as well as an ideal lecture schedule to fully integrate this project into the class itself.

Tank Wars

Goal: Pinning teams against one another, the goal of Tank Wars is to destroy the opponent’s city before they can destroy yours. The two main components of this competition are the battlefield competition course and the student built tank prototypes. Student teams will design, manufacture, and test their prototype and then compete in a head-to-head competition against other ME 250 teams. Each prototype will use a student generated launching mechanism to shoot a soft foam ball at stacks of blocks on their opponent’s side of the course (battlefield).

Battlefield: The competition course for Tank Wars (see Figure 5) consists of several different parts. The base of the entire structure is currently designed to be a 3 ft. by 8 ft. sheet of plywood with 1in. by 4 in. wood borders to contain the projectiles, blocks, and obstructions. On each side of the battlefield is a hill structure with five horizontal platforms on which 2 in. square blocks of balsa wood are stacked, representing buildings for that team's city. These platforms vary in height from two to six inches to force teams to aim their launching mechanism differently for each building.

In front of this hill is the driving track for the tank prototypes. Barriers are built on both sides to prevent the tanks from moving any direction other than left and right on the track (see Figure 5). There is a ramp built into the track section acting as another challenge for student teams. See Figure 6 for a close-up view of the hill, barriers and ramp. Student teams have to make sure their prototype can overcome the angle of the ramp, and accurately aim and shoot the launching mechanism to account for the elevation change. Exact dimensions for all of these components can be found on the engineering drawings provided in Appendix N.

To aid in containing the foam balls and building blocks as best as possible, a net will stretch between two poles at each end of the course. These act as barricades and a safety feature without letting the balls take a "lucky bounce" off a backboard and in turn, destroy a building.

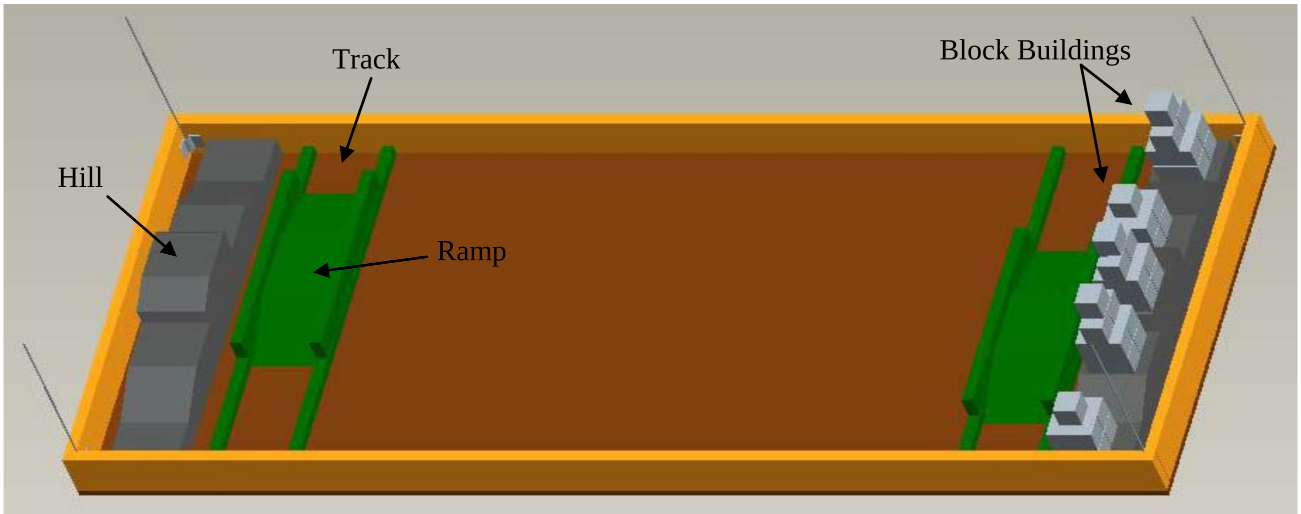


Figure 5: Tank Wars battlefield

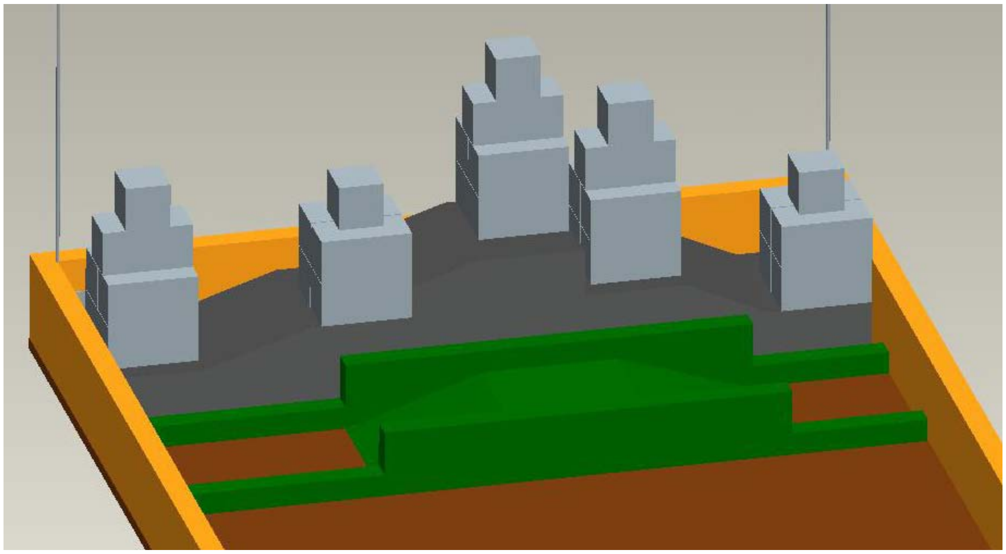


Figure 6: Tank Wars battlefield close-up

Prototype: The main deliverable for ME 250 student teams is a manufactured tank prototype. This prototype must move left and right across the track as well as launch a soft foam projectile at the opposing team's city. The cost of the driving motors and control system will have a great effect on the direction of the prototype. If these are found to be cheap enough to provide one to each team, more emphasis will be placed on designing the wheel platform of the tank. If more expensive, we will provide a functioning platform that teams will attach their launching mechanisms to.

The material kit provided to each student team will also be affected greatly by the list of potential launching mechanisms. One of the goals of this project is to give students the opportunity to express creativity in their designs; therefore, we would like to leave the design as open-ended as possible by providing any materials possibly needed. In addition, we want each team to have a small budget that they can spend on additional parts not provided in the material kit. Allowing teams to create mechanisms used for defense of opposing shots has been discussed; however, this is dependent on the functions and cost of control systems that are commercially available. The control system would be used to drive, aim and fire the prototype, as well as deploy a defensive system if included.

From our literature review, we found that a successful design course utilizes and balances creativity and analytical thinking. While working on our two tank prototypes, we realized that there are many plausible designs that encourage students to maximize their creativity. The complexity of the tank prototype is related to a team's creativity and will determine the engineering analysis needed in order to successfully produce a prototype. We believe this project creates the desired balance between creativity and analytical thinking necessary to spark further interest in mechanical engineering and encourage students to be excited about future design courses.

Lecture and Lab

As mentioned in the Concept Selection section, we believe that the ideal lecture schedule should be used in conjunction with the suggested lab schedule. The lectures can be divided into design process and teaming, engineering drawings, project components, analysis and testing, and manufacturing categories and the lab sessions can be divided into CAD and manufacturing.

Lecture Schedule: The lecture includes 26 lectures, with 2 in-lecture exams, and an in-lecture review session for each exam. As was the case for past semesters, the lectures will be on Tuesdays and Thursdays, and each will be 1.5 hours long. See Appendix L for a full list of lecture topics and suggested content.

We included multiple lectures that address the design process and teaming. Students must understand and use these topics to complete the project. Lectures on teaming and the design process will be given at the beginning of the semester to help students work with their teammates and approach the design problem effectively. A lecture on technical communication is included at the end of the semester to assist students with their final paper and presentation.

Many lectures in the first half of the class address engineering drawings. These lectures are designed to provide students with the skills needed to communicate their design concepts. Similar to the previous ME 250 schedules, we include lectures on orthographic, 3D, and sectional views, as well as dimensioning and tolerancing. However, we reduced the number of lectures spent on these topics because it is also covered in lab sessions.

Next, our schedule addresses important components of the project to give students the technical knowledge needed to create a functional mechanical device. We include individual lectures on gears, bearings, springs, and electrical motors, with each lecture addressing the governing equations for that part and its use in the project. Also, we included a lecture on project materials to discuss all of the other materials that teams are given, in particular different specialty parts.

We finish the first half of the semester with two lectures about engineering analysis. These lectures are intended to provide students with the technical information that they need to evaluate their concepts and choose the best design. The first lecture addresses force and projectile motion to ensure that their firing mechanism will perform well in the competition. The second lecture focuses on stress and failure analysis to prove that their prototype will function as expected. At the end of the semester, we included a testing lecture that describes safe testing procedure and the suggested response to different test results such as failure and mediocre performance.

The second half of the semester is spent on lectures about manufacturing. Unlike the previous ME 250 schedule, these lectures only address processes that the students have available to them for prototype manufacturing. We believe that this will be more useful to students at this point in their education than learning about industrial manufacturing processes. We included lectures regarding basic equipment (such as drill press, band saw, and hand tools), the CNC mill and lathe, fastening techniques (such as welding, screws, and bolts), and assembly. Also, we eliminated formal lectures during the week before the prototype is due to allow more time for manufacturing and team meetings with the professor and GSIs.

Lab Schedule: The lab schedule is also designed to fit into the Fall 2009 semester. It includes 14 lab sessions and 4 weeks of manufacturing and testing time. As was the case for past semesters, the lab sessions will be on Mondays and Wednesdays, and each will be one hour long. The open shop will run as needed throughout the week depending on the availability of the GSIs. See Appendix M for a full list of lab topics and suggested content.

The first half of semester is devoted to teaching students CAD. Multiple sessions are devoted to both 2D and 3D drawings with a range of complexities. There is also one session to address orthographic and sectional views and dimensions. In addition, students are taught assemblies, which will be used as they create a CAD representation of their prototype. There is a session demonstrating the interoperability of different CAD software, and a session on CES software. Finally, we included lab sessions regarding the generation of CNC tool-paths for the mill and lathe.

The second half of the semester is a combination of teaching students how to use the CNC mill and lathe and providing shop time for teams to manufacture and test their prototype. Three lab sessions are used to teach CNC mill and lathe. In the first session, the GSI shows basic use and set-up of both the mill and lathe, and the second and third sessions are dedicated to allowing the students to practice making one part on each machine. The last four weeks of lab time are open shop time, with testing equipment being available for the final two weeks.

ENGINEERING PARAMETER ANALYSIS

There are several portions of our design that require an analysis of the dynamics that are involved. We began by analyzing the impact of the foam ball and balsa wood block to determine a minimal initial velocity needed to overcome drag forces and move a single balsa wood block. This velocity was then used in the calculations for the tank prototypes. Finally, we analyzed the mass of each tank prototype to determine the torque necessary to ensure movement.

Battlefield

The dimensions of the battlefield for the Tank Wars competition required consideration of the capabilities of student designed tank prototypes. The length of the battlefield needed to be long enough that it would provide a challenging distance for launching, but also remain reasonable enough that students could be creative in the design process. At the same time, the height of the hills where the block buildings are stacked, needed to be tall enough so the tanks could not block every building during competition. Also, it needed to be low enough to account for the aiming capabilities of the student tanks. We decided on an 8 ft. length of plywood for the base, which after including the width of the hills and spacing of the tank track, results in a launching distance of approximately 6 ft. The height ranges of the platforms on the hill span from 5 in. to 15 in. giving students a wide vertical launching range. These dimensions were key to ensuring creativity for the students and maintaining a challenging project.

Analysis was required to determine the velocity at which the foam ball will knock down one of the balsa wood blocks. By dropping the foam ball at different speeds and heights, and measuring the resulting height bounce back, we determined a coefficient of restitution, 0.57, for the ball.

Using conservation of energy, conservation of momentum, and the coefficient of restitution for the ball, we determined the impact velocity necessary for a balsa wood block to be moved 2 in. (the distance necessary to fall off other blocks) to be 4.23 ft/s (1.29 m/s). Using this, the force of drag was computed and integrated to solve for the initial velocity. We then integrated a second time to solve for the time it takes the ball to travel the appropriate horizontal distance. After plugging in all the values, it was determined that the minimum initial velocity was 5.25 ft/s (1.6 m/s) (see Appendix O for all equations and solution).

All values, such as coefficients of drag and friction, were taken at their highest possible value for the situation. Because of large ranges in these coefficients (0.07 – 0.5 for drag and 0.25 – 0.5 for friction) the use of these values is likely to be an overestimate. Thus, it is possible a lower initial velocity would knock the blocks off. Testing was not done to determine exact drag and friction coefficients. Additionally, this only represents the necessary horizontal velocity. The proper initial velocity was determined using projectile motion. This caused the initial velocity to become 16.4 ft/s (5 m/s) at a 30 degree angle (as set up for the pitching machine tank). For a 45 degree angle, the initial velocity became 14.5 ft/s (4.43 m/s) (as set up for the compression spring tank). The final velocities when the ball reaches the blocks are both higher than the minimal velocity necessary to knock a block off of the platform, thus both velocities are acceptable. Drag is not considered for the vertical velocity since we calculated the initial and final heights as the same value. The velocity analysis in Appendix P contains all equations used.

Tank Platform

The tank platform was dimensioned, giving enough room for any potential launching mechanism to fit within the boundaries. A 7 in. x 10 in. PVC base with 1.5 in. spacer blocks leaves room for the microprocessor control system, Arduino, as well as any wiring. This provides a stable, robust platform for students to mount their tanks too.

Further analysis was required to calculate requirements for the tank platform driving motors. By looking at the mass of our CAD model, the mass of the tank platform, along with the coefficient of friction between plastic and wood, we were able to determine the necessary force to move the cart. The overall mass was estimated at 8.8 lbs (4 kg), and the coefficient of static friction between the wood battlefield and plastic wheels was taken as 0.5. With a 2 in. diameter on the wheels, we were able to compute a torque that the motor must provide. We determined a torque of approximately 70.8 oz-in (0.50 N-m). We determined that the motor should provide a minimum RPM of 120. This will allow the cart to move at 6.25 in. per second. This calculation can be seen in Equations 1 and 2. From these requirements, we were able to use two motors that each controlled one of the front wheels. The motor selected was the 120:1 Plastic Gearmotor 90-Degree Output. It provided a torque and speed that exceeded our requirements, and the electrical demands of the motor are acceptable for use with Arduino.

$$\tau = \mu_s mg * r \qquad \text{Equation 1}$$

$$\tau = 0.5 * 4\ kg * 9.81 \frac{m}{s^2} * 0.0254\ m \qquad \text{Equation 2}$$

Previously, there was a ramp in the battlefield. However, this was removed due to issues with clearance while using 2 in. wheels. This eliminated the additional torque necessary to climb the ramp.

Compression Spring Tank

For the compression spring tank, a spring is compressed using a rack and pinion (sector gear), where the pinion (sector gear) is attached to a motor controlled to rotate one revolution.

With the minimal initial velocity determined, we calculated the distance the spring needed to compress. The spring coefficient was determined using its outer diameter, wire diameter, and number of turns. It was calculated to be 165.8 lb/ft (2420 N/m). We used conservation of energy to relate the energy in the compressed spring to the initial velocity of the ball and rack and determined that the spring needs to compress 0.30 in. (7.61 mm) to provide the correct velocity. Since this value is less than the maximum compression value, the spring we used is sufficient. Finally, we calculated the torque to compress the spring when using a pinion of diameter $\frac{9}{16}$ in. (14.3 mm). The computed torque was 18.7 oz-in (0.132 N-m), which is less than the 180.5 oz-in (1.27 N-m) motor stall torque. See Appendix P for the complete calculations used in this analysis.

We used the mass of the body, barrel, and firing motor to determine the torque needed from the aiming motor. We assumed that this mass was centered 3 in. (0.0762 m) away from the aiming motor. This resulted in a torque of 24.9 oz-in (0.176 N-m), which is less than the 180.5 oz-in (13 kg-cm) motor stall torque. See Appendix P for the complete calculations used in this analysis.

One of the most important machined components of the compression spring tank is the body. The spring and rack fit inside a machined groove in the body component of the tank. The groove is 0.55 in. square to allow adequate space for the 0.5 in. diameter spring to fit. It is 3.3 in. long to fit the entirety of the 1.75 in. long spring and most of the 2 in. long rack. The overall dimensions of the body are 1.5 in. x 3.5 in. The extra material inch of solid PVC below the groove was included so that the firing motor has a sufficient surface area to attach to. The arm of the aiming servo motor also connects to this area to rotate the barrel, and the sleeve bearing to support this rotation is pressed into the body.

We also manufactured an end cap for the barrel by attaching a flat PVC circular disk with a diameter of 2.375 in. and a thickness of 0.25 in. to a purchased PVC pipe. The inner diameter of the pipe was chosen to be 2 in. so that the 1.75 in. diameter foam ball would easily fit inside. It was manufactured to be 2.75 in. long so that the ball would rest inside. The extra inch was provided to help direct the ball’s path to the desired angle. Finally the end cap of the barrel has a 0.5 in. diameter hole to allow the rack to make contact with the ball.

The body is supported by two support columns. These columns are approximately 5.4 in. tall. This height was chosen so that the final tank prototype is shorter than the maximum height of 6 in., but tall enough that the barrel is level with the shortest hill platform. This height means that it will take less energy to hit the buildings.

Pitching Machine Tank

The pitching machine tank utilizes rotational motion to project a foam ball by guiding it between two spinning wheels that accelerate the ball to match the tangential velocity of a point on the outer diameter of the wheel.

The dimensions of the base of this tank prototype match the tank platform dimensions. Because our base had to fit on the 7 in. by 10 in. platform, we used the same dimensions to maximize the area for the pitching machine tank. This base was manufactured from a 0.25 in. PVC sheet which supported the weight of the firing mechanism and additional objects on it, while maintaining a light weight, therefore minimizing the torque required to drive the tank.

The main components of this tank were the spinning wheels used to project the foam ball. Based on the space available, the largest diameter the wheel can have is 3 in. We chose PVC as the material for these because it is readily available, easily manufacturable and lightweight. However, material availability limited our wheel diameter to 2 in. Once the velocity necessary to knock down the balsa wood block buildings was determined, we calculated the torque and angular speed necessary to bring a foam ball to this velocity. We determined an initial velocity of 16.4 ft/s (5 m/s) at a 30 degree angle is needed. Based on the angular velocity and the wheel mass obtained through Pro/ENGINEER, we were able to determine minimum motor specifications for one DC motor per spinning wheel. These specifications along with those for the chosen motor (RS-555 DC Motor) can be seen in Table 1. Calculations can be seen in Appendix Q.

Table 1: Motor specifications for the spinning wheel

	RPM	Torque (N-m)	Operational Voltage (V)
Minimum Motor Requirements	1900	0.033	4.5-36
RS-555 DC Motor	6660	0.206	5-15

Bearings were chosen for the spinning wheels based on the highest RPM provided by the motor. The shaft diameter and outer diameter (OD) of the bearing were fairly arbitrary because their measurements do not play a crucial role in the tank performance. Because ball bearings were cheap and performed as we need them to, a Miniature Precision SS Flanged Open Ball Bearing with a 0.25 in. shaft diameter and 0.375 in. OD was chosen. The flange allowed for an easy press-fit installation. This bearing had a maximum RPM rating of 56,000, which fit our requirements.

For this design, a chute was added as a path for the foam ball. The foam ball started from a position slightly above the tank and rolled down to the firing position between the spinning wheels on the tank base. The only requirement of the chute was a 1.75 in. diameter so the foam ball can freely move through it. To accomplish this, we chose a 2 in. standard sized PVC pipe elbow connector. To release the ball from its initial position, a servo is needed to move an arm in and out of a slot in the horizontal portion of the chute. To do this, we used the simplest and cheapest servo motor we could find because there is little demand placed upon the servo. The Tower Pro SG-90 servo motor we used gave 24.9 oz-in (0.176 N-m) of torque and rotated 60 degrees in 0.1 seconds.

Design Analysis

From the analysis using CES and SimaPro, we were able to determine acceptable materials for two key portions of the prototype, the proper form of manufacturing, and the environmental ramifications that the materials hold. For the top plate of the pitching machine tank, the material should be PVC, with the manufacturing performed using abrasive jet machining and cutting. For the compression spring tank, the pinion used should be made of brass, and a milling process should be used to manufacture it. The environmental effects of both parts were deemed minimal and thus did not factor into any decisions. See Appendix R for more details

FINAL DESIGN DESCRIPTION

The following section describes the main portions of our final design including the Tank Wars competition, lecture and lab schedules, the battlefield, the tank platform, and the two tank prototypes. The final design has changed throughout the semester. Appendix S details these changes.

Tank Wars

Tank Wars is a competition in which each student team builds a device capable of firing a foam ball to destroy the opposing team's city while strategically defending their own city and protecting their tank. Each team is given a materials kit that includes several types of motors and materials, and a budget (determined by the professor) to spend on parts and components (gears, bearings, etc.) that are not included in the material kit. These components must be presented to the GSI for approval before purchasing. The following is a list of the types of materials that will be available for students in this kit:

- Raw Materials (PVC, Wood, Sheet Metal, Wax Blocks)
- Motors (DC, Servo, Stepper)
- Gears (Rack, Pinion)
- Bearings (Roller, Sleeve)
- Fasteners (Nuts and Bolts, Screws, Epoxy)

Each team will attach their tank prototype to a given tank platform. Furthermore, each team will program their device using the Arduino software to drive forward and backward, and aim/fire as necessary. The following is the list of rules for the Tank Wars competition:

1. Safety glasses must be worn during play
2. Time to attach to platform and load code must not exceed 3 minutes
3. Time to remove tank from platform must not exceed 2 minutes
4. Manual interaction with tank during play is limited to loading the tank
5. Teams alternate turns (load, aim, fire), firing one ball per turn
6. Teams may only aim at object on the battlefield
7. Match time limit is 10 minutes (with an even number of turns)
8. A single knocked off block denotes a destroyed building
9. Team with the most destroyed buildings at the end of the match wins
10. First tie-breaker: team with the most total blocks knocked off wins
11. Second tie-breaker: center building is reset, team with the most blocks knocked off wins (with even turns)

We created a document that will be distributed to students describing tank wars. This document describes the project, competition rules, tank specifications, and the materials available to teams. The document is shown in Appendix T.

Lecture and Lab Schedules

The lecture and lab schedules are intended to support the Tank Wars design project. The suggested lecture topics include supporting information on the design process, engineering analysis, and prototype manufacturing methods. The lab topics include hands-on lessons on 2D and 3D CAD drawings and CNC machining. The suggested topics and schedules for both lecture and lab are unchanged from the alpha design. For complete lecture and lab schedules see Appendix L and M, respectively.

Battlefield
The first piece of equipment we designed for the Tank Wars competition was the battlefield. Knowing the environment the tanks compete in will allow student groups to tailor their designs to these specifications. The battlefield consists of a 4 ft. x 8 ft. plywood base on which all other components are attached. Balsa wood blocks sit on hills at each end of the plywood base. A track on each end in front of the hill contains the tank prototypes, and a border and net contain the balls and blocks after firing. Half of the fabricated battlefield is shown in Figure 7. Drawings of all individual parts with dimensions can be found in Appendix U.

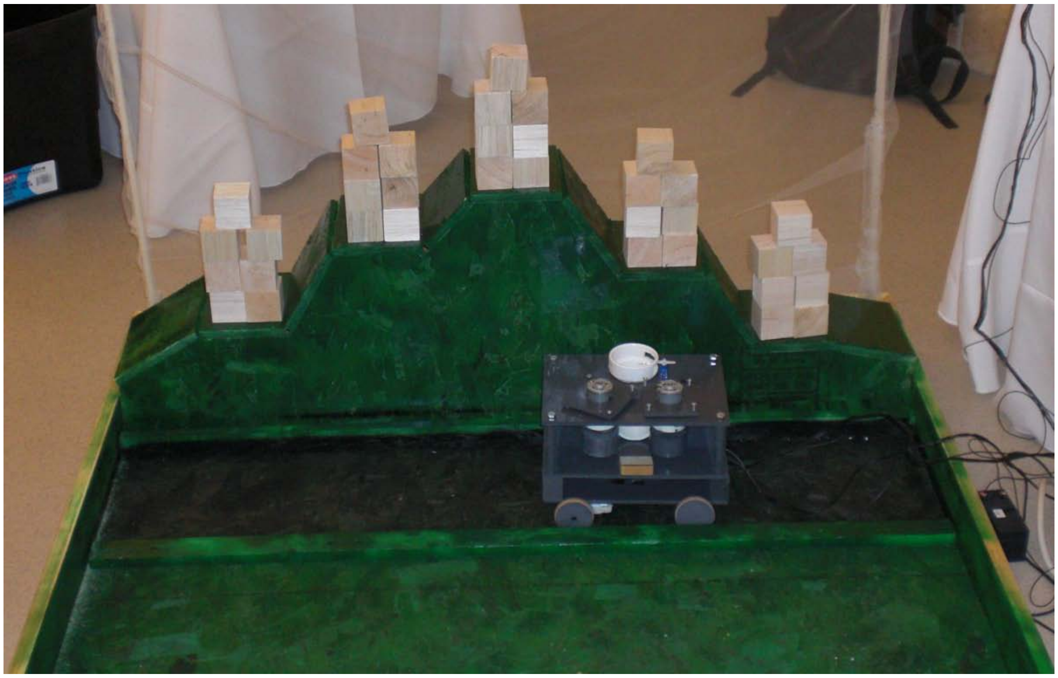


Figure 7: Half of the fabricated battlefield

Changes to the battlefield from the alpha design are limited to sizing as well as the removal of the ramps on the tank track. The base for our final design is 4 ft. by 8 ft., as opposed to 3 ft. by 8 ft. in our alpha design. This adaptation was made to create more space for the tanks to drive and line up to fire at the left- and right-most buildings. The height of the horizontal platforms on the hills was adjusted to prevent tank prototypes from blocking all of the buildings; they now range from 5 in. to 15 in high. The platforms are 5 in. wide and 7 in. deep so that multiple building configurations are possible. The dimensions of the face of the hill are shown in Figure 8.

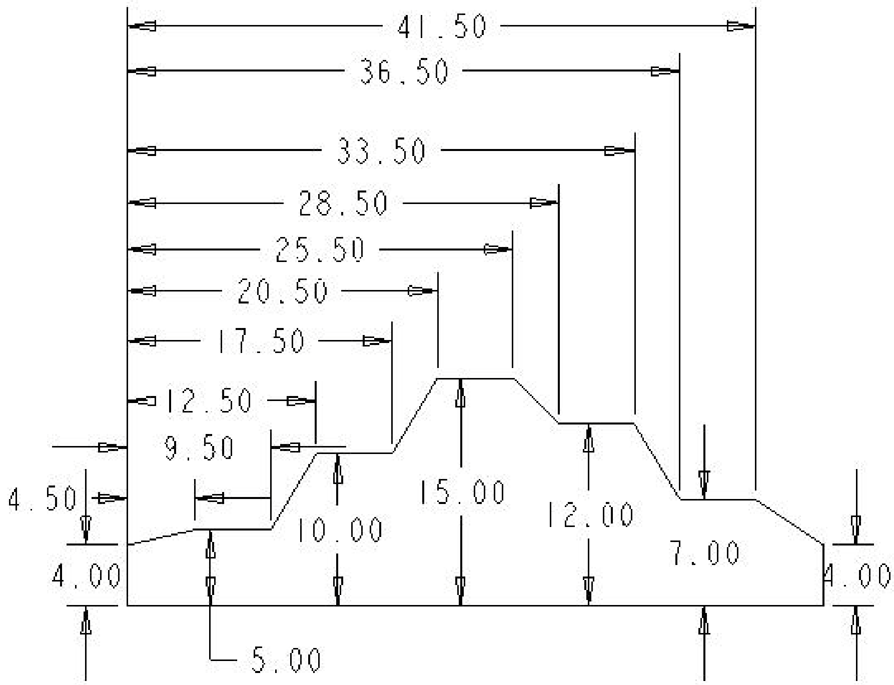


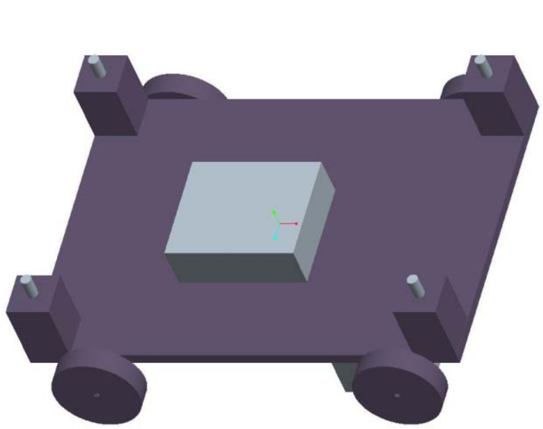
Figure 8: Front View of the Hill with Dimensions

The battlefield is a simple object as its only function is to provide a solid arena to facilitate competition. It does not move, and does not support a substantial load and because of this, no analysis was performed to validate the design.

All elements of the battlefield were constructed using wood. Wood was chosen because it is an inexpensive material that is widely available in a variety of sizes. It also provides the strength needed so that the battlefield is stable without adding unnecessary weight. Finally, it is an easy material to machine using a variety of basic tools, which makes construction of the battlefield relatively simple.

Tank Platform

The tank platform is provided to students to reduce the cost of materials for each group without sacrificing any aspects of the Tank Wars competition. The tank platform includes the DC motors used to drive the cart and the Arduino control system used to control the motors. The tank platform is designed so that students can place their tank prototype on top and easily attach it using nuts and bolts. This design creates a secure connection between the tank platform and tank prototype while still allowing the tank prototype to be attached quickly. See Figures 9 and 10 for a CAD drawing of the tank platform. See Appendix V for dimensioned drawings.



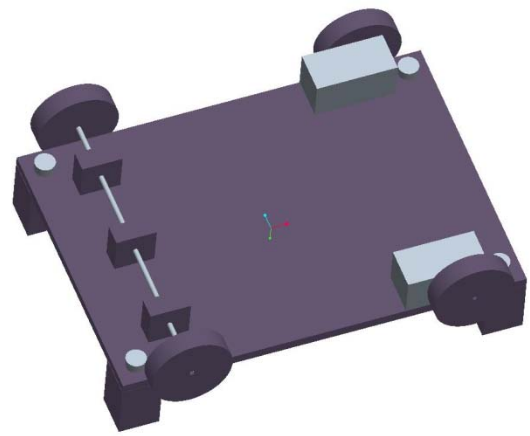


Figure 9: Tank Platform Top **Figure 10: Tank Platform Bottom**

Arduino is an open source electronics prototyping platform that will be control each team’s tank. The tank platform includes the Arduino Duemilanove, which is an Arduino USB Input/Output (I/O) board. Each team will use the Arduino software to program their desired tank functions (driving, aiming, firing, etc.). In addition, the Arduino is compatible with several shields that allow Arduino to perform additional functions. The Shields included on the tank platform are the Adafruit Motor/Stepper/Servo Shield, Arduino XBee Shield and XBee Module, Liquidware HiCap Lithium Backpack, and Liquidware DoubleTall ExtenderShield. Figure 11 shows the Arduino with the Motor/Stepper/Servo Shield.

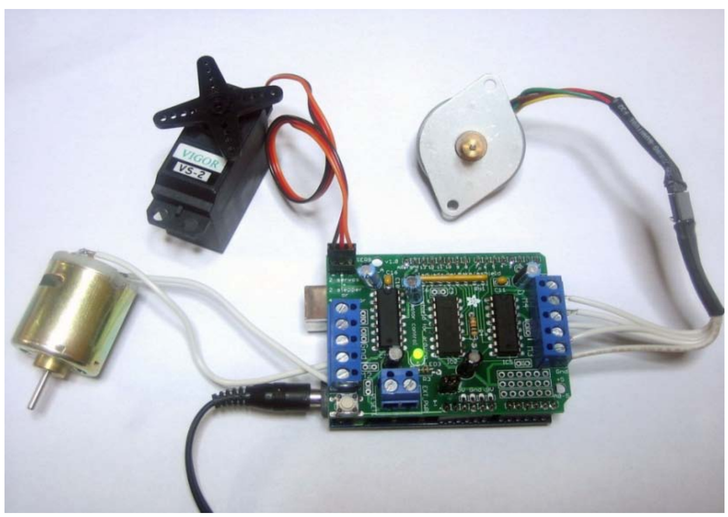


Figure 11: Arduino Duemilanove and Motor/Stepper/Servo Shield

The Adafruit Motor/Stepper/Servo Shield allows the Arduino to control the mechanical motions of attached servo, DC, and stepper motors. This shield is intended to allow teams to drive, aim, and fire their tank prototypes. Not included in our prototype, but used in the final design is an Arduino XBee Module and XBee Adapter Kit that will allow teams to wirelessly control their tanks using their computer keyboard and the Liquidware HiCap Lithium Battery Backpack which will power Arduino. The Arduino, its Shields, and the Liquidware HiCap Lithium Battery Backpack will attach to the Liquidware DoubleTall ExtenderShield. The ExtenderShield allows arrangement of the Arduino, the two Shields, and the battery to connect electronically in a more compact space.

Tank Prototypes
Requirements for the tank prototypes were created and are as follows:

- Assembled tank prototype must fit inside a 7 in. x 6 in. x 6 in. space. However it can expand during play.
- Tank prototype (without tank platform) has a weight limit of 3 kg.
- The foam ball is 1.75 in. in diameter and weighs 4.5 g.
- The foam ball must be fired a horizontal distance of 6 ft, and must hit buildings on platforms ranging from 5 to 15 in. in height.
- Tank prototype is limited to 2 servos and either 2 DC motors or 1 stepper motor to control its motion. More motors cannot attach to the Arduino motor shield.
- If motors draw more than 0.6 A of continuous current or 1.2 A peak current, and they need specific controls, they must be attached to an H-Bridge that can support their current load.
- If motors draw more than 0.6 A of continuous current or 1.2 A peak current, but do not need specific controls, a MOSFET may be used to act as a switch to control the motors.
- The Arduino supplies 5 V, if more voltage is needed the tank prototype must include a battery to supply that voltage.
- Motors and other moving parts should be protected from opponent's shots. If your tank is damaged during play you may not repair it.
- The tank prototype may not rapid fire; only one ball may be loaded and fired at once.
- Explosives, fire or compressed air tanks may not be used in firing mechanisms.
- Design must be approved by a GSI/Professor before manufacturing

With these ideas in mind, we brainstormed a list of potential launching mechanisms including a bow and arrow, catapult, sling shot, compressed air, compression spring, air soft gun (spring and compressed air), and automatic pitching machine. For prototype 1, we chose a compression spring because we were familiar with the mechanics of a spring, and could base the mechanism off of air soft and paintball guns. For prototype 2, we chose a pitching machine because it is a unique mechanism that differs greatly from prototype 1. By providing two example prototypes, we are able to showcase a wide range of ideas students would consider. Students are allowed to choose any mechanism, as long as it fits the design requirements and is approved by an instructor.

Prototype 1 - Compression Spring Tank: The first tank prototype designed by our team uses the energy stored in a compressed spring to fire a foam ball. A motor rotates a sector gear, which in turn moves a rack that compresses a spring. When the teeth of the sector gear are no longer engaged with the rack, the spring forces the rack forward causing it to strike the ball, transferring its energy to the ball. The tank is aimed by using a servo motor to rotate the barrel of the tank to the desired angle. Figure 12 shows the final design for the compression spring tank. Appendix W shows dimensioned drawings of all parts of the compression spring tank.

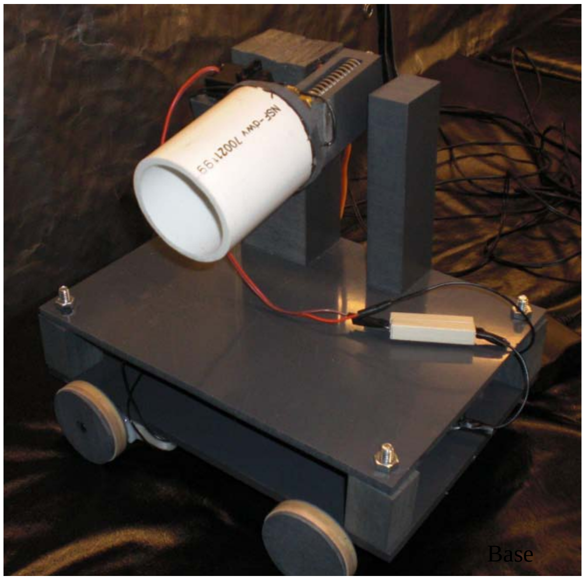


Figure 12: Compression Spring Tank

The compression spring tank is constructed on a base sheet of PVC, which will be attached to the tank platform for competition. There are two PVC support brackets which attach the firing mechanism to the base. The larger support bracket contains the servo motor to control aiming and provides support for the mechanism. The smaller support bracket has a dowel pin inserted into a flange bearing in the body to ensure that it rotates properly. The firing mechanism is shown in greater detail in Figure 13.

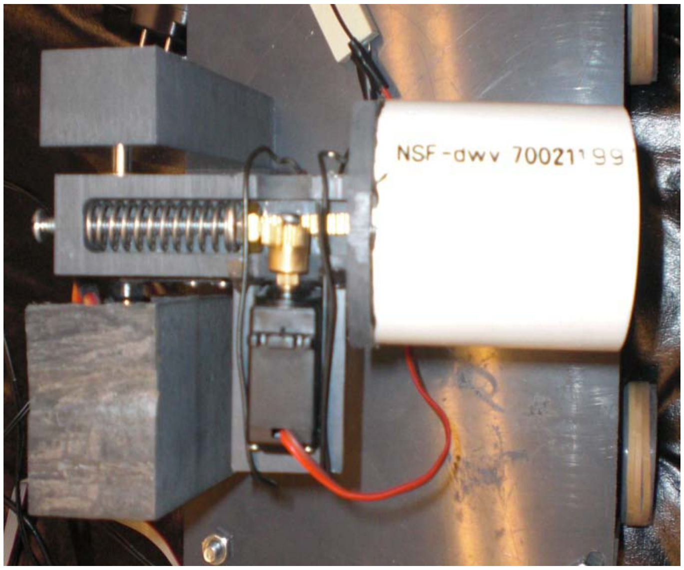


Figure 13: Compression Spring Firing Mechanism

The motion of the Compression Spring tank is created by two Tower Pro High Torque Professional Speed MG995 servo motors. A high torque motor was chosen for aiming because it can support any moment caused by the weight of the body and barrel, while still providing a smooth aiming motion. The same type of motor was purchased to rotate the sector gear because the torque provided by the motor can resist the energy in the compressed spring. After the motors arrived, we realized that it would not provide 360 degree motion as required for firing, so the mechanical stop and electrical controls were removed to make one of the servo motors into a DC motor and gearbox.

The sector gear used for the launching mechanism was purchased as a 32 pitch 20 degree pressure angle spur gear with a 0.5625 in. diameter. 12 of 18 teeth are machined off so that the rack can move and release the stored energy in the spring to fire the ball. The rack has the same pitch and pressure angle, and is 2 in. long. The rack is pressed into a brass nut which prevents it from flying through the barrel when the energy in the spring is released. The spring used for this tank is 1.75 in. long, with a 0.5 in. outer diameter and a 0.054 in. wire diameter. This spring is placed around a bolt through the body, and held in place using a 0.5 in. diameter washer and nut. The bolt prevents the spring from bending as it is compressed. Appendix P shows all of the calculations that were used to validate our motor and spring choices.

These parts are all connected to the PVC body. This body has a groove in the top for the rack and spring, and a solid lower half for the motors to connect to. The front of the body is attached to the PVC barrel which holds the foam ball. The cap at the end of the barrel has a hole so that the rack can strike the ball.

The aiming and firing motors are connected to the Arduino and motor shield to control their motion. For this tank, the two driving motors are connected to DC motor inputs M1 and M2 on the motor shield, and the aiming servo motor is connected to Servo1. After the firing motor was converted to a DC motor, its maximum current exceeded the limit of the H-Bridge provided in the motor shield. Therefore, the firing motor is connected to an Infineon Technologies TLE 5206-2 H-Bridge with a maximum current of 6 A. Power resistors with an equivalent resistance of 6 ohms are also wired between the firing motor and the H-Bridge to reduce the current. The input pins of the H-Bridge are connected directly to I/O pins 5 and 6 on the motor shield. The motor shield and H-Bridge are powered directly from the external 12 V 1.3 A-hr. battery, and the Arduino is powered through the 9V wall power supply.

A breadboard and switches are used as a controller for this tank. The breadboard is powered using the 5V and ground pins on the motor shield. The buttons connect to digital I/O pins 14-18 (labeled analog 0-4). The buttons connected to pins 14 and 15 drive the tank, pins 16 and 17 adjust the aiming servo motor up and down, and pin 18 rotates the firing servo motor. The switches were wired using 10 kΩ resistors. Figure 14 shows how the breadboard is wired. Appendix X shows the Arduino code used to control these buttons and motors.

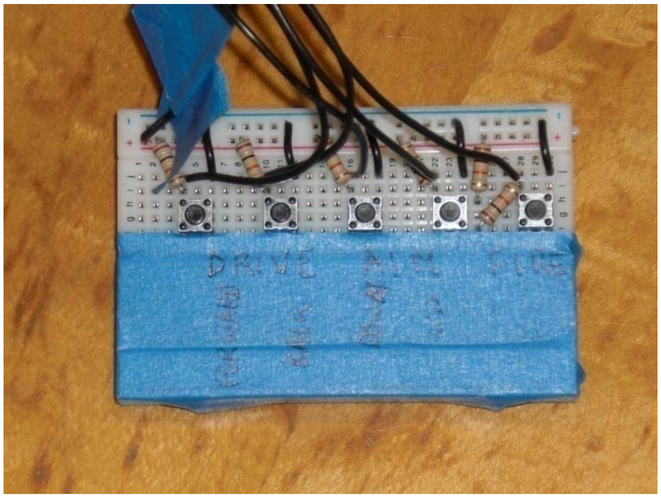


Figure 14: Breadboard controller for compression spring tank

Prototype 2 – Pitching Machine Tank: The second launching mechanism used for our tank prototype mimics a pitching machine. Two wheels are spun in opposite directions at a high angular velocity while a ball is fed between them and is projected outward. The spinning wheels are placed so that the distance between the two is slightly smaller than the diameter of the ball. This causes the wheels to force the ball between them and out the other side at the same velocity as a point on the outside of the spinning wheel.

To recreate this motion, the pitching machine tank consists of a rectangular PVC base that is attached to the tank platform with bolts. Two PVC wheels are mounted to this base using press fit dowel pins and a roller bearing placed on the inner diameter of the wheel. The bearing being used is a Flanged Open 0.25 in. Inner Diameter Miniature Precision SS Roller Bearing. Initially, the Mabuchi style RS-555 motors (attached to the spinning wheels) were powered through the Arduino. After testing, we determined that the Arduino was insufficient for powering our motors and we instead connected them to an external 12 V 1.3 A-hr. battery. The motors are attached with a bracket to a PVC plate located above the wheels. This plate connects to the base to stabilize the motors and allow only the wheels to spin.

Another main component of the pitching machine tank is the chute through which the balls are dispensed. A ball is released through this chute by the movement of an extended servo motor arm. The arm initially blocks a portion of the chute, restricting the ball from falling freely. When the servo motor program is initiated, the arm moves, allowing the ball to fall through the elbow joint and be fed through the spinning wheels. These components can be seen in Figure 15. For dimensioned drawings of all components of the pitching machine tank, see Appendix Y.

Figure 15: Pitching Machine Tank

The servo motor controlling the release of the foam ball along with the driving motors for the tank are connected to the Arduino and motor shield. For this tank, the two driving motors are connected to DC motor inputs M3 and M4 on the motor shield, and the firing servo motor is connected to Servo2. The Arduino and motor shield are powered using a 9 V wall power supply. The DC motors used to spin the wheels in the launching mechanism are powered with an external 12 V 1.3 A-hr. sealed lead acid battery.

A breadboard and switches are used as a controller for this tank. The breadboard is powered using the 5V and ground pins on the motor shield. The buttons connect to digital I/O pins 14-16 (labeled analog 0-2). The buttons connected to pins 15 and 16 drive the tank, while pin 14 controls the servo. The resistors connected to the breadboard are rated at 10 kΩ. Figure 16 shows how the breadboard is wired. Appendix Z shows the Arduino code used to control these buttons and motors.

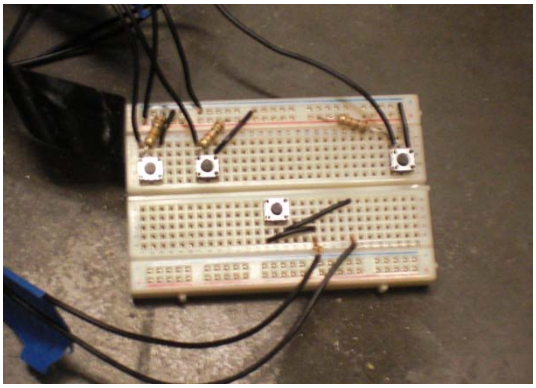


Figure 16: Breadboard controller for compression spring tank

PROTOTYPE DESCRIPTION

Our prototype includes our competition description, lecture and lab schedules, the battlefield, two tank platforms for students to attach their projects to, and two examples of student projects. There are several differences between our prototype and our final design. The lectures, tank platform, and material kit differ from the final design. The prototype does not provide complete lecture and lab materials. We made this decision because professors prefer to format their lecture slides themselves.

There are a few differences between our prototype and our final design for the tank platform. Most importantly, due to budget constraints, our prototype tank platform will have a wired controller. The Arduino XBee Shield and XBee Module system that provide the wireless capability for our tank platform cost approximately $150 for each platform and is therefore too expensive to purchase with our $400 budget. The wired controller, consisting of a small breadboard and multiple switches, ensures that we are able to demonstrate the function of our tank prototypes and the Tank Wars competition without requiring expensive wireless equipment. The breadboard is attached to the Arduino control system by wires that are long enough so that it can be held and operated from the side of the battlefield, so as not to interfere with the function of the tank prototypes. Also, because of the $50 cost of the lithium ion battery described in the tank platform design, the Arduino system and motors in our tank platform prototype are powered through a wall outlet with the use of an external 12 V 1.3 A-hr. sealed lead acid battery to power the motor shield.

Additionally, the material kit we provide for our prototype is a general list, compared to the complete list the final design would include. We have provided information regarding the motors and other parts used for our example tanks including specifications as well as distributors. This should aid in the creation of a much more extensive material kit for the project. Also, GSI/Instructor preferences should be taken into account regarding the categories of launching mechanisms they will allow students to design. There is a high likelihood that students may generate entirely new concepts, requiring different parts; therefore, the materials list is likely to remain a work in progress even after our project is implemented.

FABRICATION PLAN

This section describes the process used to fabricate the Tank Wars battlefield, two tank platforms, the compression spring tank, and the pitching machine tank. For the bill of materials used, see Appendix AA.

Battlefield Fabrication

The following are the materials (Table 2) and procedures (Table 3) that were used to build the battlefield.

Table 2: Raw material inventory used to create the battlefield and its components

Material	Size	Quantity	Use	Source
Balsa Wood	2 in. x 2 in. x 3 ft.	6	Stacked Block Buildings	National Balsa
Pine	1 in. x 2 in. x 8ft.	2	Road Barriers	Home Depot
	1 in. x 4 in. x 8 ft.	3	Battlefield Walls	Home Depot
	2 in. x 4 in. x 8 ft.	2	Hill Supports and Net Supports	Home Depot
Plywood	8 ft. x 4 ft. x ½ in.	2	Battlefield Base and Hill	Home Depot
Pine Dowel	½ in. diameter x 4 ft.	4	Net Posts	Home Depot
Tulle Fabric	54 in. x 8 ft.	1	Nets	JoAnn Fabrics

Table 3: Tools used to create the battlefield and its components

Tool	Brand and Model	Uses
Circular Saw	Black & Decker 7308, 7.25 in	Cutting plywood for base Cutting plywood hill face
Compound Miter Saw	Delta ShopMaster MS250, 10 in.	Cutting miters on wall and road bump Cutting wall pine planks to length
Electric Drill	Black & Decker 3A, 1200 RPM	Driving screws to attach parts

When building the battlefield, we began by cutting all parts to the dimensions shown in Appendix U. Additionally the pine dowels were cut to 36 in. to be used as net posts and the tulle was cut to 54 in. x 48 in. The following is a list of the steps used to assemble the battlefield one half of the battlefield and should be repeated for the other half. CAD drawings corresponding to each assembly step are shown in Appendix BB.

1. Place the battlefield walls along the 4 sides of the battlefield base. Screw through the base into the battlefield walls to attach.
2. Place a hill support on the inside bottom edge of each hill. Screw through hill into hill support to attach.
3. Place all hills on the battlefield base so that the hills face each other as shown in Figure 17. Screw through battlefield base into hill supports to attach.

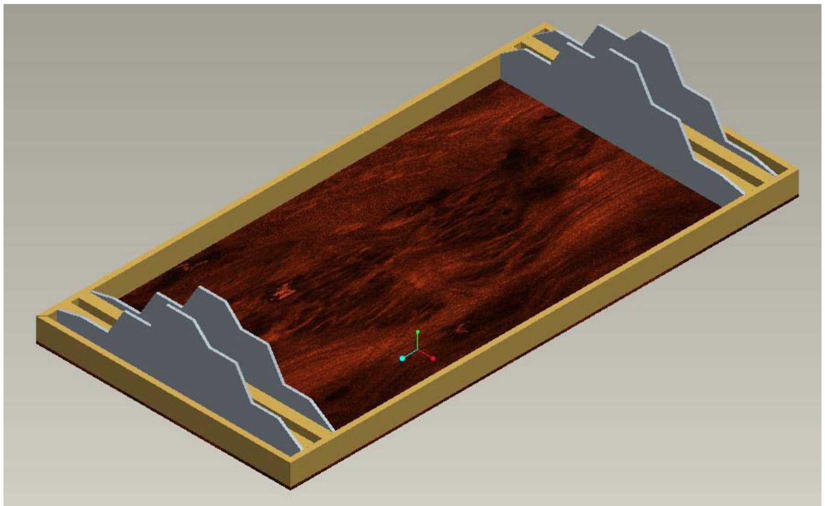


Figure 17: Placement of hills on battlefield base

4. Place the horizontal and angled hill tops onto the hills. Screw through the hill tops into the hills to attach.

5. Place the road barriers on the battlefield base as shown in Figure 18. Screw through the road barriers into battlefield base to attach.

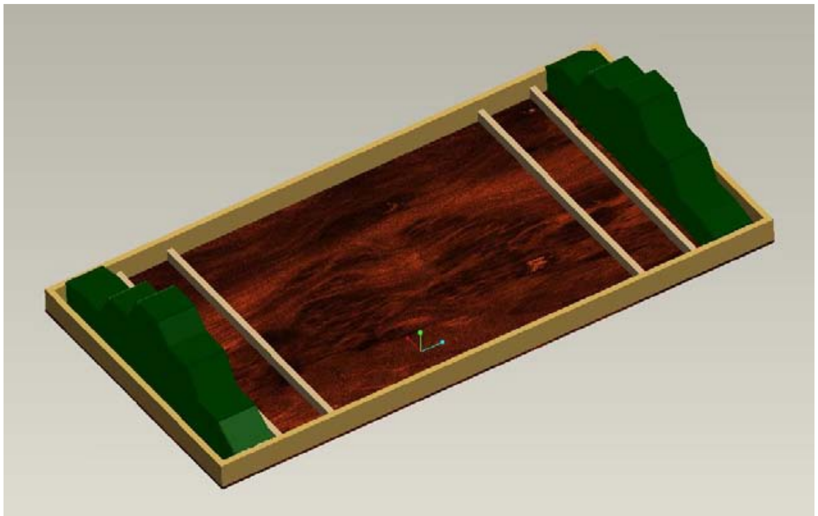


Figure 18: Placement of road barriers on battlefield base

6. Place the net supports in each corner of the battlefield behind the hill. Screw through battlefield walls into the net supports to attach.
7. Sew a 2 in. channel along the shorter side of each net. Place the net posts into each of these channels. Place the net posts in the net supports.
8. Stack the balsa wood blocks on each horizontal hill top to form the buildings. The battlefield is now completed as shown in Figure 19.

Figure 19: Completed battlefield

After assembly, all sharp edges should be sanded to prevent splinters or other injury. The battlefield base and hills should be spray painted forest green, and the roads (battlefield base between the road barriers) should be spray painted black.

If additional battlefields were desired for use in ME 250, they would be manufactured as described above. There is no need to alter the fabrication process because the battlefield is not intended for mass production.

Tank Platform Fabrication

The tank platform was constructed in the machine shop (GGB room 1119) using the tools available there. Below are the materials and procedures necessary to build one tank platform. Two identical tank platforms were fabricated, so the same procedure must be repeated for a second tank platform. Below in Table 4, a list of parts and materials, along with the manufacturing processes, are listed. Table 5 contains the purchased components.

Table 4: Manufactured components used to create one tank platform

Part	Size	Quantity	Material	Machining Process
Base	7 in. x 10 in. x 0.25 in.	1	PVC (sheet)	Band Saw/Hand Drill
Wheels	2 in. diameter x 0.25 in.	4	PVC (cylinder)	Band Saw/Drill Press
Axle Brackets	1 in. x 1 in. x 0.5 in.	3	PVC (sheet)	Band Saw/Drill Press
Arduino Bracket	0.125 in. x 0.5 in. x 2.5 in.	1	PVC (sheet)	Band Saw
	0.125 in. x 0.5 in. x 3 in.	2	PVC (sheet)	Band Saw
Spacer Blocks	1 in. x 1 in. x 1.5 in.	4	PVC (sheet)	Band Saw/Drill Press

Table 5: Purchased components used to create one tank platform

Part	Specifications	Use
Arduino Duemilanove	14 Digital I/O pins 6 Analog/Digital I/O pins	Control the movement of the motors for driving and firing
Motor/Stepper/Servo Shield	Connects 2 Servos and 4 DC/2 Stepper Motors	Connect motors to Arduino
9V Wall Power Supply	120V DC, max 660 mA	Power Arduino
200:1 Plastic Gearmotor	51 RPM, 0.71 N-m	Rotate front wheels
Metal Axle	0.125 in. diameter x 36 in. length	Support rear wheels

The first step in the construction of the tank platform is to cut PVC stock to the required sizes using a band saw. The wheels were cut from 2 in. round stock. The metal axle should also be cut into 8 in. lengths. See Appendix V for dimensioned CAD drawings of all parts. After the pieces were cut to size, the procedure below was used to machine and assemble the tank platform. See Appendix CC for complete assembly drawings.

1. Drill holes in each corner of the base using a hand drill with a size D drill bit.
2. Drill holes in the center of the 1 in. x 1in. face of each spacer block, using a drill press with a size D drill bit.
3. 0.25 in. diameter, 2.5 in. long bolts should be threaded through each hole in the base and then through one of the spacer blocks.
4. Drill holes in the center of the 1 in. x 1 in. face of each axle bracket, using a drill press with a size D drill bit.
5. Place the axle brackets and gearmotors on the surface of the base that does not have the spacer blocks, as shown in Figure 20. Use PVC cement to attach all of these components. Allow 15 minutes to set.

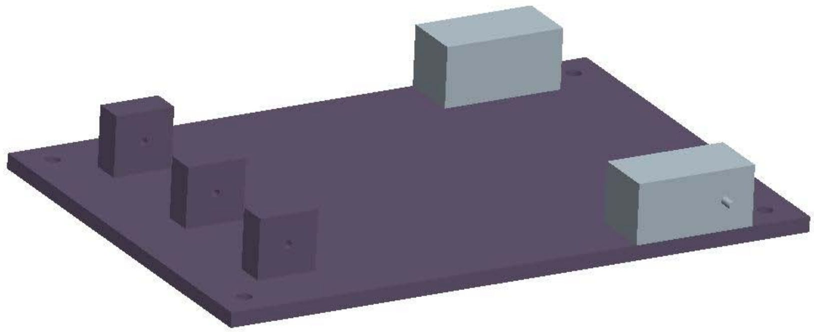


Figure 20: Placement of axle brackets and gearmotors on base

6. Use a drill press with a #31 drill bit to drill holes in the center of 2 of the wheels.
7. Press fit one wheel onto the metal axle. Place the axle through all three axle brackets. Press fit the other wheel onto the metal axle.
8. Use a drill press with a 0.25 in. drill bit to drill holes in the center of the other two wheels.
9. Press the wheels onto the gear motors, using PVC cement to secure the connection. Allow 15 minutes to set.
10. To protect from shorts, Apply electrical tape to the base area where Arduino will sit.
11. Solder the motor/stepper/servo shield kit using the instructions at www.adafruit.com.
12. Attach the 9V DC power supply and motor/stepper/servo shield to the Arduino. Place this assembly on the base on top of the electrical tape. The tank platform is now completed as shown in Figure 21.

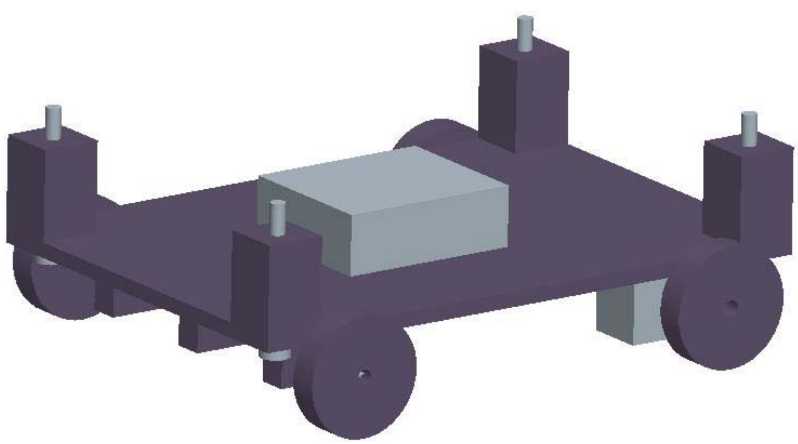


Figure 21: Completed tank platform

If other tank platforms are desired for ME 250, they should be fabricated as described above. Because the tank platform is designed for a class, there is no need to adapt its fabrication for mass production.

Compression Spring Tank Fabrication
The tank platform was constructed in the machine shop (GGB room 1119) using the tools available there. Below in Table 6, a list of parts and materials, along with the manufacturing processes, are listed. Table 7 contains the purchased components.

Table 6: Manufactured components used to create the compression spring tank

Part	Size	Material	Machining Process
Large Support Column	3 in. x 5.4 in. x 2 in.	PVC (sheet)	Manual Mill/Drill Press
Small Support Column	1.5 in. x 1 in. x 5.4 in.	PVC (sheet)	Manual Mill/Drill Press
Base	7 in. x 10 in. x 0.25 in.	PVC (sheet)	Band Saw/Hand Drill
Firing Motor Bracket	2 in. x 1 in. x 2.25 in.	PVC (sheet)	Manual Mill/Band Saw
Body	3.5 in. x 1 in. x 1.5 in.	PVC (sheet)	Manual Mill/Drill Press
Barrel Cap	2.25 in. x 2.25 in. x 0.25 in.	PVC (sheet)	Manual Mill

Table 7: Purchased components used to create the compression spring tank

Part	Specifications	Use
Tower Pro High Torque Professional Speed MG995 Servo	Stall Torque (4.8V): 13 kg/cm	Sets the barrel to the desired angle
Tower Pro High Torque Professional Speed MG955 Servo	Stall Torque (4.8V): 13 kg/cm	Turns the sector gear to compress/release the spring
Rack	Pitch: 32 Turns/Inch, Pressure Angle: 20 Degree	Compresses the spring until is released by sector gear impacting the foam ball
Spur Gear	Pitch: 32 Turns/Inch, Pressure Angle: 20 Degree, 18 Teeth x .188” Bore Diameter x .562” Pitch Diameter	Retracts the rack (compressing the spring) and then releases the rack when there are no more teeth
Compression Spring	1-3/4” Length x 1/2” Outer Diameter x .054” Wire Diameter	Stores energy
PVC Pipe	2 in. Diameter x 2.75 in. Length	Barrel
Dowel Pin	0.25 in. Diameter x 1.25 in. Length	Attach body to small support column
Flange Bearing	0.25 in. Inner Diameter	Allow body to rotate smoothly
Power Resistors	2 ohm and 10 ohm	Reduce the current in the firing motor
Infineon Technologies TLE 5206-2 H-Bridge	6V Minimum voltage 5A Maximum current	Apply programmed logic to firing motor
Half Breadboard		Connect buttons and motor shield to control tank
Miniature Switches		Use Arduino program to control tank

The first step in the construction of the compressing spring tank is to cut PVC stock to the required sizes using a band saw. The large support column was cut from 2 in. flat stock, the small support column, servo motor bracket and body were cut from 1 in. flat stock and the base and barrel cap were cut from 0.25 in. flat stock. The rack should be cut to 2 in. pieces and 12 of the 18 teeth on the spur gear should be filed off. The mechanical stop and electronic components were removed from the firing servo motor, making it act as a DC motor and gearbox. See Appendix W for dimensioned CAD drawings of all parts. After the pieces were cut to size, the procedure below was used to machine and assemble the compression spring tank. Complete assembly drawings are included in Appendix DD.

1. Use a manual mill with 0.375 in. flat mill bit with a 1.8 in. flute length to machine the groove in the body.
2. Drill a hole in the back of the body, centered on the machined groove, using a drill press with a 0.25 in. bit.
3. Place a 2.5 in. long bolt through the hole in the body, with the head of the bolt outside of the groove. Place the spring around the bolt inside the groove. Place a 0.5 in. washer on the bolt and secure with a nut.
4. Use PVC cement to attach a 0.5 in. x 0.5 in. x 0.125 in. piece of PVC in the groove, forward 0.25 in. from the bolt.
5. Press the brass rack into the brass nut using a combination of the press fit machine and a mallet.
6. Place the rack into the groove in the body so that the brass nut makes contact with the bolt.
7. Use a manual mill with 0.375 in. flat mill bit with a 1.8 in. flute length to machine the hole in the firing motor bracket. Leave excess material on one end to prevent the vise from breaking the bracket.
8. Use a band saw to cut the excess material off of the firing motor bracket.
9. Press fit a screw and sleeve into the sector gear. Screw this assembly into the firing motor.
10. Use PVC cement to attach the firing motor to the bracket. The top of the bracket should align with the center of the sector gear. Allow 15 minutes to set.
11. Place the firing motor bracket on the body so that the teeth of the sector gear align with the teeth on the rack as shown in Figure 22. Use PVC cement to attach and allow 15 minutes to set.

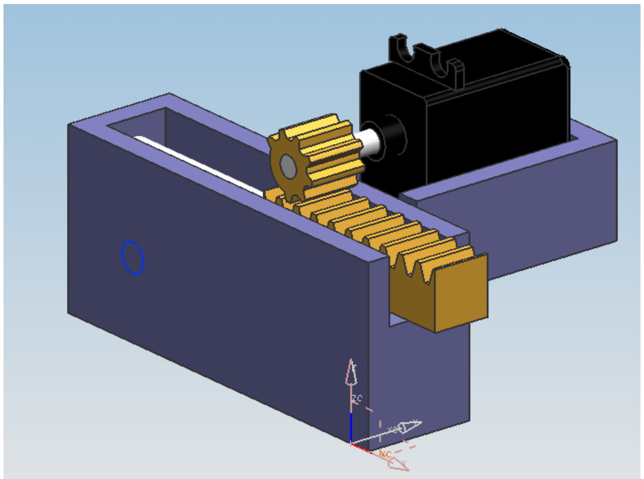


Figure 22: Placement of the firing motor bracket on the body

12. Use a manual mill with a 0.375 in. flat mill bit with a 1.8 in flute length to machine the hole for the rack in the barrel cap.
13. Attach the PVC pipe barrel to the barrel cap using PVC cement. Allow 15 minutes to set.
14. Use a dremel to round the corners of the barrel end cap so that it is the same diameter as the outside of the barrel.
15. Place the assembled barrel on the end of the body, centering the hole in the barrel cap with the groove in the body. Use PVC cement to attach, and allow 15 minutes to set.
16. Use a manual mill with a 0.375 in. flat mill bit with a 1.8 in. flute length to machine the servo motor hole in the large support column.
17. Attach the servo arm to the aiming servo motor with the provided screw.
18. Use a hand drill with a 1/16 in. drill bit to drill two holes on the 0.5 in. deep face of the servo motor hole. Attach the servo motor to the large support column using the provided screws and this hole.

19. Use the manual mill with a 3/16 in. drill bit and a reamer bit to drill a hole in the small support column.
20. Press fit the dowel pin into the small support column.
21. Use the manual mill with a drill bit and reamer just smaller than the flange bearing to drill a hole in the body.
22. Press fit the flange bearing into the body.
23. Drill two holes through the aiming servo motor arm into the body using a hand drill and a 1/16 in. drill bit. Screw the servo motor arm into the body using the screws provided with the servo motor. This will attach the large support column to the body.
24. Place the dowel pin into the flange bearing, attaching the small support column and body as shown in Figure 23.

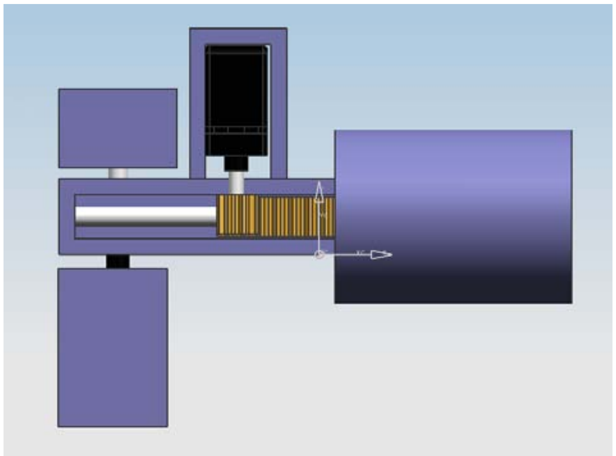


Figure 23: Placement of small and large support columns on the body

25. Drill holes in each corner of the base, 0.5 in. from the sides, using a hand drill with a size D drill bit. The hole should pass all the way through the base.
26. Place the firing mechanism on the base and drill pilot holes through the base into both support columns using a hand drill with a size D drill bit. Place 4 holes in the large support column and 2 holes in the small support column.
27. Use 0.25 in. bolts to attach the firing mechanism to the base. The tank platform is now completed as shown in Figure 24.

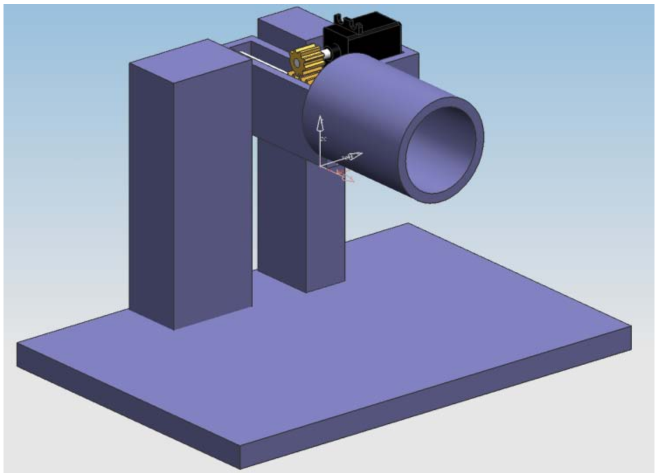


Figure 24: Completed compression spring tank

After the compression spring tank is assembled the motors must be wired to the Arduino on the tank platform and the breadboard controller must be assembled. The driving motors on the tank platform were wired into M1 and M2 on the motor shield, and the aiming servo motor was wired to Servo1. The servo shield was powered through an external battery. The firing motor was wired to parallel 2 ohm power resistors and parallel 10 ohm power resistors. It was then attached to an Infineon Technologies TLE 5206-2 H-Bridge, which was powered directly from the external battery. The input terminals of the H-Bridge were attached directly to I/O pins 5 and 6 on the motor shield. The connections of the motors to the motor shield are shown in Figure 25.

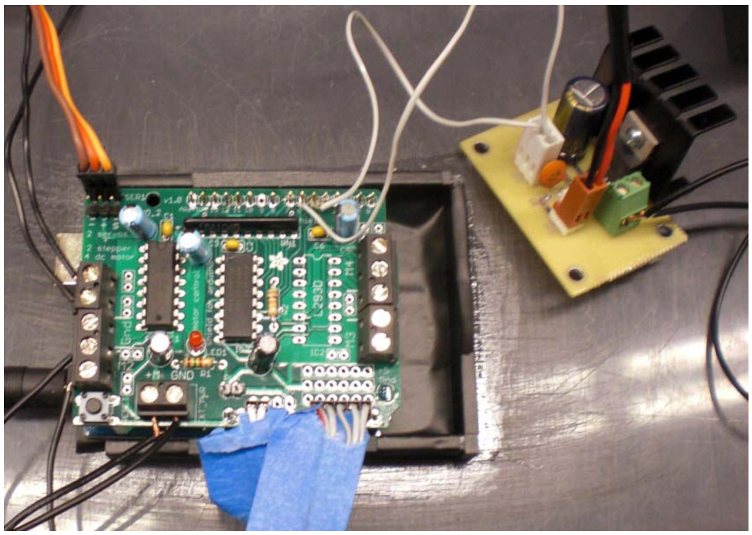


Figure 25: Wired motor shield for the compression spring tank

The breadboard controller was attached to the motor shield using 6 ft. wires. It was powered through the 5V and ground pins on the motor shield. The buttons were attached to digital pins 14 to 18 (analog pins 0 to 4) also using 6 ft. wires. Pins 14 and 15 control the forward and backward driving of the tank, pins 16 and 17 control up and down aiming, and pin 18 controls the rotation of the firing motor. The breadboard itself was set up as shown in Figure 14. The resistors shown are 10 kΩ. Once these connections have been made, the tank is ready to be attached to the tank platform.

If this tank is reproduced, the firing motor bracket should be attached with screws rather than PVC cement. Two screws should be placed through the bracket into the body on each vertical side. This will prevent the connection from breaking during use. No other changes are required because the tank prototype is not intended for mass production.

Pitching Machine Tank Fabrication

The pitching machine tank was constructed in the machine shop (GGB room 1119) using the tools available there. Below in Table 8, a list of parts and materials, along with the manufacturing processes, are listed. Table 9 contains the purchased components.

Table 8: Manufactured components used to create one pitching machine tank

Part	Size	Quantity	Material	Machining Process
Base	10 in. x 7 in. x 0.25 in.	1	PVC (sheet)	Band Saw/Hand Drill
Top Plate	10 in. x 7 in. x 0.25 in.	1	PVC (sheet)	Band Saw/Hand Drill/Hole Saw
Supports	7 in. x 2 in. x 0.5 in.	2	PVC (sheet)	Band Saw/Drill Press
Wheel	2 in. diameter x 1.25 in.	2	PVC (cylinder)	Band Saw/Manual Mill
Motor Bracket Top	3 in. x 3 in. x 0.25 in.	2	PVC (sheet)	Band Saw/Hole Saw/Drill Press
Motor Bracket Middle	1.5 in. diameter x 1.5 in.	2	PVC (pipe)	Band Saw
Motor Bracket Bottom	2 in. x 2 in. 0.125 in.	2	PVC (sheet)	Band Saw/Drill Press
Ramp	2 in. x 2 in. x 2 in	1	Wood	Compound Miter Saw

Table 9: Purchased components to create one pitching machine tank

Part	Specifications	Use
RS-555 DC Motors	6660 RPM 0.206 N-m 5-15 Volts	Spin wheels
Miniature Precision SS Flanged Open Roller Bearing	0.25 in. shaft diameter 0.375 in. outer diameter	Decrease friction in wheels
Hardened Steel Dowel Pins	0.25 in. diameter 1.5 in. length	Mount wheels and bearings
Tower Pro SG-90 Servo Motor	0.176 N-m 60 degrees/0.1 seconds	Ball release mechanism
PVC Elbow (Hub x Hub)	2 in. diameter 90 degree elbow	Chute for ball to drop through
Half Breadboard		Connect buttons and motor shield to control tank
Miniature Switches		Use Arduino program to control tank

The first step in the construction of the pitching machine tank is to cut all of the PVC stock to the required sizes using the band saw. All flat pieces were cut from stock PVC with the same thickness as the final part while the wheels were cut from 2 in. diameter round stock PVC. See Appendix Y for dimensioned CAD drawings of all parts. After these pieces were cut to size, the following procedure was used to machine and then assemble the tank prototype. Complete assembly drawings are included in Appendix EE.

1. Drill the holes in the base using a hand drill with a size D drill bit.
2. Drill the smaller holes in the corners of the top plate using a hand drill with a size D drill bit. Cut the larger holes in the top plate using a 2 in. hand saw. Manually mill out the slot for the servo motor using a 0.25 in. flat mill.
3. Drill the holes in the supports using a drill press and size D drill bit.
4. Mill both sides of the wheels to obtain a flat surface using a manual mill and a 0.375 in. flat mill.
5. Drill holes in the wheels using a manual mill with a size D drill bit for the center hole and a size 0.125 in. drill bit for the two smaller holes. To find the center of the wheel use a dial indicator. After drilling, use a 0.125 in. reamer on the center hole.
6. Drill holes in the wheel connector using a hand drill with a 0.125 in. drill bit for all the holes.

7. Cut the hole in motor bracket top using a 1.5 in. hole saw. Drill the smaller holes in the motor bracket top using a drill press with a 0.125 in. drill bit.
8. Drill holes in the motor bracket bottom using a drill press with a 0.25 in. drill bit for the center hole and a 0.125 in. drill bit for the two smaller holes.
9. Press fit both of the dowel pins into the machined holes in the base so they are flat with the bottom of the base.
10. Ready the wheels by press fitting one bearing into the center hole of each wheel. With the bearings in place attach the wheel connector to the side of the wheel opposite the bearing with screws.
11. Press fit the wheel assemblies onto the two dowel pins.
12. Cut a 30 degree angle into the ramp using a compound miter saw. Line the ramp up so that it sits at the front edge of the bottom plate, centered between the two wheels. Use a hand drill to screw it into place.
13. Attach the supports to the base with bolts and a socket wrench. The assembly of the base portion of this tank can be seen in Figure 26.

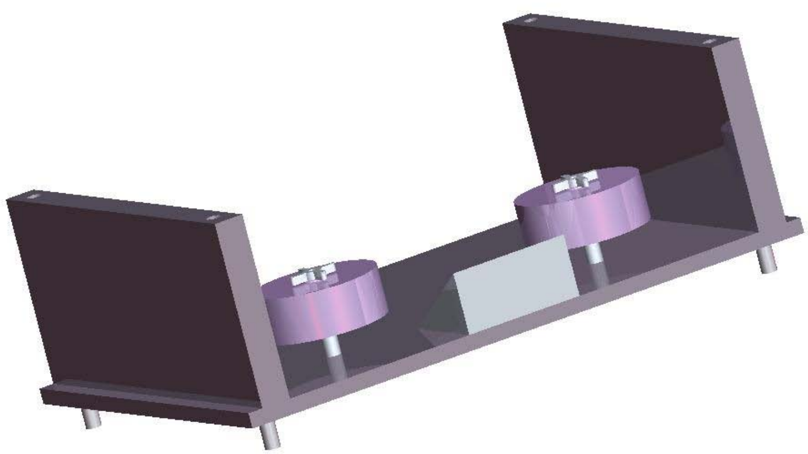


Figure 26: Assembled base portion of the pitching machine tank

14. Attach the motor bracket bottom to the DC motor. Apply PVC cement to the motor bracket middle, slide it over the motor, and press it onto the motor bracket bottom. Apply PVC cement to the motor bracket top, slide it over the motor and press it onto the motor bracket middle. Use a clamp to hold this motor assembly in place until set (15 minutes).
15. Cut one of the hub ends off of the PVC elbow using a band saw. On the remaining hub, use a hack saw to cut out a slot for the servo arm.
16. Apply PVC cement to the area between the remaining hub end and the elbow of the PVC elbow and place in the large centered hole on the top plate. Apply more PVC cement around the outside of the join on both sides of the plate and let set for 15 minutes.
17. Apply PVC cement to the slot for the servo motor. Line up the servo arm with the slot cut in the PVC elbow, and press the motor into place. Let set for 15 minutes
18. Attach the top plate to the supports using bolts and a socket wrench, lining up the large holes on the top plate with the wheel assemblies previously attached to the base.
19. Insert the motor assemblies into the holes in the top plate, pressing the motor shaft into the center hole of the wheel assembly. Secure these assemblies to the top plate with screws through the holes created in the motor bracket top. The final assembly of the pitching machine tank can be seen in Figure 27.

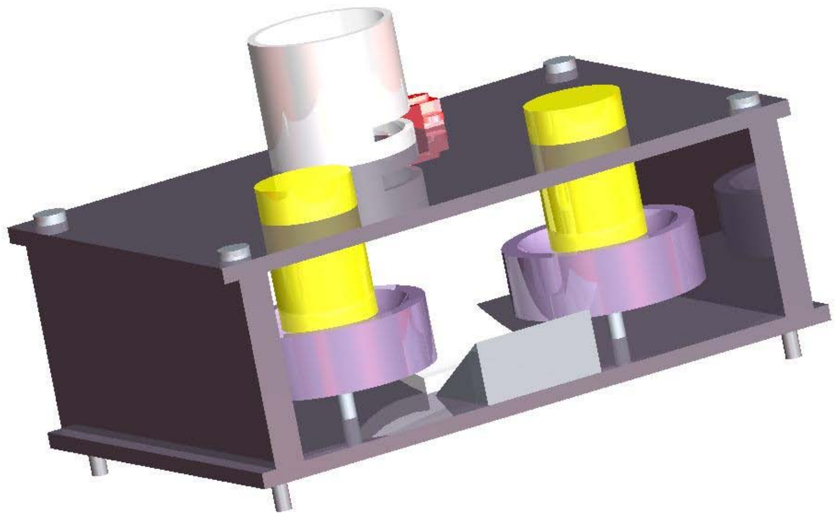


Figure 27: Fully assembled pitching machine tank

After the pitching machine tank is assembled, the motors must be wired to the Arduino on the tank platform and the breadboard controller must be assembled. The driving motors on the tank platform are wired into M3 and M4 on the motor shield and the servo motor was wired to Servo1. This servo shield and the Arduino itself were powered through a wall outlet. The DC motors used to spin the wheels were connected directly to an external 12 V 1.3 A-hr. sealed lead acid battery.

The breadboard controller was attached to the motor shield using 6 ft. wires. It was powered through the 5V and ground pins on the motor shield. The buttons were attached to digital pins 14 to 16 (analog pins 0 to 2) also using 6 ft. wires. Pins 15 and 16 control the forward and backward driving of the tank, pin 14 controls the ball release. The breadboard itself was set up as shown in Figure 16. The resistors shown are 10 kΩ. There was also a button wired that controlled the DC motors controlling the wheels. This button was used as an open and closed switch between the motor and battery.

Once these connections have been made and the tank is ready to be attached to the platform, remove the bolts connecting the base to the supports and instead use the bolts in the tank platform to connect the entire tank.

VALIDATION RESULTS

We evaluated the cost of our prototypes, the time to teach lectures, the time to design, build and test the prototypes, the use of moving parts, the size of the competition equipment, the difficulty of programming Arduino, and the response of sophomores to Tank Wars to validate our final design for an improved ME 250 class and project. The following are our results.

Cost

To determine if the cost (per group) to design, build, and test a prototype for Tank Wars was kept to a reasonable level, our team contacted various administrators in the Mechanical Engineering department. Through this research, we determined that there is approximately $3500 per semester dedicated to the materials used by all ME 250 teams. With around 140 students per semester and groups of 4-5 students in each, this gives each team approximately $100 for prototype materials. To validate whether or not our project meets this cost requirement, we compared it to the amount of money spent on each of our tank prototypes.

Our team spent approximately $80 on the compression spring tank, and $70 on the pitching machine tank. These values include the motors, bearings, and gears that were purchased for each tank, the shipping on these items, and assorted hardware. PVC stock and bolts taken from the shop were not included. The cost of these materials would likely make both of our tank prototypes more expensive than prototypes for the current ME 250 class. However, we believe that the difference in cost is worth the academic gain for the students. Students will learn and apply more mechanical engineering skills with the added complexity.

Time

Timing is an integral part of our final design. Professors must have enough time to cover material in lecture and labs, and student teams must have enough time to create successful prototypes. To evaluate the time spent on lectures and labs, we gathered schedules from previous ME 250 semesters and similar courses at peer universities. Our final lecture schedule has the same number of lectures as previous semesters, and spends a similar amount of time on engineering drawings/design and on manufacturing. The technical topics applicable to the project are given a single lecture, similar to other universities. The similarities in lecture schedules allow the professor sufficient time to cover the suggested material. The lab schedule remains virtually unchanged from previous semesters of ME 250; therefore, allowing GSIs adequate time to teach CAD and CNC manufacturing.

We are aware that Tank Wars is technically challenging for students at a sophomore level than previous ME 250 projects; therefore, it will take longer to complete. To account for this, the project is introduced in the first lecture of the semester, giving students ample time to design a complex prototype. The manufacturing time is kept at 4 weeks, since it was deemed sufficient. Also, testing equipment is available for the last two weeks to ensure that students' tanks are safe and fully functional. To verify that this time is sufficient for each group to design and build their tank, we kept track of the amount of shop and testing time we spent on our tank prototypes. We spent approximately 2.5 days building and 1 day testing each tank. We considered that our schedule allows 2.5 weeks for manufacturing and 1.5 weeks for testing, that 10 teams are allowed in the shop at a time (5 teams using the CNC mills, and 5 using the CNC lathes), and that there are 30 teams in a semester of ME 250. This would give each student team nearly twice as much time to build and test as we used (4.33 days to build and 2.33 days to test). This is an appropriate scale factor because as seniors we have more manufacturing experience than sophomores. Also, we were building and testing in groups of 2 rather than groups of 4. These calculations demonstrate that students will have enough time to successfully complete a tank prototype.

Moving Parts

One of the main requirements of our final design was that student prototypes utilize moving parts. In Tank Wars, students are given the freedom to design a firing mechanism, and as such the moving parts they use will differ based on the specific firing mechanism they choose. As demonstrated by our tank prototypes, students can use gears, springs, bearings and spinning wheels, and must use motors. This variety will introduce students to a wide range of moving parts and enhance their education.

Size

When analyzing our competition concepts, we looked at the size of the competition equipment for each concept, keeping in mind that the equipment will likely be used for multiple semesters and must be stored when not in use. A large battlefield would limit the locations available for testing and competitions. Although the battlefield for Tank Wars measures 4 ft. x 8 ft. x 3 ft. when in use, it can be reduced to 4 ft. x 8 ft. x 15 in. for storage. The base is cut into two pieces which can be stacked on top of each other, and the net can be removed to reduce the height. This size is large enough to allow for many buildings on each end, and it provides students with a challenging distance to fire their tanks.

Programming Arduino

Student teams will be required to program their motors using the Arduino microprocessor to have a functional tank prototype. Arduino was chosen as the microprocessor because we believed that the compatible motor shield and the open source code available would simplify the programming for students. To validate our choice of Arduino, our team needed to successfully program our tank prototypes using only open source code. Although we initially faced challenges finding open source information that connected all of our components (Arduino, the motor shield, and switches), we were able to create functional code for both tanks. These results are promising; however, we did not use the XBee wireless adapter that ME 250 students would be using, so they may face problems integrating this equipment with the motor shield. On the other hand, we found that users on many open source websites are extremely helpful, and would be a good resource for students. Overall, we believe that Arduino is a good microprocessor for use in Tank Wars, and that students will be able to use it with minimal difficulty.

ME 250 Student Survey

Because our group is comprised of senior mechanical engineers, it is difficult for us to determine how the project would appear to a sophomore mechanical engineering student. Many of our customer requirements are focused on the experience and opinions of sophomore students regarding the design project. We visited lab sections during the Winter 2009 semester to get sophomore opinions about the creativity involved in Tank Wars, their interest in the project, and whether they believed they were capable of creating a tank prototype. The survey questions and results are shown in Appendix FF. We received responses from 11 students.

First, students were asked whether they would be interested in Tank Wars as a project, and 80% of students responded positively. The other 20% expressed reservations about its difficulty level, but did not say that they would not be interested. These results show that Tank Wars is a project that would capture the interest of a majority of students, which is crucial in motivating students to pursue mechanical engineering. Next, students were asked if they believed that the project would allow them to produce a creative design. 60% of students responded that they could be more creative than previous semesters. The other 40% of students focused on the requirement of a protective housing for the tank. Some expressed the belief that the housing would allow them to be more creative while others believed that the housing was too much work when combined with the firing mechanism. These results indicate that Tank Wars allows students to be more creative than other projects. Finally, we asked students whether they believed they could create a successful tank, assuming lectures taught relevant technical material. 100% of the students surveyed believed they would be capable of creating a tank prototype, although 20% specified that it would depend on how well the professor taught the material. This supports our belief that Tank Wars is a project that is appropriate for sophomore level students.

Overall our survey results support Tank Wars as a project for future ME 250 semesters. Tank Wars meets our requirements by capturing the interest of the majority of students and allowing them to develop a creative prototype. Although students recognize that it would not be a simple project, they believe that it is a project at which they could succeed.

DISCUSSION

After manufacturing and testing the prototypes, we found several issues that arose that have led to design changes necessary for proper implementation of this project. First, our tank requirements call for a size of 10 in. by 7 in. for the base. This was chosen because we did not want to limit creativity with a strict size limit. Though this was accomplished, there was empty space, additional weight, and manufacturing issues that were caused by the larger size. The biggest change that reducing the size creates is that students would be able to manufacture there prototype as two halves. The CNC machines allow for manufacturing a piece that has a maximum size of 7 in. by 3 in. Students would be expected to manufacture their project as two 7 in. by 3 in. pieces, and then connect them. Because our examples were too large, we were unable to have the accuracy and precision that CNC machines produce. Sophomore students are less experienced in machining and are not trained on the manual mills and lathes, so a smaller size will avoid the manufacturing challenges we faced in creating our prototypes

Second, we would adjust the electronic components of the project. When testing with the Arduino, we discovered that the Arduino is unable to handle large voltages and currents. This is not an issue for low demand motors, but for certain applications, such as the high speed motor used in the pitching machine, it created problems. To avoid this, a separate battery and circuitry would be necessary. For the pitching machine, the problem could be solved by using the Arduino as a switch that controlled a MOSFET. This would allow for the Arduino to control the motor, while not having the high current and voltage pass through it. This will work for situations where specific speed controls of motors are not necessary. When specific speed controls are needed, there must be additional controls, which would be tailored to the specific use. This would be dealt with by the GSI since the students would not have a large electronics background at the current point in their education. It would also be encouraged that students attempt to avoid such an issue.

Finally, we would have manufactured the tank platform precisely to ensure robustness. The tank platform was made using stock PVC that was easily available. To ensure that it is better suited for use by an entire class, we would have done a more precise and accurate manufacturing process. The platform would require hobby wheels with treads rather than circular pieces of PVC. The rear wheel axle would also require bearings and a better axle rod instead of simple thin steel rod. Finally, the manufacturing of the platform would be performed using CNC and manual mills to ensure that the tolerances of the parts are acceptable, since students are required to manufacture their prototype to assemble to the platform.

RECOMMENDATIONS

The following section describes our recommendations to improve upon our final design.

Tank Platform

Although the tank platform described in our final design will function as needed for the Tank Wars project, it will not withstand extended use by multiple student teams. A more robust design will ensure that each student team has the same quality platform to work with for their tank. The tank platform prototype was created using stock materials (mainly PVC sheets) from the machine shop. After seeing its functionality while connecting our example tank prototypes, we realized many changes should be made. Because dowel pins generally require a press fit connection to provide stability to a device, we recommend that the attachments between the platform and tank prototypes are all bolts (0.25 in. diameter, 2.5 in. length). We also recommend that the base of the tank platform, as well as the support blocks that the bolts are inserted through, are made of aluminum. This is a lightweight and fairly inexpensive material that will extend the life of each platform. Electrical insulation will need to cover the aluminum base to prevent the Arduino control system from shorting. With continuous testing it became apparent that wheels cut from round stock PVC did not perform as well as expected. Because of this, the use of actual wheels found at various hobby stores would allow much more stable and accurate movement of the tanks. These wheels must be design for a 0.25 in. axle so that they fit on the driving motors. The wheels on the rear axle are not connected to driving motors, but instead, to a metal rod. To ensure that they spin well, we recommend that each wheel be connected to a dowel pin and ball bearing. The dowel pin should have a 0.25 in. diameter and be press fit into the wheel and into the bearing (0.25 in. inner diameter, 11/16 in. outer diameter). The bearing should be flanged so that it can be press fit into the tank platform and double sealed so that it does not have to be lubricated. The ball bearings can be found for $5.19 each at www.mcmaster.com (6384K352).

Arduino
Because our team found some limitations with the Arduino microprocessor, we recommend that there are additional electronic resources available to students to combat these issues. From the experience with our tank prototypes, we found that external battery sources and circuit components such as MOSFETs, H-Bridges, and additional resistors are useful in achieving a wide range of launching mechanisms. Because ME 250 students have little to no experience using these components, we also recommend that a GSI be available to assist students in the creation of their circuits.

Tank Prototypes
After manufacturing our example tank prototypes, we have come across several changes that need to be made for the final course design. We recommend shrinking the size requirements of the tank to be 7 in. by 6 in. by 6 in. to allow student teams to use CNC manufacturing processes. Our experience during testing of the tank prototypes showed us that parts may need to be assembled and disassembled several times to access the Arduino and various other components for adjustments. Because of this, we recommend aluminum be available for use for student tanks. This will allow students to thread pieces where bolts will need to be moved often, and have the material withstand this movement. The addition of aluminum as a material for students will require that tools (for the mills and lathes) be purchased for the CNC machines in the CNC shop to accommodate the new material.

SUMMARY AND CONCLUSIONS

We have been challenged to redesign the project and other course materials for ME 250 (Design and Manufacturing I) at the University of Michigan. Our sponsor, Professor John Hart, believes that this class would benefit from a project that incorporates an end of semester competition, moving parts, additional tools and materials, and that allows students to develop a creative design. Our research into engineering education supported his conclusions. It showed that design courses early in engineering curriculum deepen students' interest in engineering. In addition, research shows that it is beneficial to use creativity and analysis together in the design process. A project that meets Professor Hart's requirements would give students ample opportunity to use both of these skills.

We created a QFD to relate our customer requirements and engineering specifications, quantify the specifications, benchmark the schools researched, and evaluate concepts. Our customer requirements focus on improving ME 250 by incorporating analytical thinking through the use of moving parts and a competition. The other requirements support these tasks by ensuring that students have enough time to complete the project, the lectures provide any technical information they need, and safety is a priority throughout the course.

Our team began the process of generating concepts for the project competition and a supporting lecture schedule. We created nearly 50 ideas that could be divided into multifunctional, projectile, race, strength, and survival categories. We analyzed these concepts according to their feasibility for both our team and ME 250 students, and their compliance with the customer requirements. After this analysis, we determined that Tank Wars was the best concept. For this project, each team builds a tank prototype to mount on top of an already assembled tank platform that drives side to side in between a road barrier. The battlefield involves a hill with buildings made of stacked balsa wood blocks representing a city. The tank prototype is required to aim and fire a foam ball at an opponent's city. An Arduino control system will be mounted onto the tank platform, and the teams will be required to program the Arduino to enable the tank to drive, aim, and fire.

To develop the lecture schedule, we looked at lectures used at all of the universities we researched. We then evaluated how these lectures fit into our customer requirements and used them to build two different lecture schedules and one lab schedule. We created a schedule in which every lecture provides a portion of the information students need to complete the project.

We were able to successfully manufacture our battlefield and two tank prototypes, and program the Arduino to perform the desired functions. Upon completing this, we finalized the tank design specifications, student material kit, and Tank Wars competition rules. The student material kit consists of various materials that cover a wide range of potential firing mechanisms and additional material can be added to this kit as deemed necessary by the professor. Furthermore, we want to give each team an additional budget to purchase parts not found in the provided material kit.

The Winter 2009 ME 250 student feedback verified that our project would be successful in an actual ME 250 class. Students responded positively that Tank Wars is a more interesting project than past semester projects, and allows students to maximize their creativity. In addition, students felt that while Tank Wars is more complex and challenging, they believed they could successfully produce a tank prototype assuming the necessary material was taught in lecture.

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Professor John Hart – The University of Michigan
Professor Gregory Hulbert – The University of Michigan
Dan Johnson – The University of Michigan
Professor John Marshall – The University of Michigan
Chandresh Mehta – The University of Michigan
Ryan Morrow – Student at MIT
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Professor Jim O'Brien - Villanova University
Ben Peda - Instructables
Professor Kazuhiro Saitou - The University of Michigan
Professor Joe Shepherd - CalTech
Kaushik Gurunathan Subramanian - The University of Michigan

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APPENDIX A.1: UM WINTER 2009 ME 250 SYLLABUS

ME250 Design and Manufacturing I
Course Syllabus

Lectures

Tues and Thurs, 1:30 p.m. – 3:00 p.m. in 220 Chrysler (Chesebrough Auditorium)

Labs

Mon and Wed, one-hour sections (select one) beginning at 9:30 a.m. in G019 Auto Lab (CAD laboratory) and in 1131 GGB (CNC laboratory).

Instructor

Professor Kazuhiro Saitou
Office: 3211 EECS
Email: kazu@umich.edu
Phone: 763-0036
Office hours: Mon 3:00-5:00 pm

Graduate Student Instructors

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bradenc@umich.edu	lavalley@umich.edu	mehtacr@umich.edu	hyunpark@umich.edu
Office hours: TBA	Office hours: TBA	Office hours: TBA	Office hours: TBA

Unless otherwise stated all GSI office hours will be held in G019 Auto Lab before Spring Break and 1131 GGB after Spring Break.

Course objectives and outcomes

https://me-web2.engin.umich.edu/zope/abet/printviewprofile?catNumber=250

Course packs

The lectures will follow ME250 course packs (required) which will be available at Dollar Bill Copying. Lecture PPTs and supplementary materials will be posted at course CTools site MECHENG 250 001 W09.

Grade breakdown

Exam I	20%
Exam II	20%
Lecture homework	15%
Lab homework	15%
Project	30%

Lecture and lab homework

Late homework will not be accepted. Lecture and lab homework are to be completed on your own unless specified as group assignments. This means:

- You are not allowed to sit together and work out the details of the problems with anyone.
- You are not allowed to discuss the problem set with previous class members, nor anyone else who has significant knowledge of the details of the problems set.
- Nor should you compare your written solutions, whether in scrap paper form or your final work product, with other students (and vice versa).
- You are also not allowed to possess, look at, use, or in any way derive advantage from the existence of solutions prepared in previous years.

Violation of this policy is grounds for the Instructor(s) to initiate an action that would be filed with the Dean's office and would come before the College of Engineering's Honor Council. If you have any questions about this policy, please contact the Instructor(s).

Project

The course project is on design and manufacturing a simple mechanical product using CAD software and CNC machining, done by a team of 4-5 students. The project deliverables are a prototype (15%), a 2-minute video clip (5%), and a final report (10%). Details of the project deliverables will be provided separately. No late submission will be accepted.

Since team activity is an essential part of this course, you will be asked to submit a peer evaluation sheet at the end of the semester, in order to evaluate participation of each team member (including yourself) to project activities. Peer evaluation form is available on the course Ctools site.

Lab safety

Safe use of the ME 250 lab facilities and equipment is a primary concern and responsibility of ALL users. Everybody is expected to follow the safety and equipment procedures without fail. If these procedures are not followed you may not be able to use the lab facilities.

- Everybody without exception must undergo the shop and safety training to work in the ME 250 Lab. Contact Mr. Bob Coury (hornet@umich.edu) for further information.
- SAFETY GLASSES ARE A MUST AND ARE REQUIRED UPON ENTRY OF THESE LABS. They can be bought at most hardware stores.
- Proper attire is required. Some types of clothing that will NOT be suitable are
  - Open shoes and sandals
  - Loose flowing garments that may catch in a machine
  - Shorts or dresses less than full length
- Keep the work area clean and report any damaged, broken or unsafe tools to GSIs.

Schedule (subject to change)

Lec #	date	topic	HW due
1	01/08/09	Course Introduction, CAD lab issues, Safety Training	
2	01/13/09	Orthographic views	
3	01/15/09	Orthographic views	
4	01/20/09	Pictorials	HW#1
5	01/22/09	Pictorials	
6	01/27/09	Sectional views	
7	01/29/09	Tolerances	
8	02/03/09	Material selection; semester project	HW#2
9	02/05/09	Material selection	
10	02/10/09	Gears	
11	02/12/09	Gears	
12	02/17/09	Exam I Review	HW#3
	02/19/09	***Exam I – in-class. Rooms TBA***	
	02/24/09	**Spring break**	
	02/26/09	**Spring break**	
13	03/03/09	Electric motors	
14	03/05/09	Electric motors	
15	03/10/09	Machining processes	HW#4
16	03/12/09	Machining processes	
17	03/17/09	Machining processes	
18	03/19/09	Polymer shaping processes	
19	03/24/09	Polymer shaping processes	HW#5
20	03/26/09	Polymer shaping processes	
21	03/31/09	Metal forming processes	
22	04/02/09	Metal forming processes	
23	04/07/09	Rapid prototyping	HW#6
24	04/09/09	Micro/nano-fabrication	
25	04/14/09	No class – project work	
26	04/16/09	Exam II Review	
	04/18/09	Prototype demo (tentative)	prototype
	04/21/09	***Exam II – in-class. Rooms TBA***	
	04/24/09		final report & video

APPENDIX A.2: UM WINTER 2009 ME 250 COURSE SCHEDULE

Schedule (subject to change)

Lec #	date	topic	HW due
1	01/08/09	Course Introduction, CAD lab issues, Safety Training	
2	01/13/09	Orthographic views	
3	01/15/09	Orthographic views	
4	01/20/09	Pictorials	HW#1
5	01/22/09	Pictorials	
6	01/27/09	Sectional views	
7	01/29/09	Tolerances	
8	02/03/09	Material selection; semester project	
9	02/05/09	Material selection	HW#2
10	02/10/09	Gears	
11	02/12/09	Gears	
12	02/17/09	Exam I Review	HW#3
	02/19/09	***Exam I – in-class. Rooms TBA***	
	02/24/09	**Spring break**	
	02/26/09	**Spring break**	
13	03/03/09	Electric motors	
14	03/05/09	Electric motors	
15	03/10/09	Machining processes	HW#4
16	03/12/09	Machining processes	
17	03/17/09	Machining processes	
18	03/19/09	Polymer shaping processes	
19	03/24/09	Polymer shaping processes	HW#5
20	03/26/09	Polymer shaping processes	
21	03/31/09	Metal forming processes	
22	04/02/09	Metal forming processes	
23	04/07/09	Rapid prototyping	HW#6
24	04/09/09	Micro/nano-fabrication	
25	04/14/09	No class – project work	
	04/15/09		**video**
26	04/16/09	Exam II Review	
	04/18/09	Climbing test	**prototype**
	04/21/09	***Exam II – in-class. Rooms TBA***	
	04/24/09		**final report**

APPENDIX A.3: UM WINTER 2009 ME 250 PROJECT DESCRIPTION

ME250 W09 Project
Self-Propelled Miniature Vehicle Design and Manufacture

1. Objective

The objective of this project is twofold: to improve your appreciation of the capabilities and limitation of basic machining processes -- turning, milling, and drilling -- through hands-on experience with CNC machines; and to exercise your ingenuity in designing, building, and testing a device that meets prescribed functional specifications using only limited resources. After the completion of the project, you will gain an experience in working as a team to solve an open-ended engineering design problem, and to deliver a manufactured product by a specified deadline.

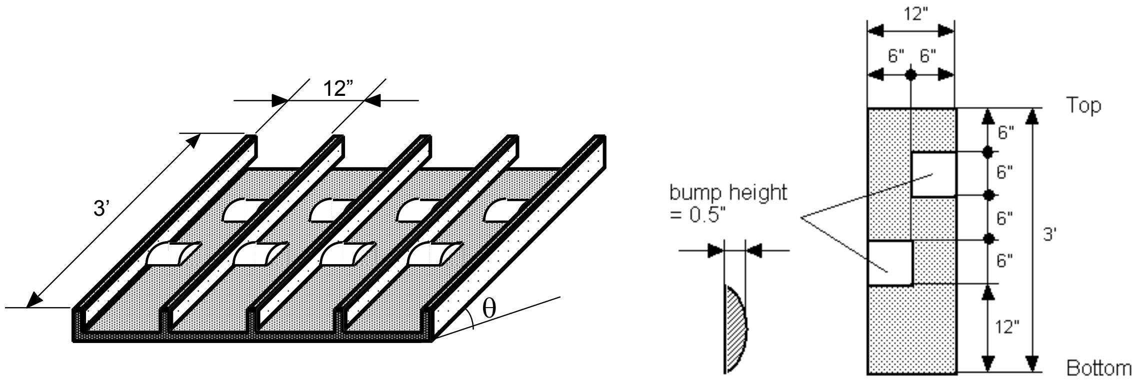
2. Design specifications

You are requested to design and build a self-propelled miniature vehicle capable of climbing up an inclined plane in accordance with the following specifications:

- It must use and carry the supplied DC motor, gear box, battery holder and switch.
- It must have at least two rims for the wheels and a chassis made of PVC or epoxy using ME250 CNC lathes and mills.
- It must not use off-the-shelf wheels, tires and/or rims, such as the ones for toy cars, either as they are or modified.
- It must use only two non-rechargeable, Alkaline AA batteries as energy supply.
- It must not use adhesives (eg., tapes or glues) to contact the inclined plane or side walls.
- It must not damage or otherwise alter the surface of the inclined plane.
- It must fit in the interior of an 8” X 6” X 5” box for shipment purposes
- It must stay within the designated 12” wide lane during the climbing (can contact side walls).
- It must be aesthetically pleasing to satisfy demanding customers

Each team's vehicle will be evaluated by means of a sequence of climbing tests on a special test rig, whose schematic is shown in Figure 1 (a). The test rig is an unfinished plywood board with an adjustable angle of inclination, divided into four lanes separated by side walls --- it is designed to test four vehicles simultaneously. The overall length of the lane is 3 feet and the width of each lane is 12 inches. On each lane, there are two bumps with 0.5 inches in height made of plywood pieces attached on the lane as shown in Figure 1 (b).

The slope of the inclined plane is not specified a priori -- rather, you are requested to design a vehicle that can climb a slope *as steep as possible* . Accordingly, each vehicle will be tested at the increasing slope angles $\theta = 10^o$, 20^o, 30^o, … The speed at which the vehicle climbs the slope is also a design target. Among the vehicles that succeed in climbing the specified distance up a given slope, those that do so in the shortest time will receive the highest score. See Section 5 for detail.



(a) (b)

Figure 1: (a) schematic of the test rig for climbing tests; (b) sizes and locations of the bumps on a lane.

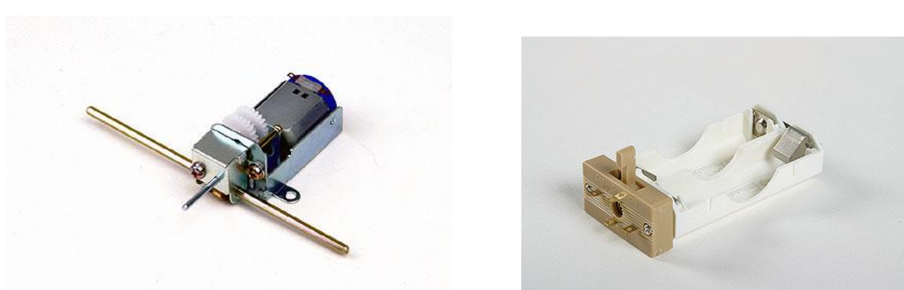
3. Supplied items

Each team will be supplied with the following components:

- Gear box and a DC motor (see the attached sheet for the specs)
- Battery holder for 2 AA cells with switch

Figure 2 show the photos of these items. The gear box can achieve 3 different reductions among 101:1, 269:1, and 719:1, depending on the chosen gear combination (details are given in the instruction pamphlet). The gearbox kit contains many small parts --- do not lose any of them: you will be required to purchase your own replacements!

You must manufacture the rims of the wheels and the chassis of your vehicle using ME250 CNC lathes and mills. The designs of rims and chassis are unspecified to facilitate creative design of your vehicle, and they can be produced by machining PVC stocks or epoxy and wax molding. PVC stocks in several shapes/sizes, Wax blocks, and epoxy will be supplied in ME250 CNC lab. See the PDF document called “ME250_Manufacturing_Info.pdf” for additional information about the materials and tools available in CNC lab.



(a) (b)

Figure 2: (a) DC motor and gearbox; (b) AA battery holder and switch.

In addition to the above supplied items, unlimited quantities of any of the following materials may be used: paper or cardboard, wood, metal, plastic or other synthetic materials, and various fasteners (nails, wood screws, bolts & nuts, glue, and adhesive tape). Note that you cannot use glue or adhesive tapes on any surfaces that contact the test rigs. You may also use basic machine elements such as springs, bearings and shafts. If in doubt about the suitability of any items, consult the instructors. You must purchase (or scrounge) these additional materials yourself, and you must supply your own batteries. The maximum allowed cost for the project excluding the cost for the supplied items is $40.00, and you are requested to include the receipts of the all purchased materials in your final report.

4. Design and manufacture

Do not rush into building your vehicle! A successful design requires careful pencil-and-paper consideration of issues such as power, torque, gear ratio, speed, weight, stability, friction, etc. You will be required to incorporate such an analysis in your project report: we need to see evidence that your success (or lack thereof) results from engineering insight, not dumb luck! The following is a suggested process for designing and manufacturing your vehicle.

Concept generation

You should start with the concept generation phase, wherein each team member generates several different design concepts that address the given specifications. Draw sketches (without details) of each of your concepts, and examine how well you think they will achieve the desired functional goals using back-of-he envelope calculations if necessary. Examine also how easily each concept can be realized with low cost in terms of materials, fabrication and assembly. Finally, select the best concept, or choose a hybrid incorporating the best features of several concepts.

Detailed design

Next, the detailed design of the selected concept should be performed, where you are to develop complete specifications and expected performance figures for your design -- include all dimensions materials, and fabrication and assembly methods.

Since building and testing a prototype is often very costly and time-consuming in real-world engineering design, designers perform very careful analyses to facilitate rational decisions on the details of the design. Although this is not the case for your miniature vehicle, you are also requested to perform the analyses of the design on paper, before building and testing a prototype. Wherever appropriate, use the analysis and evaluation methods discussed in class. Note that analyses are to facilitate your design decisions -- your report must include both the analyses and the design decisions resulting from the analyses.

Choice of materials, and fabrication and assembly methods must be specified to complete the detailed design. Note these choices will significantly impact not only the performance of the vehicle, but also the cost and time to manufacture the vehicle. Although you may choose to purchase some components off the shelf if necessary, you are encouraged to fabricate the components yourself from raw materials.

Accordingly, preferences will be given to the vehicles which exhibit ingenious use of raw materials and significant efforts in component fabrication.

Manufacturing and testing

Once you feel that you have a satisfactory detailed design and manufacturing plan, a prototype device may be built. The test rig will be available for the preliminary testing of the prototype prior to the scheduled climbing tests. Depending on the performance of the prototype, you may need to redesign and rebuild the device. Since you will almost certainly face a severe time-pressure toward the end of the semester, a careful planning on manufacturing methods and schedule will be the key to success of this project.

5. Grading

The project deliverables are a prototype (15%), a 2-minute video clip (5%), and a final report (10%).

Prototype

The vehicle you construct will be graded according to the following criteria:

- Climbing test results: 6%
- Design ingenuity including creative use of materials: 3%
- Efforts in component fabrication: 3%
- Craftsmanship and aesthetics of construction: 3%

Climbing tests of your vehicle with the test rig will be performed in the EECS atrium on Saturday, April 18. The detailed time schedule of the tests will be announced in the class. It is expected to be a half-day event. At least 2 members of your team must be present throughout the testing schedule (you may stay around to spectate, and cheer or jeer the other teams, for as long as you wish). Four teams at a time will run at each angle: teams 1-4 first, then 5-8, then 9-12, etc.. Prior to the climbing tests, each vehicle will be placed in a box of size 8” X 6” X 5”, to see if the dimensional specifications are met. All vehicles must fit in this box in order to enter the climbing tests.

The tests will be performed at the increasing slope angles $\theta_1 = 10^\circ$, $\theta_2 = 20^\circ$, …, with a maximum time t_{max} = 40 seconds allowed for each test. If t_k is the time taken to climb the ramp inclined at angle θ_k, k = 1, 2, …, your overall performance will be measured by the composite index:

$$SCORE = \sqrt[4]{\max\{0, c_{max} - c\}} \times \sqrt[2]{\sum_{k=1}^{n} \theta_k \times \max\{0, t_{max} - t_k\}}$$

where c and c_{max}= 40.00 are the total cost of the vehicle (excluding the cost for the supplied items) and the maximum allowed cost, respectively. Note that $t_k = \infty$ if the vehicle does not reach the end of the ramp at angle θ_k within the time t_{max}. A maximum of two gentle sideways taps to your vehicle are allowed to cure collisions with side walls of the test ramp. At each angle θ_k, we will take t_k to be the smaller value achieved in two independent runs.

Video clip

Each team will submit a short video clip that demonstrates the key features of your prototype. Start the video with a quick introduction of group members. Thereafter, explain features of your vehicle including design intent, material use, and manufacturing processes. The video should be no longer than 2 minutes. If your video is longer than 2 minutes, then we will not play it at all. The video clip will be graded based on the following criteria:

- Presentation content (what are presented in the video): 3%
- Presentation quality (how they are presented): 2%

The video can be created using a device of your choice, such as Digital Camera, Camcorder, etc.. However, the video should be submitted in one of the following file formats: .asf, .avi, .m1v, .mp2, .mp2v, .mpe, .mpeg, .mpg, .mpv2, .wm, and .wmv. Also, your video must play on the Windows Media Player that is installed on a CAEN computer.

Final Report

The final report gives detailed descriptions of your manufactured vehicle. View this report as a complete documentation of your product (i.e. vehicle) so that someone else can duplicate your vehicle by referring to the report. See the report template project_report_TOC.docx for details on the report contents.

Massachusetts Institute of Technology

Syllabus & Schedule

2.007 Design & Manufacturing I

Prereq: 2.670, 2.001
Spring 2008
3-4-5

Introduction

2.007 is a student's chance to use the material from 8.01 and 2.001 to turn their creative ideas into a robust working machine! This is what engineers do and it's the student's chance to demonstrate their engineering prowess! A student's grade is based on how well they meet weekly milestones (documented with a design notebook), a substantial mid-term closed book exam, the quality of their machine's engineering and manufacture, website and written final reflections. The real grade, however, comes from the better job offers the student is likely to get when they show off their design notebook, website and machine at job interviews!

2.007 teaches a creative design process, based on the scientific method, with lectures and the creation, engineering and manufacture of a remote controlled machine to compete in a major design contest (celebration) at the end of the semester. Students learn to identify a problem (opportunity!) and create, develop and select best strategies and concepts using fundamental principles, appropriate analysis and experimentation. Students then divide their best concept into modules and after developing the most critical modules first in descending order of criticality, proceed to system integration, testing and debugging. Project and risk management are introduced as tools to keep the development process under control in order to deliver a robust working machine <u>on</u> <u>time</u> and <u>on</u> <u>budget</u>. Fundamental principles are emphasized including Occam's razor, Abbe Errors, Reciprocity, Saint-Venant's Principle, Sensitive Directions, Self-Help, Centers-of-Action, Structural Loops, the Golden Rectangle… The physics and application of machine elements to enable students to create and engineer their machines are introduced by lectures (pre-recorded), the text and in-class examples. Throughout the course, engineers' professional responsibilities are stressed. Students are assumed to be competent at parametric solid modeling, spreadsheets or MatLab and basic machine shop skills. Educational, reference and design assistance materials are provided on-line to enable students to learn as much as they want/need whenever they want/need.

2.007 this year:

1. The first half of lectures will assume the reading assignments in the FUNdaMENTALS book have been done by the students before class and lecture will thus be for a) answering questions on the readings (students can drop their questions in a box at the front of the class as they enter, or ask them out loud); b) doing engineering design examples (e.g., proof of concept calculations and using the methods taught in the FUNdaMENTALS book.

2. The second half of the lectures will be for realistic sketching and solid modeling the concepts shown to be viable in the first half of lecture (as opposed to quick stick figure

concept sketches needed to get the idea across so the engineering design analysis can be done). Students will be expected to "sketch along" and turn their sketches in at the end of class into lab-section marked bins. Participation in this active learning can thus also help a student's grade as well as help the student to become a better design engineer.

a. **Important** – **by the 1st day of class**: The drawing and visualization part of 2.670 is being woven into 2.007 this year; hence it is vital that by 11:00 AM February 7th, as part of the units you receive for 2.670, each student must be familiar with SolidWorks. Go to the ME server. Download and install the software. https://meche.mit.edu/resources/computing/software/ (certificates required)
   Do the self-taught tutorial so you will be familiar and reasonably competent with the program, (basic parts and assemblies). Much more detail will then be taught in 2.007 lectures, so bring your laptops to lecture!
b. **Special SolidWorks Training Sessions**: Feb. Wed. 6th and Thurs. 7th, 15:00-17:0 and 19:00-21:00 in Bldg. 35's Ralph Cross Lab.
   i. All four 2-hour sessions will be identical; please come to whichever is convenient.
   ii. These are optional but recommended! By special arrangement, Marie Planchard, SolidWorks' Director of Education Marketing is donating her time.
   iii. If you have a laptop, bring it with SolidWorks loaded. The training files are available at http://pergatory.mit.edu/2.007 and should be downloaded before hand.

By Popular Request, returning to 2.007 this year:

1. A substantial mid-term exam on Topics 1-10 that will be given in-class on **Thursday March 20** SO DO NOT BE LATE FOR CLASS AND MAKE SPRING BREAK PLANS ACCORDINGLY. THERE IS NO MAKE UP EXAM (folks with official MIT events like sports will of course be accommodated, please see Prof Slocum).
2. Students do NOT have to be in their assigned lab section for the entire 4 hour period. Students will form 4 person Peer Review Teams and each team need only schedule one hour per week to meet with their lab instructor. Students can then design and build their machines anywhere/anytime they want/can. 2.007 instructors will be on-call in the Pappalardo lab every afternoon 1-4:30 pm for consultation (you can ask for help from any instructor).

Course Objectives (learning outcomes)

The objective of the course is to enable students through lecture and hands-on experience to:

1. Learn a ***design process***, based on the scientific method, to combine creative thinking with engineering principles (physics) to turn ideas into robust reality:
   - Identify a problem (opportunity!).
   - Use ***FUNdaMENTAL*** principles and ***appropriate analysis*** and ***experiments*** to generate, select and develop ideas
   - Generate & create ***strategies*** for solving the problem
   - Generate & create ***concepts*** for implementing the selected "best" ***strategy***
   - Break the ***concept*** into ***modules*** and develop the ***most critical module*** first

- Complete the detailed engineering design of the ***modules*** and manufacture, test and debug them
- Integrate ***modules*** and test, debug and modify the system as needed
- Document the results (closing the design loop)
- Operate their machine in a final celebration with other students and their machines
- Reflect on the above process with respect to what worked and didn't and why and what would be done differently next time

2. Effectively utilize fundamental design principles, machine elements and manufacturing and assembly techniques
3. Assess risks, develop countermeasures and manage projects to be "on-time" and "on-budget"
4. Develop visual thinking (and drawing skills)
5. Practice professionalism, be safety conscious and maintain high ethical and professional standards

Practicing designer engineers often follow this type of systematic process; and they receive raises, responsibility and reflect well on themselves and their profession. Bad designers are of little use to anybody. A bad designer:

- Has no respect for project management and thinks they can just cut-&-fit on the fly.
- Thinks they can see it all in their head and does not need to sketch, test and plan.
- Works late hours the night before the due date to produce something.
- Gets at best a "D" in 2.007, regardless of how they do in the contest (history has shown they will do poorly)

2.007 is about learning a process for design by systematically engineering and building a machine. It is NOT a course about just building a machine based on what you already think you know in order to compete in the contest. Without knowing a process of design and fundamental principles, you will not be able to compete on real design projects in the real world and your job will be outsourced!

Instructor in charge:
Alexander H. Slocum,
Pappalardo Professor of Mechanical Engineering, MacVicar Faculty Fellow
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Gertsen, Bob	Technical Instructor, no email Room 3-050, 617-252-1538
Guerrero, Julio	Section Instructor, jguerrero1@slb.com Schlumberger-Doll Research, 617-768-2198
Habarek, Steve	Technical Instructor, smhabere@mit.edu Room 3-046, 617-252-1538
Hanumara, Nevan	Section Instructor, Head TA, Webmaster hanumara@mit.edu, Room 3-470, 617-258-8541
Katsikopoulos, Konstantinos	Section Instructor, katsikop@mit.edu Room 3-449G, 617-258-8114
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Meeker, Dave	Section Instructor, meeker@mit.edu Room 3-470
Neeley, Lawrence	Section Instructor, neeley@mit.edu Room 3-436, 617-258-9490
Nuttall, Robert	Technical Instructor, nickie@mit.edu Room 3-033, 617-258-6993
Riskin, Noah	Technical Drawing Instructor, nriskin@mit.edu Room W31-120, 617-258-0330
Sclavounos, Paul	Section Instructor, pauls@mit.edu Room 5-320, 617-253-4364
Slocum, Alex	Instructor-in-Charge, slocum@mit.edu Room 3-445, 617-253-0012
Tubilla Kuri, Fernando	Section Instructor, ftubilla@mit.edu Room 35-136, 617-308-7020

Webpage and e-mail lists (official course business ONLY)

http://pergatory.mit.edu/2.007/
2.007-all@mit.edu - E-mail Entire Class
2.007-staff@mit.edu - E-mail Instructors
2.007-court@mit.edu - For any questions regarding the contest rules
2.007-uas@mit.edu - E-mail UA's

2.007-secN@mit.edu (N= 01 to 13) - E-mail Your Section

The Textbook, which incorporates the lecture notes, (*FUNdaMENTALS of Design*) will be posted on the course website, along with a LOT of other information that can help you design your machine. Students should look to the website for notices and look through the web site and find the goodies that are placed there! This is excellent training for the real world!

Text Book

The textbook (*FUNdaMENTALS of Design*) is on-the course website. You will also find your 2.001 text extremely useful! Reference books (e.g., Machinery's Handbook) are available in the Pappalardo Lab.

- **Incredibly useful handbooks every practicing design engineer should own:**
  - Machinery's handbook, Industrial Press
    Available online at MIT if you have a certificate:
    http://www.knovel.com/knovel2/Toc.jsp?SpaceID=10110&BookID=309
  - R. J. Roark, W. C. Young, Formulas for Stress and Strain, McGraw-Hill Book Company
- **Suggested readings for those who are interested in the process of design include:**
  - G. Pahl and W. Beitz, Engineering Design, A Systematic Approach, Springer-Verlag, New York, 1988
  - N. P. Suh, The Principles of Design, Oxford University Press, New York, 1990
- **For students interested in hardware details:**
  - Shigley, J. E., Mitchell, L. D., Mechanical Engineering Design, McGraw-Hill Book Company, New York 1983.
  - Slocum, A. H., Precision Machine Design, Society of Manufacturing Engineers, Dearborn, MI., 1995

Lectures

Tuesday and Thursdays in Room 1-190, 11:00 a.m. – 12:30 p.m. Lectures on the Course Topics have been pre-recorded and a DVD will be provided to each student. The DVD includes pdfs of the lecture notes and spreadsheets that should be useful. The lecture notes will not be printed and handed out.

Students are expected to watch the pre-recorded lecture on a topic and read the notes BEFORE the topic is scheduled for in-class discussion. In class, the focus of the lectures will be "designers in action" using the material that is in the lecture, so the student needs to be familiar with the material before lecture. See the attached schedule for lecture topics. The course closely follows the schedule! Lectures only last through March 23rd so come to them and learn!

It is highly advisable for students during the first week when not much is due, to watch all the lectures, so the student can become preloaded with course knowledge which will help them early-on to develop their machines.

Recitation

There is no formal recitation. 2.007 students are to arrange additional meeting time with their lab instructors as needed. Prof. Slocum will generally be available after class. Please e-mail him if you want to confirm a specific meeting time.

Labs

2.007 students are assigned by the registrar to a lab section from **1-5:00 pm** M, T, W, R. The labs are only scheduled in the afternoons and they are 4 exciting hours to give students more scheduled build time:

- Students in a lab section will be divided into groups of 4 to form peer-review groups which will be responsible for reviewing each others' work before it is turned in for weekly evaluation by the section instructor. Each peer review group will then meet with their section instructor once per week for about an hour to review their work.
- Students thus do not need to be in lab for the entire 4 hours, they only need to meet with their lab section instructor in their peer-review group when scheduled. It is critical that students do not miss their weekly meeting time with their lab instructors.
- It is assumed that students are responsible enough to schedule their time, such that if they cannot be in the lab for a four hour period on their scheduled lab day, they will come to the lab at another time (preferably in the morning hours when the lab is not crowded).
    - There will always be 2.007 instructors in the lab in the afternoons and many UAs too and students should feel free to ask any instructor or UA or lab technician for advice!
- We will experiment with in-lab quizzes on safety and how-to-do-stuff.

Labs start the second week of class in the Pappalardo Lab, BUT you must get your kit and locker assignment as directed in the first lecture or you will be bumped from the class!

- Your 2.670 toolbox is your "passport" to getting into the lab. Bring it and put it in your locker!
- There are no scheduled weekend or evening hours for the shop!
- The Pappalardo Lab opens at 8:30 AM and closes at 4:30 PM, so create a normal working person's schedule! Students may not skip other classes to spend extra time in the lab.
- Use the early mornings when the lab is not crowded. Accomplish a little bit each week according to schedule! If you "wait until the last minute", you will fail (D and lower grades are indeed "earned" by students who try and do everything at the last minute, even if their machines work) not only in 2.007, but also in the real world!
- You are free to use another shop if you have access to one.
- *Most of lab time should be for you to explore ideas by creating hands-on experiments. Instructors will spend little time "leading the group." Your instructor is your coach, advisor and mentor.*

Sections

It is important for students to realize that each instructor is responsible for their own section. This means that much of the organization of the class is very decentralized and instead in control of lab section leaders. As a result, assignments and expectations may vary somewhat between sections. Furthermore, the schedule that has been laid out above is only a guideline. For example, many Monday lab sessions interfere with holidays, often throwing off their schedules. As a result, even the major assignments (ex. Milestones and Milepebbles) may be due in different weeks depending on your section. If you have any questions as to what is due, or what expectations are for each assignment, **ask your TA**. If you ask peers or TAs outside of your section you risk receiving faulty information.

Changing your lab section

This year's new system of peer review groups who meet weekly with their lab instructor and then students are on their own to come to lab whenever they wish to work on their machines; this means there should be no need to change lab sections! In the first lab section, peer review groups can form according to schedule compatibility. This said, lab section changes will only be possible in the case of a severe conflict.

Safety

You **MUST** wear safety goggles or safety glasses (polycarbonate eyeglasses are fine) and closed-toed shoes at ALL times in the Pappalardo lab. Violators will be asked to leave immediately and not to return until outfitted appropriately. Tie your hair back and take off your jewelry before coming to class.

Ethics & Professionalism

As in the real-world, unethical and unprofessional behavior will NOT be tolerated. When in doubt, ask any staff member for guidance! Nevertheless, every student must write their name in several places on their critical components (especially drills and batteries!) as critical components have been known to get "lost". If you have a problem or see a potential problem brewing between others in lab, please let an instructor know as soon as possible Do not let things fester! (yet try to work things out with your peers).

Contest Kits

Contest kits and lockers will be given out between 12:00 and 3:00 PM after the first lecture in the Pappalardo Lab. There are a lot of materials required for 2.007, but due to the fantastic generosity of our corporate sponsors, there is **no lab fee for consumables** and you get to keep your machines at the end (including the motors used on your machine)! You must bring your 2.670 toolkit to lab, as you will need it. Your kit will be in your locker.

One of the most common operations in the shop is drilling a simple hole and every student is provided with their own cordless drill kit. This will greatly increase productivity. The power supply for your machine will be ONE battery from the drill and it is your responsibility to keep it charged.

Write your name on all your kit contents!

Your first action with your kits is to write your name on the drill, motors and critical items! Keep components locked up. If you lose anything you need to buy your own replacement! Consumable materials will be replaced by UA's provided justification is given for their consumption.

Equipment Charge - $120 to be paid the 1st day of class when collecting kit

Payment via *Cash* or *Check* made out to MIT Mechanical Engineering.

This nominal fee is assessed to cover the cost of your drill, calipers and teaching materials, which are yours to keep. **You will not receive your kit without payment**. Consider this an investment in your future!

Design Notebooks and a personal 2.007 website

Like any good engineering project, 2.007 runs on a schedule! As you develop your machine, you MUST keep a ***Design Notebook***, which will be an important part of your grade. (on course website see *Guide to Lab and Design Notebooks*). Ideally, this is a bound (spiral is OK) book in which you do all your sketches, calculations (printouts can be pasted in) etc. This notebook is a complete diary of what you did to create your machine. We recognize that you may also want to keep other 2.007 materials in it as well, so a 3-ring binder is OK, but it would be better to get in the industry groove and keep a real notebook. Make sure to date each entry. In the real world, this is a critical document, especially if the need arises for intellectual property litigation, or product liability. In 2.007, bring your Design Notebook to lab each week. Your instructor will want to see your Design Notebook each week to check on your progress (how well you meet milepebbles and milestones) and to see how well your PEER Review Evaluation Process is being done. You will create spreadsheets, solid models… and these can be printed and pasted in your design notebook.

It is also ***strongly suggested*** that each student create a personal 2.007 website (use your own Athena space), which is also a good place to post milestone reports as well as the details of your machine development. Ideally each week you would summarize progress made and post it on your website. You can even just scan in pages from your design notebook. Having an up-to-date website will also help your instructor. At the end of the class, the website will become your first portfolio entry. Having a quality portfolio is great asset for job interviews!

Milestones and MilePebbles

Milestones are major events were significant pieces of work have been completed. The major milestones for this course are:

1. Final strategy (4-6 pages: overall description, FRDPARRC sheet, pictures of sketch models, sketches, scoring calculation, appropriate analysis, description of bench level experiments).
2. Final concept (4-6 pages: overall description, FRDPARRC sheet, pictures of sketch models, sketches, appropriate analysis (e.g., time to move, power budget), description of bench level experiments, preliminary solid model).
3. Demonstration of most critical module; and MCM detailed engineering report (overall description, 4-6 pages: FRDPARRC sheet, pictures of sketch models, sketches, appropriate analysis, picture of module, solid model).
4. Assembly and integration of all modules (3-5 pages per module: overall description, Solid model of machine and part drawings, critical calculations).
5. Demonstrate working machine (3 pages: overall description, Picture of machine and a critical analysis of what works and what does not work and why and how to fix it or what countermeasure you will now implement. Describe plan for remainder of shop build time).
6. Reflection (4-6 pages: Self-evaluation of machine performance in final contest (what did and did not work and why) and what you would do differently next time.) Final lab notebook check off, follow-up.

These 6 milestones are to be documented in order to best allow your instructor (or anyone else) to understand how you created your machine. The documentation of your milestones can then be entered into your website which will also be of great help when you look for engineering employment!

Milepebbles are things to be done each week. Milepebbles will be evaluated by your lab instructor when you meet with them on a weekly basis.

In general, the Milestones should be brief documents approximately 3-5 pages in length (including pictures/sketches). Think of them as executive summaries of the topic at hand. The gory detail is to be in your design notebook (which if you are smart, you will periodically scan and upload to your website). Milepebbles, on the other hand, require no report; grading of milestones is based upon your lab notebook and discussion with your TAs.

Contest Preparation

The final celebration ("contest") is the ultimate 2.007 experience. It is analogous to having your product first used by a customer. Thus in preparation for the contest, you complete your engineering and building and then "check off" your machine and "ship it to the customer" (you!). This is done the final week of lab, (April 30 - May 4) when your lab instructor will schedule you to have your machine sized. In addition, during the final week, you will drive your machine by itself on the table to obtain your seeding score. The shop closes Friday, May 4. The contest will be Wednesday (first round) & Thursday (final rounds) evenings, May 7 & 8.

Grading

This is very much an interactive course and you have a very low chance of passing if you do not read the textbook, come to the lectures and meet with your section instructor. Your grade is very dependent on meeting the milestones (just like in industry, your salary depends on meeting milestones). Each milestone focuses on helping you create your 2.007 machine. The mid term will help you design a better machine because you will want to know how to do real-world engineering design calculations in order to do well on the quiz!

Week	Grading Item (lab instructor will provide due date)	Points
1-6	In-lecture activity to be handed in at end of lecture (6*5)	30
1,2,4,6 10,11	Milepebbles (6*10)	60
3	Milestone 1: Final Strategy	30
5	Milestone 2: Final Concept	30
9	Milestone 3: Demonstrate Most Critical Module, MCM engineering report	30
12	Milestone 4: Assemble and integrate modules	30
13	Milestone 5: Demonstrate Working Machine, plan for remaining time	30
15	Milestone 6: Final contest, reflection, documentation	30
	In-class Exam on Topics 1-10	100
	Peer Review	30
	Machine (concept, manufacturing)	40
	Lab Notebook	40
	Website	20
	Total:	500

Grade	>%	>pts	Performance Level
A	85%	425	Great preparation, acting like a professional, did all the reading and did well on the mid term exam, successful implementation of design process and FUNdaMENTALS, well executed working deterministic machine design (no sloppiness such as sharp edges loose wires etc, the machine looks and functions like a real product).
B	70%	350	Usually prepared, did most of the reading, did OK on the exam, good understanding of the FUNdaMENTALS, machine works pretty much as designed.
C	55%	275	Often not prepared, did not do much reading, not too well on exam, poor understanding of FUNdaMENTALS, machine put together mostly by trial and error.
D	40%	200	The student either just doesn't care, was not prepared, or could not focus.
F			

The key to earning an "A" is not putting in long hours, the key to earning an "A" is to follow the schedule, come to class and lab and to think creatively and deterministically (e.g., can you use a spreadsheet to justify and optimize major design decisions, such as the size of a motor?). The student's grade will thus be largely based by how well the student learns the design process taught in 2.007. If you wait until the last couple weeks to "go into hyper mode", you will fail (D grades are indeed given to students who try and do everything the last few weeks of the course, even if their machines work) not only in 2.007, but also in the real world! There is NO grading curve in this class. You do not get partial credit for a plane's landing gear that opens but breaks upon impact! We hope everyone earns an "A". What do the grades actually mean in terms of your engineering capabilities?

- An "A" is for a student who could lead the design of a major product (after they get more education and experience). These students are self-starters, love to learn for the fun of it and can learn by finding and studying needed materials when they realize they are lacking in knowledge. These are also the students who create new ideas and identify tasks to be done in order to complete a project according to schedule. (Truly understands the fundamentals [analysis] and can use them to solve challenging engineering problems.)
- A "B" is for a good solid potential engineer that sometimes needs guidance, but overall can be given a task and will complete it effectively. They can usually pick things up from references as needed. (Mostly understands the fundamentals and needs some help to address challenging problems). They still do a little too much "shoot from the hip" selection of elements because they really are not that comfortable with using analysis in their design as much as they should.
- A "C" is for the student who needs a lot of direction. Some just do not understanding the material, despite trying. Some just ask a lot of questions because they rarely study or come to class or read the notes. Some expect to be spoon fed because they do not have the time to put in the effort. On a project, they must be given a specific task and solution direction instructions. (Need help to grasp the fundamentals and needs help to understand basic problems). These people may seem like they are good creative

designers, but they are afraid of analysis and do not see how to use it to select design parameters and rather than ask, they hide.

- A "D" is for the student who is never around much but might manage to get a machine to work. They never justify any of their engineering decisions (they meet no milestones except the last one) and are not part of the team (lab section). (Have you really grasped the fundamentals? Are you really ready to move on?).
- An "F" is for a no-show student that never accomplished anything and barely even tried, but likely claims to have a good excuse.

Peer Review

Students will be responsible for using the *Peer Review Evaluation Process (PREP)* for providing feedback on each other's lab Milestone reports. **You will be part of a 3 or 4 person Peer Review Evaluation Team that you are responsible for forming in your section!** Your section instructor will review the teams' comments and will give feedback to the team on how effective they are at providing constructive criticism. This is a critical part of learning to become a great engineer. As in industry, how well you critique each other's work affects your grade (see grading). When other classes let you collaborate on problem sets and projects, try using PREP!

Course Schedule

Create a schedule for all your courses and activities, noting milestone due dates, exams, etc. Use the plan as a reminder to not fall behind! If you are falling behind, you need to ask for help, but also ask yourself if you are doing TOO much! If you follow the schedule and work smart on the milestone reports, you can earn an "A" without ever having to spend an evening or a weekend in the shop. THE DESIGN PROCESS WORKS and you can also use it in other classes! 2.007 is a 12-unit course designed to be completed on time and on budget!

Lecture Schedule & MilePebbles and MileStones Due Dates

The MilePebbles and MileStones are due in the week indicated, in your lab section.

Wk	Mon.	**Tues.** 11-12:30 Room 1-190	Wed.	**Thurs.** 11 - 12:30 Room 1-190	MilePebbles & MileStones *Due*
1	**2/4 Reg Day**	**2/5** Topic 1 *Design Process,* & Topic 2 *Generating and Creating Ideas* ***Kits today only 12:30-3:00 pm In the Lab***	**2/6**	**2/7** Special lecture by Prof. Wallace - *drafting* *Lab Conflict fixing: 12:30 pm Room 1-190*	*Milepebble 1* a) Get Kit and Locker and play with kit elements and the table b) Review website and lectures c) Attend SolidWorks training session
2	**2/11**	**2/12** Topic 3 *Fundamental Principles* & Topic 7 *Force and Torque Sources*	**2/13**	**2/14** Topic 4 *Linkages*	*Milepebble 2* a) Assemble Tamiya motor gearboxes b) Download SolidWorks, see link on website b) Make sketch models of strategy ideas

					c) FRDPARRC 3 *Strategies* d) Preliminary analysis: scoring, power budgets for strategies
3	**2/18 Prez's Day Lab Close d**	**2/ 19** Monday schedule, no lecture, lab open. Tuesday lab people go to lab when they can	**2/20**	**2/21** Topic 5 *Power Transmission Elements I*	<u>Milestone 1</u> a) Start to design and build simple car b) Best *Strategy* selected & FRDPARRC'd
4	**2/25**	**2/26** Topic 6 *Power Transmission Elements II*	**2/27**	**2/28** Topic 8 *Structures*	<u>Milepebble 3</u> a) Appropriate analysis b) Bench level experiments c) 3 *Concepts* on FRDPARRC sheets d) Finish simple car
5	**3/3**	**3/4** Topic 9 *Structural Interfaces*	**3/5**	**3/6** Topic 10 *Bearings*	<u>Milestone 2</u> a) Demonstrate simple car b) Best *Concept* FRDPARRC'd and 1st-order solid model c) All *Modules* defined (ideally no more than 3)
6	**3/10**	**3/11** Topic C *Control System*	**3/12**	**3/13** Topic M: *Manufacturing*	<u>Milepebble 4</u> a) *Most Critical Module* (*MCM*) detailed engineering done so work can begin on building the *MCM*. b) Mfg plan for *MCM*
7	**3/17**	**3/18** Topic E *Ethics and Professionalism*	**3/19**	**3/20 Mid Term in-class Exam on Topics 1-10**	Work on *Most Critical Module* (*MCM*)
8		SPRING BREAK, RELAX (UNLESS behind, Lab is open all week)			
9	**3/31**	**4/1** *Check email and website for special guest "Designers in Action" lecture, otherwise work on your machines*	**4/2**	**4/3** *Check email and website for special guest "Designers in Action" lecture. Otherwise work on your machines.*	<u>Milestone 3</u> a) Demonstrate working *MCM* b) *MCM* detailed engineering report
10	**4/7**	**4/8** *Check email and website for special guest "Designers in Action" lecture, otherwise work on your machines*	**4/9**	**4/10** *Check email and website for special guest "Designers in Action" lecture, otherwise work on your machines*	<u>Milepebble 5</u> a) 2nd module complete
11	**4/14 Pat's Day**	**4/15 Patriot's Day, student holiday but lab is open**	**4/16**	**4/17** *Check email and website for special guest "Designers in*	<u>Milepebble 6</u> a) 3rd module complete b) Assemble & integrate

	Lab closed			*Action" lecture, Otherwise work on your machines*	*modules*
12	**4/21**	**4/22** *Check email and website for special guest "Designers in Action" lecture, otherwise work on your machines*	**4/23**	**4/24** *Check email and website for special guest "Designers in Action" lecture, otherwise work on your machines*	Milestone 4 a) Demonstrate good working machine b) Plan for remaining time
13	**4/28**	**4/29** *No lecture! Work on your machines*	**4/30**	**5/1** *No lecture! Work on your machines*	Milestone 5 a) In-class seeding contest, Get T-Shirt! b) Pack and "ship" machine **IMPOUND May 2**
14	**5/5**	**5/6** *No lecture*	**5/7 – 5/8** *No lecture!* **CONTEST NIGHTS! Attendance Mandatory!**		*Relax, work on reflection document*
15	**5/12-5/15 Meet in regular lab sections and review what worked and what did not and turn in Milestone 6 Reflections**				Milestone 6 a) Reflection

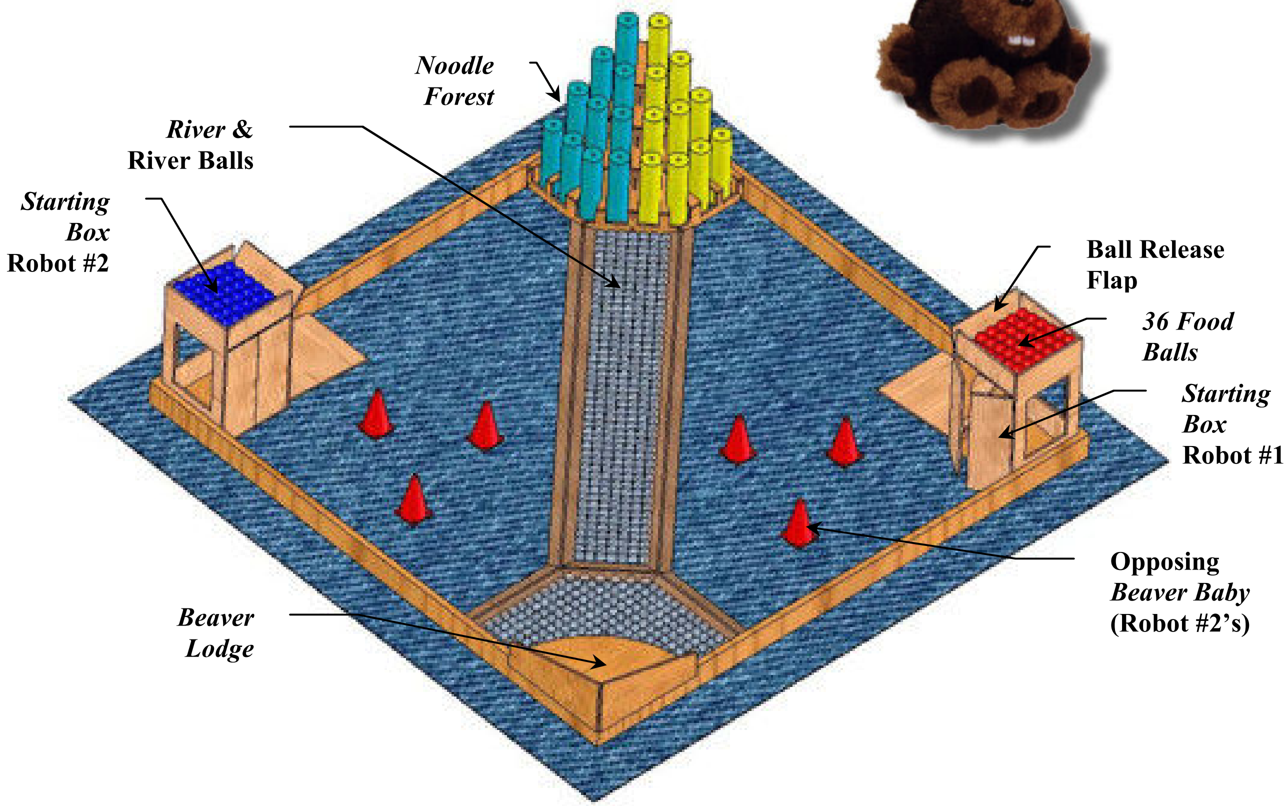
Massachusetts Institute of Technology

Table Description & Contest Rules

Da MIT- Yes MIT!

Updated: 9 March 2008

Table Description & Objectives



Your mission: Find, Feed, House & Protect your *Beaver Baby* family!

Robots begin inside the starting box with the doors closed. Once time starts, you will have 45 seconds to exit the box, make a dam and collect more food than the opposing Robot! In order to make your dam, you will need to harvest your own logs from the forest and place them in the river. You can also release *Food Balls* and collect them inside the *Starting Box* to give to your babies later! Last, but not least, you have three *Beaver Babies* hiding under cones that need to be rescued, but one of your babies is lost and has wandered off to the other side of river! Bring them all to safety by placing them on the *Beaver Lodge*. Be careful while you are on your rescue mission however, as many Robot*s* have gotten stuck in the *River*!

The fate of the *Beaver Babies* is in your hands!

Scoring

Three scoring items: ***Beaver Babies***, ***Noodle Forest***, and ***Food Balls***
Three scoring zones: ***Beaver Lodge***, ***River***, ***Starting Box***

Scoring is a function of item and location and the possible scoring tasks are listed below:

- Removing your color-coded, N*oodles* from the forest. The higher the *Noodle* removed, the higher the score. Opponent's *Noodles* will score for your opponent.
- Placing the felled *Noodles* within the *River's* environs to build a dam. If more than half a *Noodle* crosses the *River* boundaries it counts as being in the *River*. *Noodles* forming a dam are all worth the same, regardless of what level they originated from.
- Saving *Noodles* in the *Starting Box* hole.
- Collecting food balls and placing them into the *Starting Box*. *Food Balls* are located over the *Starting Box*; pulling the door down will release them. *Food Balls* may enter the box via the slot or hole, not the doors. (Note: River balls are smaller and lighter than food balls.) Each Robot may begin with up to 5 food balls onboard, but these must be re-entered through the slot or hole to be scored. Opponent's balls can be absconded with.
- Finding your *Baby Beavers* and placing them on the *Beaver Lodge* is the highest scoring activity with an exponential effect. Two of your *Baby Beavers* are located on your side of the table; one has wandered off and is located on the other side and is worth more. *Beaver Babies* and cones are color coded. *Beaver Babies* may not be removed from the *Beaver Lodge* once scored.

Crossing the *River* is only permitted once a Robot has scored at least once. This year's contest is designed to provide numerous scoring opportunities without (necessarily) having to hinder the opponent's Robot.

The scoring algorithm is as follows:

$$\text{Score} = [(N+1)(M+1)(3O+1)(2^{\wedge}P)]+25Q$$

N – number of *Food Balls* in
  your *Starting Box* – 1 pt each
M – total noodle points taken from the *Noodle Forest*
  level 1 – 1 pt
  level 2 – 2 pt
  level 3 – 3 pt
  level 4 – 4 pt

Q – noodles in the *Starting Box*
  1 point each
O – your noodle in *River*
  1 point each
P – number of *Baby Beaver* points
  in *Beaver Lodge*
  Beavers from your side (2) – 1pt each
  Beavers from opponent's side (1) – 3 pts each

In the event of a tie, the winner will be the Robot which has consumed less power, as recorded by the control interface.

Rules & Regulations

1. **Timing**
    a. Each round of the contest is 45 seconds long.
    b. At the end of a round the robots must be stopped.
    c. Judges will wait until all balls and obstacles to stop moving when the round ends, before scoring. Thus, anything in motion (e.g. rolling into a scoring bin) will be allowed to come to rest before the score is calculated.
2. **Winning & Advancing**
    a. Robot*s* start on opposite side of the table in their respective *Starting Boxes*. Failure to exit the box within 10 seconds will constitute a defeat.
    b. The starting box is sized: **16" wide x 16" deep x 23" high**
    c. Seeding rounds will be held during the lab time. Robots will compete against the table unopposed. A contestant's seed will be determined by their points scored. It is against the spirit of the rules to deliberately under-perform so as to seed lower.
    d. The highest scoring robot in each match advances to the next round. However, the top percentage (to be determined) of losers from the first round will advance into the 2^{nd} round. Each round will end with an even number of Robots advancing.
3. **Driving**
    a. Contestants must drive (control the movement of) their own Robots – **no substitute drivers**, without an excused absence.
    b. Contestants may have **one** person help drive their Robot (e.g. trigger a mechanism at a certain time, etc.) or to provide coaching at the driving podium.
    c. Contestants and Assistant Drivers must wear safety glasses when in the vicinity of the table. Only some prescription glasses are acceptable.
2. **Robot Configuration**
    a. On the day before the competition, your entire Robot must fit in the *Starting Box* with the door closed. Oversize machines will likely become stuck and expose the operator to ridicule.
    b. Machines will not be weighed this year, it is believed that overly heavy machines will self-penalize through poor performance.
    c. No energy may be stored in elastomers (e.g., rubber bands) prior to the start of the contest. Springs are not elastomers.
    d. Contestants will be responsible for charging the batteries included with their drill for the contest. Contestants may only use one battery per machine.
4. **Sporting Conduct & Safety**
    a. Wanton destruction (or overturning) of an opponent's robot, the contest table and or control equipment is strictly forbidden! Immediate disqualification will result and beavers will gnaw upon your ankles.
    b. In the case of destruction deemed by the judges to be accidental, but severe enough to unfairly influence the competition's outcome the judges may permit repairs and a rematch.
    c. Contestants (i.e. the human being) may not directly interfere with the motion of the table, machines, or control boxes during each round.

d. Any robot components or table items that depart the table will not be re-introduced to the table during a round.
e. Nets or entanglement devices and projectiles are not permitted. Multi-part Robot*s* are permitted, however until you score, all parts of your machine must remain connected together. Be careful if you create a tethered "botherbot" or barrier because if the tether prevents motion of your opponent, even if it's "their fault," you will be disqualified for entanglement.
f. Robots must be constructed using standard kit parts and using the provided controllers. Custom electronics, such as limit switches, are permitted as are special fasteners, adhesives and decorative elements.
g. NO DANGEROUS MACHINES. THE "NAKED PHONE BOOTH" RULE WILL APPLY AT ALL TIMES!

Note: These rules are subject to optimization, and may be altered by the staff to preserve the "spirit" of the contest. Changes to these rules will be posted to the 2.007 website and this document updated.

General questions may be asked of UA's and Instructors, however, direct all rule clarifications to the Supreme Court - 2.007-court@mit.edu. The Court's ruling is final.

APPENDIX B.4: MIT 2.007 MATERIAL KIT LIST

2.007 - Design and Manufacturing I

Spring 2008 Kit List

#	Picture	Q	Item Description	SW File / Info
Stock (provided in storage container)				
1		1	Plastic storage container (Rubbermaid Roughneck 14 gal 2212)	
2		1	Drill - Black & Decker 18 Volt	
3		1	Calipers - Digital!	
4		1	Black permanent marker	
5		4	Tamiya planetary gearbox kit and motor	
6		4	Plastic motor coupling	
7		1	Birch plywood square - nominally 16" x 16" x 3/8"	
8		1	6063-T6 Box Extrusion - 1" x 3" x 12" - 1/8" thick	
9		1	6063-T6 Box Extrusion - 1" x 1" x 18" - 1/8 " thick	
10		4	6063-T6 Box Extrusion - 1" x 1" x 18" - 1/16" thick	
11		1	6061-T6 Bar - 2" x 12" x 1/4" thick	
12		1	6061-T6 Angle Bar - 1.5" x 1.5" x 12" - 1/4" thick	
13		2	Al angle Iron 1"x"1x1/8"x18"	
14		1	6061-T6 Rod - 1/4" x 18"	
15		2	6061-T6 Rod - 5/16" x 18"	
16		2	5052-H32 Sheet - 1/16" x 18" x 18"	
17		2	2011 Hex Rod - 5/16" x 12"	
18		1	Threaded steel rod - 1/4-20, 12" length	
19		24"	Steel strips -1" x 0.048" (not in container, too big, as need)	
20		1	Steel Sheet - 18" x 18" x 1/32"	
21		4	1/8" diameter x 36" welding rod (not in container, too big, as need)	
22		1	Delrin Rod 1" Diameter x 6" Length	
23		1	Delrin Rod 2" Diameter x 4" Length	
24		2	ABS Sheet 12" x 12" x 1/4"	
25		2	Small PVC pipe - 1.0" I.D. x 18"	
26		2	Large PVC pipe - 1.25" I.D. x 18"	
		1	Medium pipes 1.5" ID this year only	
27		2	Square HDPE Bar 1/2" x 1/2" x 6"	
Wheels (provided in storage container)				
28		4	Four Inch Wheels - 4" diameter x 1" thick for 5/16" axle	
29		2	Caster Wheels - 2" diameter x 13/16" thick x 2.5" high	
Electrical (provided in storage container, spares limited)				**DigiKey Part #**
30		1	Battery wire to control box female connector	A1411-ND
31		2	Crimp terminals for above connector	A1421-ND
32		1	Motor wire to control box female connector	A25575-ND
33		8	Crimp terminals for above connector	A25692-ND
34		2	Battery wire to battery female quick disconnects	A29936CT-ND
35		1	Heat shrink 3/16 dia, 6" long	VER316K-ND
Wire (provided on spools)				
36		as need	Black & Red 18 gauge twisted together, type 1007	
Springs (stocked in bins)				**McMaster Part #**
37		4	Constant force spring (small)	(special order from Vulcan)
38		4	Compression spring	9657k152
39		4	Extension springs (small)	9654K14
40		4	Extension springs (medium)	9654K52
41		4	Extension springs (large)	9654K369
42		4	Torsion spring (small)	9271K452
43		4	Torsion spring (large)	9271K232
Gears (stocked in bins)				
44		4	Nylon spur gear, module 1, 12 teeth	
45		4	Nylon spur gear, module 1, 24 teeth	
46		4	Nylon spur gear, module 1, 36 teeth	
47		2	Nylon bevel gear, 24 diametral pitch, 24T	
48		2	Nylon bevel gear, 24 diametral pitch, 48T	
49		1	Length 12", 24 Diametral Pitch, 1/4" Face, 1/4" Height	
Little Bits (stocked in bins)				**McMaster Part #**
50		as need	Spring pins	98296A133
51		as need	1/4" Nylon bushing	6389K627
52		as need	5/16" Nylon bushing	6389K626
53		as need	E clip for 1/4" shaft	97431A300
54		as need	E clip for 5/16" shaft	97431A310
55		as need	1/8" Flat push-on retaining clips	94807A024

56		as need	1/4" Flat push-on retaining clips	94807A029
57		as need	5/16" Flat push-on retaining clips	94807A030
58		as need	1/8" Washer - .130" ID, .285" OD, .054"-.070" Thk	90295A070
59		as need	1/4" Washer - .260" ID,.687" OD, .054"-.070" Thk	90295A150
60		as need	5/16" Washer - .340" ID,.740" OD,.057"-.067" Thk	90295A160
Odds n'Ends (stocked in bins)				
61		as need	1/8" x 48" Buna-N cord, 70 durometer	
62		as need	3" x 24" x 1/16" Buna-N sheet stock	
63		as need	25' of braided nylon twine, 0.046" dia, 95 lb strength	
64		as need	Alcohol wipes	
65		as need	Two part epoxy packets	
66		as need	Zip tie wraps - 4" length	
67		as need	Cable zip tie mounts	
68		as need	Rubber bands	
Standard Lab Supplies				
		as need	An Assortment of Glues and Loctites	
		as need	Pop Rivets - 1/8" diameter, others possible	
		as need	Stocked Fasteners	
		as need	Other supplies provided by Pappalardo staff as needed	

Updated: 10 Feburary 2008, N. Hanumara

APPENDIX C.1, C.2: CALTECH ME 72 SYLLABUS & SCHEDULE

ME 72: Engineering Design Laboratory

Instructors:

- **Class Instructor:** Joel Burdick, Thomas 319, 395-4139, jwb@robotics.caltech.edu
- **Class Instructor:** Joseph (Joe) Shepherd, 306e Guggenheim, 395-3283, joseph.e.shepherd@caltech.edu
- **Shop Instructor:** John Van Deusen, Spaulding 024 (Sub-basement M.E. Shop), 395-4120, jvand@caltech.edu,
- **T.A.:** Jimmy Paulos, jpaulos@caltech.edu
- **T.A.:** Matthew Feldman, feldmanm@caltech.edu
- **T.A.:** T.B.D.

Course Web Site: *http://robotics.caltech.edu/∼me72/*

Goals of ME 72:

The goal of ME 72 is to give students a reasonably complete experience with the design process from initial concept, through analysis, to prototyping, testing, and refining. This process is organized around a contest, whose description and rules can be found in a separate handout (entitled "Amphibious Clean-Up"). More concretely, this course also aims to:

- Give student teams the experience of solving an open ended electro-mechanical design problem.
- Review and extend basic design methodologies that were introduced in ME 71.
- Introduce students to basic motor control technology.
- Give students the experience of building an electromechanical system.
- Introduce a limited subset of the basic mechanical elements which are typically used in machine design.

Class Format of ME 72:

ME 72 is a project class, and most of the learning in this class will take place during the process of building and fielding your contest design solution. Class time will be devoted to:

(1) reviews of appropriate design issues and design methodologies, (2) reviews of relevant technical issues (electric motor modeling, motor control, fluid dynamics of propulsion, buoyancy and stability of water vehicles, basic linkage principles); (3) student project reviews (a poster session, a preliminary design review, and a critical design review). Also, class time will be used for M.E. shop demonstrations on subjects that are relevant to the contest. During the last few weeks of each quarter, when students are intensively working on their projects, class lecture time will be limited so that students can devote more time to the shop.

Homework, Finals, and Grading:

The course work will consist almost entirely of a final project. There is no midterm or final exam in the traditional sense. However, the work of the final project will broken down into a series of tasks that involve milestones and intermediate deliverables, mock-ups, system analyses, simulations, drawings, and documentation, in addition to the actual physical construction of the project. The various activities and their timing are aimed to keep everyone on track to effectively compete in March, 2009. Additionally, each student must keep a "design notebook" throughout the two quarters. These notebooks will be checked at regular intervals, and a final grade will be assigned to the notebook at the end of each quarter.

The final grade for the first quarter will be computed as:

- 90% for the deliverables related to the final project. This final project deliverables, and their weighting in the overall grading, are as follows:
  - 3%: Shop exercise–Thursday, Oct. 11, 2008
  - 5%: Structured design artifacts (objectives, functions, and constraints)–Tuesday, Oct. 14, 2008.
  - 7%: Poster Session (initial concepts and their justification for the contest design, preliminary analysis, skeches of design candidates)–Tuesday, Oct. 21, 2008.
  - 15%: Preliminary Design Review (PDR), including device mock-up, and development of critical objectives, functions, and design constraints–Tuesday, Oct. 28, 2008.
  - 23%: Mobility Demonstration: you must demonstrate a working mobility platform in the Millikan pond–Thursday, Nov. 12, 2008.
  - 17%: Critical Design Review (CDR), including calculations, simulations, and design plan based on the outcome of the mobility experiments–Thursday, Nov. 20, 2008.
  - 20%: Demonstration of a scoring mechanism–Tuesday, Dec. 9, 2008
- 10% for the quality of the design notebook.

You will receive separate instructions, with more detailed guidelines and grading information, for each of these deliverables.

Note that all of the projects are done in teams of two. The grade assigned to the team on each team-based deliverable is the grade received by all team members. However, the course notebook and some of the intermediate deliverables will come from individual efforts. Thus, there is some room for individual effort to affect the final grade. The grading scheme during the second quarter will be similar, though there will be a component of the grade that relates directly to your performance in the final contest. However, only 20% of the final grade in the second quarter will be related to your contest entry's actual performance. The rest of the grade will be based on the quality and creativity of your design process (as evidence by the various design artifacts that you create), and the quality of your final project's fabrication and operation.

Grading of design projects is often subjective. We will attempt to be as fair as possible and lay out the grading procedure for each deliverable in a handout that describes the details that make up each deliverable. Students are encouraged to aggressively ask questions when the grading procedure is not clear.

Course collaboration policy. We encourage students to discuss the competition and the intermediate milestones with other students and with the class instructors and T.A.s. Group projects by their nature involve collaboration. On individual homeworks or deliverables, while discussions with other class participants is encouraged, the submitted work should entirely reflect the effort of the individual.

Shop Materials and Tools

We will provide a ready supply of the basic contest materials that you need for most of the class activities. As described in the contest rules document, students may wish to buy additional battery packs, decoration supplies, bonding material, etc. that may be needed to efficiently design, build, and test their contest entries. Only one set of radio control modules and motors will be provided to each team. Damage radio control systems and motors must be replaced at your cost.

Basic hand tools are available for each student to use in the M.E. shop. We encourage those students who have not already done so to purchase their own basic set of measurement tools.

References

There is no text for this course. We will photocopy and distribute course material as necessary. We will try to keep copies of handouts on the course web site.

Tentative Course Syllabus

In addition to the subjects described below, we also hope to have a few guest lectures, whose schedule will be determined by the availability of the lecturers. Additionally, some class meetings will be devoted to shop demonstrations of relevant mechanical fabrication methods and common mechanical components. It is our intention to have a lighter lecturing schedule during the periods when prototypes are being constructed.

- Review of structured design methods (2 lectures)
- Simple modeling of motors and transmissions (2 lectures)
- Review of fluid dynamics of propulsion (2-3 lectures)
- Buoyancy and stability of watercraft (1-2 lectures)
- Description of servomotor mechanisms and operation (1 lecture).
- Basic mechanism design and analysis (1-2 lectures)

ME 72(b): Engineering Design Laboratory

Overview of Course Schedule and Course Mechanics

Instructors:

- **Class Instructor:** Joseph (Joe) Shepherd, 306e Guggenheim, 395-3283, joseph.e.shepherd@caltech.edu
- **Class Instructor:** Joel Burdick, Thomas 319, 395-4139, jwb@robotics.caltech.edu
- **Shop Instructor:** John Van Deusen, Spaulding 024 (Sub-basement M.E. Shop), 395-4120, jvand@caltech.edu,
- **T.A.:** Jimmy Paulos, jpaulos@caltech.edu
- **T.A.:** Matthew Feldman, feldmanm@caltech.edu
- **T.A.:** Noel duToit, ndutoit@caltech.edu

Course Web Site: *http://robotics.caltech.edu/∼me72/*

Goals of ME 72(b):

The obvious goal for this quarter is to prepare for the ME 72 contest, which is scheduled to start at 1:00 p.m. on Tuesday, March 10, 2009. Now that you have chosen a design concept and have started the prototyping phase, the main focus of this quarter is to build, test, and refine your concepts in preparation for a successful demonstration on competition day.

Class Format of ME 72(b):

The primary learning this quarter will take place during the process of building and fielding your contest entry. The limited number of class sessions will be devoted to: (1) mock competitions; (2) testing/refinement strategies, (3) class presentations by contest teams; (4) some additional review of engineering concepts, if needed.

Class Deliverables and Grading:

The major events this quarter (with associated grading components) are described below. Separate handouts will provide more details on the exact nature of the deliverables and the grading scheme for each deliverable.

1. Entry/Exit Test:

- **Date:** *1:00 p.m., Thursday, Jan. 15, 2009.*
- **Description:** On this date each team is expected to demonstrate their prototype's ability to enter the pond from the contest starting zone, and swim across the pond to the exit ramp. While it is not a necessary part of this evaluation, students can gain additional extra credit for exiting the pond via the provided ramp (or via any other exit procedure that is inherent to their design.).
- **Grade:** 5% of your overall ME 72(b) grade.
- **Grading Contributions:** We will assess the quality of your device's stability upon entry–does it "splash down" at a reasonable longitudinal angle, and is it oriented so that it can quickly proceed into the contest zone? Can you steer your vehicle adroitly enough to reach the exit ramp?

2. **Scoring Subsystem Test:**

- **Date:** *1:00 p.m., Thursday, Jan. 29, 2009.*
- **Description:** On this date each team must demonstrate the ball collection and scoring capabilities of their vehicle. The contest regulation scoring balls, rope boundary, scoring bins, and exit ramp will be available during this test. Note that your vehicle should demonstrate it's ability to exit the pond via the ramp if this is an essential part of your scoring strategy.
- **Grade:** 15% of your overall ME 72(b) grade.
- **Grading Contributions:** We will assess your ability to efficiently gather scoring items, as well as the reliability of your method to place the balls in the scoring receptacles.

3. **Complete Vehicle Trial:**

- **Date:** *1:00 p.m., Thursday, Feb. 12, 2009.*
- **Description:** On this date each team will demonstrate it's ability to carry out an entire heat of the competition–entry into the pond, ball collection, scoring, negotation of the exit ramp (if that is part of your strategy), and contact with the flag in the end zone. This trial will not involve competition between different teams.
- **Grade:** 20% of your overall ME 72(b) grade.
- **Grading Contributions:** We will assess your team's ability to fluidly transition between all of the different contest behaviors, as well as your system's ability to balance all of the competing demands on your vehicle(s).

4. **Class Presentation:**

   - **Date:** *1:00-2:30 p.m., Tuesday/Thursday, Feb. 17/19, 2009.*
   - **Description:** During the scheduled class hours of Feb. 17 and 19, each team will make a 10 minute slide presentation on the status of their contest entry, including the lessons learned from the first trials, and plans to further refine and improve the team's prototype. The number of slides will be limited to six. The class instructors, T.A.s, and other students will provide feedback on your plans.
   - **Grade:** 5% of your overall ME 72(b) grade.
   - **Grading Contributions:** Do you understand the positive and negative aspects of your device's current embodiment? Do you have reasonable plans and a schedule to carry out further testing and refinement? Have you thought about how will you distribute the remaining work to be done across your team members?

5. **Mock Contest:**

   - **Date:** *1:00-2:30 p.m., Thursday Feb. 26, 2009.*
   - **Description:** We will carry out a mock contest on this date, where each team will be expected to compete twice against another team. The contest guidelines on system set-up and recovery will be loosely enforced. As this mock contest occurs two-weeks before the actual contest, it's main goal is to test the readiness of your system, and to help each team assess what modifications are needed to prepare their system for operation in the actual contest.
   - **Grade:** 15% of your overall ME 72(b) grade.
   - **Grading Contributions:** Is your prototype robust enough to withstand the expected rigors of the actual contest? Have you paid attention to all of the details that will help you have a competitive entry? Have you improved your system's performance compared to the first device trials? Does your device work smoothly within the contest environment?

6. **Actual Contest:**

   - **Date:** *1:00 p.m., Tuesday, March 10, 2009.*
   - **Grade:** 30% of your overall ME 72(b) grade.
   - **Grading Contributions:** What is the quality of the final design concept that was entered into the competition? What was the quality of the actual contest device? Was the device easy to set up and deploy? Did it perform well with respect to your predictions? Did it perform well in an absolute sense?

7. Design Notebook:

- **Date(s):** The notebook must be turned in by 5:00 p.m. on the last day of finals.
- **Grade:** 10% of your overall ME 72(b) grade.
- **Grading Contributions:** Did you keep an effective documentation of your project's progress?

Like ME 72(a), the grade assigned to the team on each team-based deliverable is the grade received by all team members.

Course collaboration policy. We will continue the collaboration policy of the first quarter. That is, we encourage students to discuss the competition and the intermediate milestones with other students and with the class instructors and T.A.s. However, the deliverables described above should come from individual and team efforts.

APPENDIX C.3: CALTECH ME 72 PROJECT DESCRIPTION

Preliminary Version of Contest Rules, Draft 3
(Jan 9, 2008)
ME72: Engineering Design Laboratory

"Amphibious Clean-Up"

Contest Description and Rules
Twenty-fourth Annual Engineering Design Competition
Tuesday, March 10, 2009

1. Introduction and Overview

Your mission this year is to design, build, and deploy amphibious craft that will:

- crawl into and swim around the Millikan pond,
- clean up floating debris in the pond (with scores associated with the quality of the debris)
- place the debris in scoring zones
- crawl out of the pond and claim your place at the top of the bridge that crosses over the pond.

The final contest will take place at 1:00 p.m. on Tuesday, March 10, 2008 in and around the pond on the east side of the Millikan library on the Caltech campus. The contest is a double elimination tournament where teams comprised of two students each will compete head-to-head. Each team's entry will be placed in a launching zone, a 1 meter x 1 meter square area (see Figures 1 and 2), which will be positioned on the south side of the Millikan library pond, to the east of the bridge over the pond. Each team (consisting of two people) will have 45 seconds to place their system within the launching zone, and then a 3 minute period during which all of the scoring takes place. As described more fully below, the goal is to gather floating balls and place them in scoring bins. Scores will depend upon the colors of the balls, and the difficulty of the scoring bins' placement. Additional points can be gained if one or more contest vehicles end the heat within a scoring zone on top of the bridge.

More details about each aspect of the contest are given in the following sections.

2. Starting Zone and Starting Procedure

- *A 1 meter square starting zone will be designated for each team by the inside edge of a colored tape boundary. The forward edge of the starting zone will be set back 60cm from the water's edge. The starting zones will be placed 1 meter appart, symmetrically located about the midline of the competition zone (see Figure 2).*
- Prior to each heat, a team will be permitted a maximum set up time of 45 seconds (beginning with the instructors' start command) to place their device(s) within their start zone.

- For sake of efficiency, the contest judges may optionally request teams to set up their entries while another contest round is still taking place. Therefore, the contest judges will notify teams that they are "on deck" for the next heat. Any team "on deck" must be able to start their set-up procedure at a moment's notice.
- During the 45 second setup period, passive mechanical energy, up to the limits described elsewhere in these rules, can be stored in a team's entry.
- At the end of the 45 second setup period, *your device must be statically stable and self-supporting*. Moreover, at the end of this 45 second set-up period, the total ensemble of each team's contest entry must fit within an imaginary rectangular box that is 60cm x 60cm at the base, and 60cm in height.
- ~~*Each system must have a launching procedure that can be simply activated by the press of an electronic or mechanical switch, or by operation of a radio-control system command.*~~ *Devices must be activated through their radio controls*. From the beginning of the heat (end of the set up period) until the end of the heat, contestants may have no physical contact with their device. So, pushing, throwing, or kicking of devices to enable launch is not allowed.
- Some teams may choose to design and build systems containing multiple components—i.e., different vehicles whose characteristics are optimized to beat different types of opponents. This is permitted as long as: (1) ALL devices do not contain more than the prescribed amount of material, (2) the ensemble of ALL devices respects the weight limit; (3) and ALL devices fit inside the virtual launching box by the end of the 45 second setup period.
- No external electrical, chemical, or other mechanical connection can be made to the system during the setup or launching phases. I.e., additional sources of energy besides those in the approved contest material list cannot be connected to your device during the setup or launching period.
- After the end of the each heat, all parts of the system must be removed from the starting zone *and contest arena* within 30 seconds. Failure to do so can result in a loss for that round.

3. The contest arena

3.1 Geometry of the contest arena.

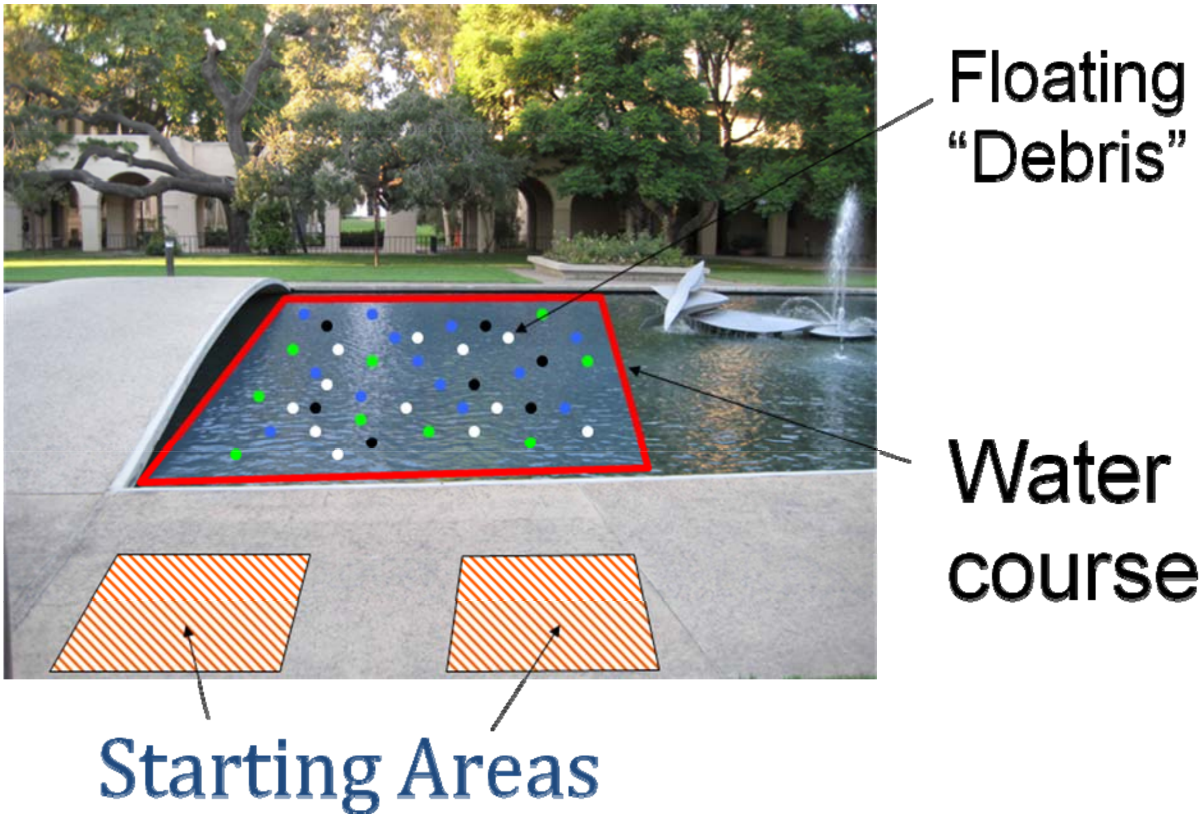


Figure 2: approximate placement of starting zone and main contest arena in Millikan pond.

The contest will take place in and around Millikan pond. As shown in Figures 2, 3, and 4, most of the activity will occur in the region east of the bridge and west of the fountain.

Each team will have a starting zone on the south side of the pond. Two sets of scoring zones will be located on the pavement surrounding the pond – at each of the two locations a color coded scoring bin is dedicated to each team. The lower level scoring bins (the "A" bins in Figure 3), are placed on the northern edge of the water course. The "B" scoring bins are located at the center of the bridge, on the bridge's eastern side.

On contest day, the contest boundaries will be clearly marked with tape over pavement and lane markers in the water. The actual contest area includes the water region seen in the figures, the water under the bridge, and the water 0.5 meter to the west of the bridge. The contest area also includes all of the paved area north and south of the main water region, the bridge itself, and a 3 foot width of pavement going clockwise around the eastern side of the pond (see Figure 4). The southern quarter of the bridge is off limit to any contest vehicles, but accessible to contestants to aid their ability to monitor their vehicles during a heat. *Leaving the contest boundaries intentionally or as part of a game strategy will result in disqualification. Being pushed out of* *play or accidentally leaving the playing field will be excused so long as the device makes an immediate effort to return.*

A single ramp, approximately 2 feet in width and 4 feet in length (with the lower end approximately 6" below water, and the upper end flush with the decking surrounding the pond) will be placed between the two A scoring regions to facilitate egress from the pond. The ramp will be available in the shop to borrow for testing, but please inform John before borrowing it. Finally, a flag will be located at the center of the bridge and a one meter diameter circle surrounding the flag will indicate the vehicle finishing zone.

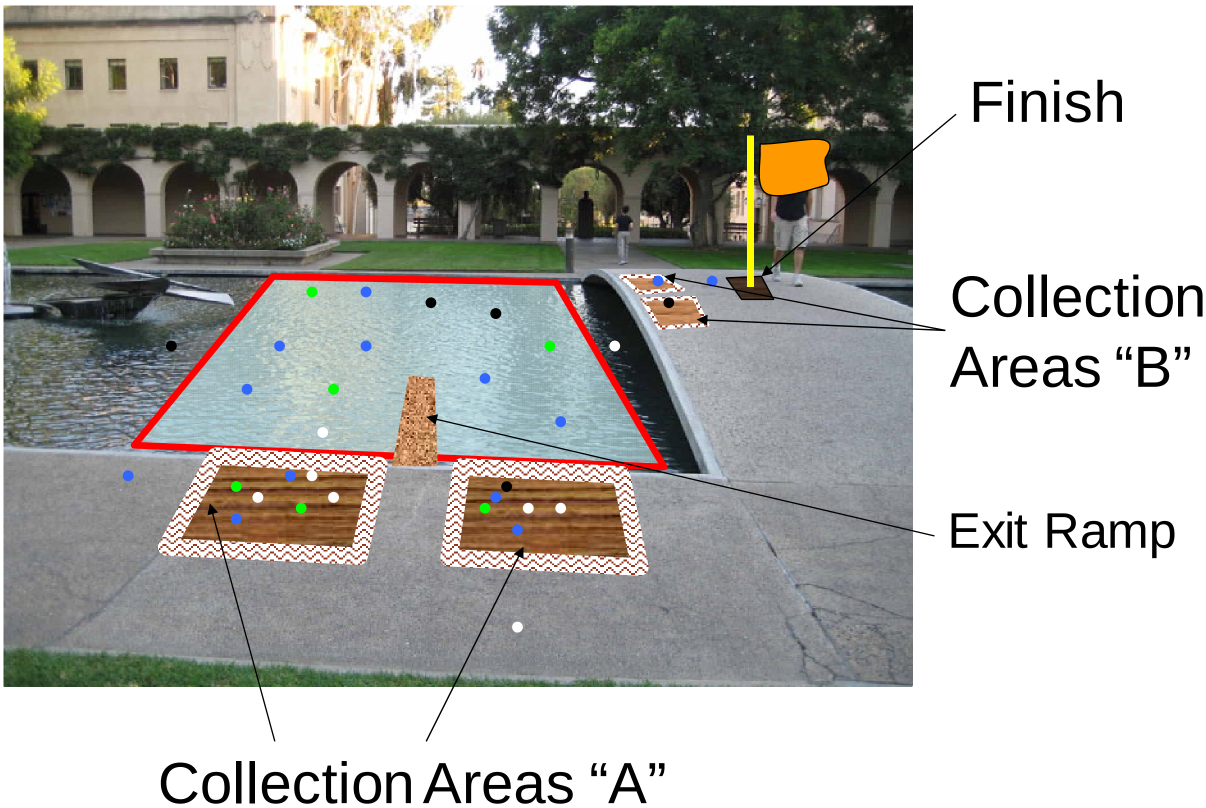


Figure 3: approximate placement of scoring zones and main contest arena in Millikan pond.

3.2 Allowed Movement of Contestants. *Human contestants must make their way to the operator area before the start of each round, and must remain there for the duration of the match.* After the launch, both team members may move within the allotted contestant area as needed in order to monitor and radio control their system (see Figure 4). However, from the beginning of the launch period until the end of the heat, at no time can a team member, or any other person, have contact with the components of their system. Moreover, no team member, other person, or mechanical device may interfere with the movement or activities of their human competitors during the setup, launch, and main heat periods.

3.3. Possible interactions between competing machines. You may not interfere in any way with the conduct of any opponent's device during the set-up and launch period. However, you are allowed to interfere with an opponent's device once your devices and your opponent's devices have both left the launching zone. While you may block, impede, annoy, or otherwise slow down your opponent during the heat, you may not cause intentional damage to your opponent's system. The contest judges will disqualify a team for what is deemed intentional damage. *Pushing and shoving is explicitly allowed even if it results in devices flipping over or falling into the water. Intentional tearing, grabbing or striking is not allowed. Additionally devices must avoid creating entanglement hazards such as nets or strings which may ensnare and damage motors, shafts, and propellers.*

You may not interact with, modify, or intentionally block the radio control signals from the opposing teams' transmitter. Intentional damage to any receiver/control module will result in disqualification. Each team's transmitter/receiver pair will have a different frequency to minimize interference effects. It is your responsibility to avoid damage to the receiver/control module during the design, fabrication, testing, and contest phases. Competitors should make efforts in the design and fabrication of their devices to avoid placement of the receiver/control module in a vulnerable position. This is particularly true for the aquatic nature of this year's contest.

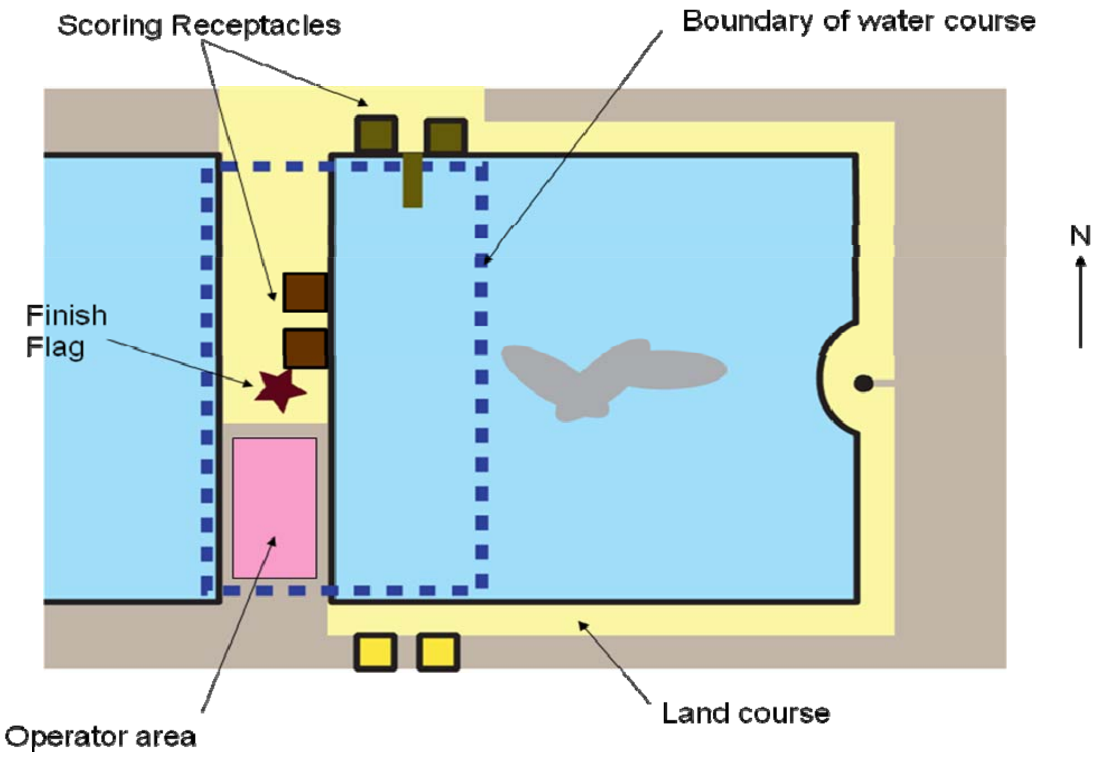


Figure 4: top view of the contest arena, showing water and land course, with operator area, scoring zones, and finish flag. The figure is not drawn to scale.

3.4. Geometry of the scoring bins. The bins will be rectangular regions whose bounding sides have different heights. The bins will be 1 meter wide and 80 cm deep. One of the wider sides will be open and placed at the edge of pond (or bridge). We anticipate that most scoring items will be place in the bins via this side of the bin. The far side of the bin will have a 6 inch tall backstop to minimize the chance that balls bounce out of the scoring zone. The two sides of the scoring zone will be made from 2 inch PVC pipe, sawn in half (see Figure 5). In this way, vehicles can readily enter and exit the collection areas from the sides.

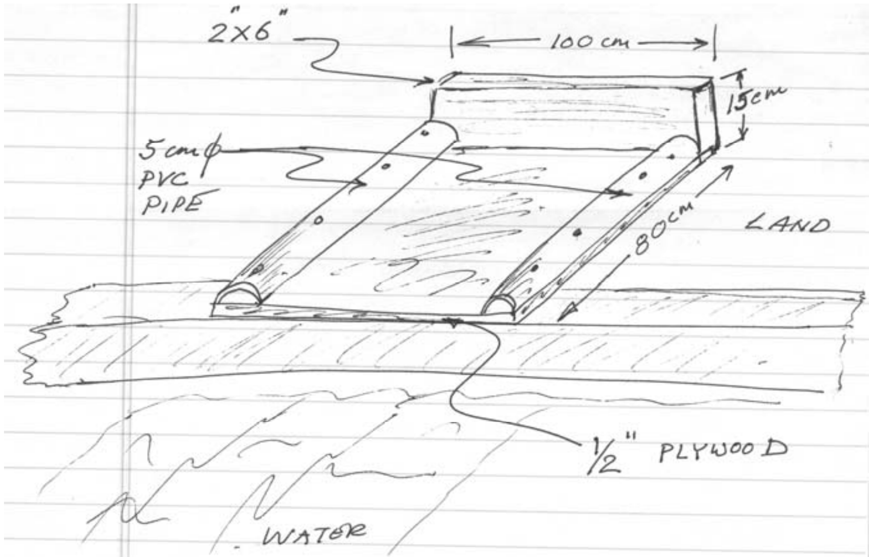


Figure 5: geometry of the scoring receptacles.

3.5. Physical limitations of the contest arena. On contest day, competition boundaries and scoring zones will be clearly marked. The contest arena includes all air-space above the ground and water surface, and within the lateral contest boundaries described above. The contest area will also include all of the pond water, and the pond bottom, lying inside the contest boundaries. *The underside of the bridge is also included as part of the contest arena.*

4. Scoring

Each team can score (or lose) points in these ways.

- **Positive scoring debris.** White and red colored balls will respectively have scores of 1 and 3 points. The balls will be, to the best ability of the contest judges and assistants, randomly distributed over the main water course region. Only balls which are lying within the collection zones *(and its infinite vertical extent)* at the end of the regulation period will be scored. *It is perfectly permissible for your scoring balls to be contained within your vehicle, and for your vehicle to lie within the scoring zone at the end of the regulation period. If your vehicle does not lie entirely within the scoring zone at the end of the regulation period, to the best of the judge's ability, we will score those balls lying entirely within the vertical column above the receptacle boundaries.* If you mistakenly place balls in your opponent's scoring area, the score accrues to your opponent.
- **Negative scoring debris.** Black floating balls have a scoring value of -2. You may wish to place these balls in your opponents scoring area to reduce their score! These balls will have a different size then the positive scoring balls, so that they can be potentially

differentiated by a mechanical device. *Only balls which are lying within the collection zone and its infinite vertical extent at the end of the regulation period will be scored.*

- **Collection area difficulty multiplier.** The total score obtained by adding up all of the scoring ball points (both positive and negative) will be multiplied by 1 for the balls placed in Collection Area A, while the ball scores in Collection Area B will be multiplied by a factor of 2 in recognition that it is more difficult to place the balls in the B zone.
- **Finishing zone.** Each vehicle that lies *entirely within 1 meter circle zone* around the finish flag on the *top surface of the* bridge at the end of the regulation period will score an additional 5 points for that vehicle's team. The first vehicle to touch the flag will receive an additional 5 points for that vehicle's team. *For the purposes of the scoring item, a vehicle is defined to be an independently controllable system with its own motive power—it must be able to maneuver using onboard actuators, and its maneuvers must be independent of the motion of other system elements.*

NOTE: At least one scoring ball must be placed in *your team's* scoring receptacles during the regulation period in order for a team to be eligible for the finish zone points. That ball need not stay in the scoring zone until the end of the heat.

NOTE: there will be 75 white balls, 20 red balls, and 5 blue balls in the water course.

NOTE: willful damage to the scoring balls or to the scoring receptacles can result in immediate disqualification.

5. Evaluation

The team with the highest score at the end of a heat's regulation period (and satisfying the constraints outlined above) will be declared the winner of that heat. If the score is tied, and both teams have achieved at least one scoring item above, then both teams will be assigned a "win" for that round. If neither team scores during a heat, then both teams will be assigned a loss for that heat. In all cases (particularly those requiring judgment) the judges will decide the winning and losing outcomes of a heat.

An overall winner will be determined in a double elimination tournament. This is just like a single elimination tournament, except a team must lose twice (instead of once) to be eliminated from the competition. The head-to-head competition and double elimination format is chosen so as to eliminate, as much as is humanly possible, the effects of transient weather conditions (e.g., gusts) and other random factors on overall contest performance. Your device must be robust enough to survive repeated contest rounds. Basic mechanical repairs to your device are allowed between competition heats. However, it is not possible to substitute "spare" devices for the original device between contest rounds.

Pairing of teams to compete will be chosen randomly at the start of each round of the tournament. Therefore, teams should be prepared to compete at a moment's notice.

6. Energy and Actuation Sources

Every team will be provided with the same energy sources and actuators, which will consist of

1) Two “small” battery packs for the radio-control receivers
2) Six hobbyist servo-motors (three “small” and three “medium” sized).
3) Two large battery packs
4) Four “large” brushed D.C. servomotors and two “small” brushed D.C. servomotors. Speed controllers are available for these motors as an option.
5) Energy stored passively in elastic members or in compressed materials (e.g., compressed air), as long as these energy storage components are made from the prescribed contest materials, and the stored energy conforms with upper limits that are described below.

Each team will be provided two standard model-airplane radio-controllers, each having 6 channels of control that can be used to remotely control the motions of the hobbyist servos and the D.C. servo motors if desired (through the use of an optional D.C. speed controller). These radios and receivers cannot be modified in any way; they must be used in the format as they are provided to you. Similarly, the battery packs provided cannot be chemically or thermally altered.

Students will have access to an ample number of battery chargers throughout the course and during the contest. However, design teams may choose to purchase additional battery packs if so desired in order to ensure maximum charge during the contest. But no more than two small and two large battery pack may be used at any one time in the system design and deployment. Additionally, batteries will be provided during the testing and contest period for the hand-held radio control modules. The battery packs may not be modified in any way at any time (mechanically, chemically, thermally, electrically, etc.); they must be stored and operated at ambient temperature. *~~Used radio control module batteries must be recycled when depleted of electrical energy. A container for this purpose will be available in the M.E. Shop.~~*

There will be limits on the amount of mechanical energy that can be stored in your devices prior to the initiation of the launch sequence. This energy may be obtained by deforming any element or elements in the prescribed material list, or by compressing air or other contest materials. The limit of this type of energy that can be stored in the system prior to the start of the launch sequence will be 20.0 joules (approximately the amount of energy stored by deforming six (6) medium sized rubber bands). Testing and analysis that demonstrates conclusively that these limits have been met must be included in your design notebook, and approval of your analysis must be indicated by the signature of the instructor.

7. Mass, Volume, and Material Constraints.

7.1 Contest Materials

Each contestant’s device(s) must be constructed entirely from materials supplied in the contest materials list (which will be found in a separate document on the course website). No other materials (either from the M.E. Shop, or elsewhere) can be used or substituted, with exceptions described immediately below. In addition to the standard material list each contestant may also use:

(a) A maximum of 8.0 ounces (dry cured mass) of RTV silicone casting compound. This casting compound is supplied in bulk. See the Staff in the M.E. Shop (John Van Deusen or one of the class T.A.s) if you wish to cast one or more parts out of silicone. The intended purpose of this casting compound is for sealing, however, it may be used for molding components.

(b) A maximum of 3 meters [118.1 inches] of 2.38 mm [3/32 inch] diameter "Orange-Go" belt material may be used. The M.E. Shop staff can show you how to join the ends of a segment of this material into a continuous belt. The intended purpose of the "Orange-Go" is for power transmission as a belt, however, it may find other (non-decorative) purposes.

(c) Glues and epoxies that are used only for bonding. This includes hot glue sticks, which may be used in unlimited quantities, for bonding purposes only Additionally, a total of 2 ounces of glue or epoxy may be used (in combination with other materials on the approved contest material list) to create a composite material, with glue as the matrix.

(d) Paint or Shellac may be used to insulate strands of wire, if desired. Similarly, up to one meter of black electrical tape may also be used for purposes of electrical insulation. Such tape may not be used for structural purposes.

(e) Paint or Shellac may be used to seal your vehicle(s) and contents against water.

(f) Up to 6 ounces of caulk may be used for water sealing.

(g) Light machine oil, mineral oil, or vegetable oil (depending on the competitor's preference) can be used SPARINGLY to lubricate moving parts.

(h) Non-functional decorations (such as decals and paint) can be used, and are encouraged.

Each contestant's final device(s) must be able to have been fabricated from the materials or parts contained in the parts list, with the exceptions described above. During the construction and testing of your devices, you may use more total materials than are prescribed on the approved material list, but the final device(s) cannot use any more material than is specified by this list. Some of you may choose to build different types vehicles so that you can select one that is optimized for a particular type of opponent. This is permitted. However, the total ensemble of your devices must be built within the limitations of the prescribed contest materials and energy/actuation sources, and must fit within the limitations of the starting box restrictions.

Replacement supplies and materials are available on a limited basis. If you damage something, or cut it up, and then want to do something different with it, see the M.E. Shop staff or one of the TA's. We will do our best to supply replacements, but we cannot guarantee unlimited supplies of all materials. We also cannot guarantee that replacements will be identical to the original. You may want to check availability of replacements prior to conducting a risky experiment with a rare part. In particular, each team member will only be supplied with only one set of hobbyist motors and radio control system. If these devices are damaged, it is up to the students to replace them. Sources for these items can be found in the *resources* section of the class web site.

Contestants are responsible for providing their own glues and epoxies. Some glues and epoxies will be available in the M.E. Shop, but to ensure an un-interrupted supply, go to a (hardware) store, and buy your own.

The approved contest materials may be mechanically modified in any way (disassembled, cut, machined, turned, ground, etc.). However, they may not be altered chemically (except locally by glues, for bonding, or paint for decoration or insulation purposes).

Soldering and brazing are permitted, though not particularly encourage. Welding is not permitted.

7.2. Contest Entry Size and Mass:

(a) Size:

> i. Prior to the start of the tournament, each team must demonstrate to the course instructors that, in its immediate pre-launch configuration, all the devices will fit into an imaginary 60 x 60 x 60 cm box. Two weeks prior to the contest date, a measuring device will be available in the M.E. Shop to check this constraint.
>
> ii. At the start of the each contest (t=0), each team's combined devices must be positioned within the proscribed launch area as described above.

(b) Mass: Each team's total design must not weigh more than 10 kg, including the mass of the supplied actuators and battery packs (but not including the hand-held radio control module).

7.3 Allowed Changes to Design on Competition day. After each device's initial competition in the final contest, no major design changes or construction will be allowed. Crashes as well as damage while entering/leaving the pond are inevitable and repairs to these devices using materials from the approved materials list will be permitted provided that, in the judges' opinion, they involve no major design changes to the initial device. *Raw materials from the approved materials list may be used for repairs. Pre-fabricated "spare parts" are only allowed if they have been included in the device weight-in, size restriction, and materials budget.* Minor changes to parameters such as angles of scoops, placement of flotation, etc. will be permitted. Any such minor corrections to the device must respect the rules on size, mass, and materials described elsewhere.

8. Additional Clarifications of the Contest Rules

8.1. Safety:

(a) Any device which is judged to have the potential to cause injury to any participant or spectator will be disqualified.

(b) It is mandatory that safety glasses be worn while testing. This requirement will be relaxed during the final tournament. It is, of course, also mandatory that safety glasses be worn at all times while in the M.E. Shop.

8.2. Team Number. Each team will be assigned a 2-digit integer number to identify their team and their contest device(s). Each major component of each team's design must carry an identifying team number. Note that Number 00 is reserved for the contest placebo. While not required, teams are also encouraged to choose a team name.

8.3. Settling Period. At the end of the competition period, a 5 second "settling period" may be optionally allowed by the contest judges to account for any scoring items that have not stabilized at the end of the competition period. However, all power and control to the contest vehicles must be terminated at the end of the regulation period.

8.4 Pre-contest testing. Prior to the final contest, participants may choose to test their devices in Millikan pond. However, the ME 72 staff will cannot guarantee that the pond will be full on any given day, or that the water level will be maintained at a consistent level prior to the contest day.

8.5. Other intentional damage. Any intentional damage to Caltech buildings, grounds, or other Caltech infrastructure prior to or during the contest will result in disqualification.

8.6. Time:

(a) During the tournament, contestants will be called up "On-Deck" while the preceding heat takes place. Each team should be prepared to begin their 45 second set-up period when requested by a contest judge at any time during the on-deck period.

(b) Exceeding the 45 second set-up time will result in a loss in that round for the offending team.

(c) After the end of the set-up time, no action of a team's device(s) is permitted prior to the initiation of the launch switch. I.e., during the setup time, it is not permissible for motors to be working to store energy. Only those movements of the team's mechanisms that are needed to place the devices in the launch region, to store passive mechanical energy (up to the contest limits), and to bring the devices to rest by the end of the 45 second set-up period are allowed.

(e) A maximum pick-up time of 45 seconds (commencing from the end of the regulation competition period) will be allowed for removing all of your device(s) from the contest arena.

8.7. Bye Rounds in the Tournament. During a contest, if your team gets a bye, or your opponent(s) do not show, your team must be prepared to compete against a placebo device if so requested by the contest judge. ~~*In the placebo bye round, your vehicle must place at least one scoring ball (of any color) in one of your scoring receptacles in order to successfully pass the placebo round.*~~ *A team 'wins' the placebo bye round if it achieves a positive non-zero score.*

9. Weather

Since the outdoor contest will be held in March, there is a possibility that rain may cause disruption of the event. It is likely that we will proceed with the contest in the event of light or occasional rain showers. Otherwise the event will be rescheduled as soon as possible.

10. Individual Work

While you will be working in teams of two, it is expected that each individual will design and fabricate a significant portion of each functional device. It is acknowledged that interaction between teams in the class is highly beneficial. To that end, any conversations, calculations, analyses, ideas and tests may be shared among the teams, but the device design and fabrication must be an individual team effort. Note that this collaboration policy does not extend to replicating others' ideas. Occasionally two teams will arrive independently at very similar solutions. Sometimes one team will see a great idea in another team's device, and finding no superior alternative, will want to incorporate it. This duplication is permissible, however, not encouraged. In the past, some competitors have maintained a high level of secrecy around their device, and blindly copying an idea or strategy may be risky. In many respects, you should treat this design project as similar to an ordinary homework set. It is permissible to collaborate with your classmates and seek the advice of the instructor, TA's, M.E. Shop staff, other class participants, and other students. However, the final product must be your own work. It is vital to document both your own work and the contributions of others to your ideas by detailing the process of ideation, design, and fabrication in your design notebook. If you are concerned about the acceptable limits to collaboration, discuss the situation with the instructor(s). Do your own work, and as always, it is best if you use your own ideas and concepts.

APPENDIX C.4: CALTECH ME 72 MATERIAL LIST

Each team's contest entry must be constructed with no more than the list of materials given below, in the extra sheets of this spreadsheet, and other materials described in the contest rules. You may use more than this amount of material during the development of your contest entry, but ALL components of the final entry can not contain more than this amount of material. The material in this "Desk" sheet will be available on a bench in the shop. The material in the "Display" sheet can be found on the display board in the shop. You can request these materials from the shop staff or class TAs.

# of Kits Needed: 13

Item	Amt	Unit	Source	# Total	# in Shop	Go Buy:
Acrylic 1/8" x 5" x 24"	1	ea		13	0	13
Acrylic 1/4" X 5" X 24"	1	ea		13	15	0
Acrylic 1/2" X 5" X 24"	1	ea		13	32	0
Particle Board 1/4" X 12" X 12"	1	ea	Carpenter shop	13	19	0
aluminum sheet 1/2" X 5" X 12"	1	ea		13	15	0
aluminum sheet 1/4" X 5" X 12"	1	ea		13	13	0
aluminum sheet 1/8" X 5" X 12"	2	ea		26	13	13
aluminum sheet 1/8" X 2" X 12"	2	ea		26	26	0
aluminum sheet .032 6" X 12"	2	ea	Stockroom	26	26	0
aluminum sheet .020 1' X 4'	1	ea	Aircraft Spruce, 3003	13	0	13
aluminum bar 3/8" X 1" X 18"	1	ea		13	13	0
aluminum bar 3/4" X 1" X 12"	1	ea		13	13	0
aluminum bar 1/2" X 1" X 18"	2	ea		26	26	0
aluminum angle 3/4" x 1/8" thick, 18"	2	ea		26	26	0
aluminum angle 1" x 1/8" thick, 18"	2	ea		26	26	0
PIC shaft 3/16" OD X 24"	2	ea		26	7	19
PIC shaft 1/4" OD X 24"	2	ea		26	11	15
steel rod 1/2" X 6"	1	ea		13	13	0
aluminum rod 1/2" OD X 12"	1	ea	Stockroom	13	13	0
aluminum rod 1" OD X 6"	2	ea		26	0	26
brass tube, 9/32" OD x 12"	2	ea		26	49	0
brass tube, 7/32" OD x 12"	2	ea		26	17	9
brass tube, 3/16" OD x 12"	2	ea		26	41	0
brass tube, 1/4" OD x 12"	2	ea		26	40	0
brass tube, 3/8" OD x 1/4" ID x 6"	2	ea		26	12	14
brass rod, 1/4" OD x 12"	2	ea		26	19	7
1/8" x 36" wooden dowel	2	ea	McMaster 9683K51	26	24	2
1/4" x 36" wooden dowel	2	ea	McMaster 9683K53	26	17	9
3/16" x 36" wooden dowel	2	ea	McMaster 9683K52	26	26	0
Polystyrene Sheet, 1" 2' X 4'	1	ea		13	1	12
Polystyrene Sheet, 3/16" 1' X 4'	1	ea		13	9	4
Polyester Cloth, 24" X 60"	1	ea	Aircraft Spruce	13		13
Plastic Mesh, 18" x 48"	1	ea	out of production	13	30	0
Medium Rubber Bands	9	ea	Office Depot Size 64	117	90	27

Display Board
# of Kits Needed: 13

#	Item	Quantity	Unit	Source	# Total	# in Shop	Go Buy:
1	Black Gears (12, 36, 48, 64 tooth)	10	total	Shop	130	150	0
2	3/16"ID ball bearing	4	ea	Precision Bearing	52	73	0
3	1/4"ID ball bearing	6	ea	Precision Bearing	78	6	72
4	Bushing 1/4" ID	6	ea		78	0	78
7	Double sided tape	10	ft	Aircraft Spruce	130		130
8	Clear Packing tape	10	ft	Lowes	130		130
9	1" Foam tape	18	in	mcmaster.com, 7598A2!	234		234
10	adhesive foam padding	8	in		104		104
11	1" Adhesive Velcro	1	m		13		13
12	9 tooth small white gear	6	ea		78		78
13	9 tooth small pink gear	6	ea		78		78
14	14 tooth small white gear	4	ea		52		52
15	tan combo gear	6	ea		78		78
16	paper clip (2")	10	ea	Office Depot	130		130
17	Rubber Bands (3")	10	ea	Office Depot	130		130
18	String 50#	20	m		260		260
19	Orange-go	10	ft	Shop	130		130
20	Servo Extension Lead	8	ea	servohut.com	104		104
21	Single Conductor Hookup Wire	any amount, *for electrical use only*					
22	Yellow CAT-5 Cable	3	ft		39		39
23	Battery Connector (any gender)	4	ea		52		52
24	Polyethylene 1/4" OD	3	ft		39		39
25	Polyethylene 5/16" OD	3	ft		39		39
26	Polyethylene 3/8" OD	3	ft		39		39
27	Nalgene Tubing 5/16" OD	3	ft		39		39
28	Cable Tie, 40#, 5-5/8" x 0.142"	5	ea	digikey.com, PLT1.5I-M	65	880	0
29	Red plastic strip	10	ea		130	500	0
30	Tongue Depressor	10	ea		130	28	102
31	Heat Shrink 1.25" X 6"	1	ea		13	42	0
32	Heat Shrink 1/2"	1	ft		13	40	0
33	Heat Shrink 5/16"	1	ft		13		13
34	Heat Shrink 3/16	1	ft		13		13
35	Heat Shrink 1/8"	1	ft		13		13
36	Mylar 18" X 30"	1	ea		13		13
37	black plastic paddle	4	ea		52	50	2
38	Bushing .080 ID	10	ea		130		130
39	Pin .080 X 1.5"	10	ea		130	1800	0
40	Pin .063 X 1.5"	10	ea		130	1230	0
41	Standoff 1.25" 8-32	2	ea		26	65	0
44	Socket cap 1/4-20 2.75" w/nut	2	ea		26		26
45	Socket cap 1/4-20 2" w/nut	2	ea		26		26
46	Black turbine rotor	2	ea		26	30	0
47	White turbine rotor	2	ea		26	77	0
48	notched rubber grommet	2	ea		26		26
49	Gray ring	6	ea		78	34	44
50	translucent plasic cap	10	ea		130	5300	0
51	plastic gear spline	4	ea		52	2630	0
52	Black plastic cap	10	ea		130		130

53	Steel ball 1/2"	4	ea		52	209	0
54	Stamped Steel Drum	2	ea		26	34	0
55	plastic cam ratchet	10	ea		130		130
56	Rectangular magnet	4	ea		52		52
57	Magnet small circle	2	ea		26		26
58	Magnet large circle	2	ea		26		26
59	Washer 1.375" OD	2	ea		26		26
60	Washer .805"	2	ea		26		26
61	Radially grooved rubber washer	2	ea		26	820	0
62	Assorted Springs	20	total		260		260
63	Binder ring 3"	1	ea		13		13
64	Assorted O-rings	10	total		130		130
65	8-1/2"x11" Printer Paper, 20#	2	sheets		26		26
66	Standard Index Card, 4" X 6"	10	ea		130		130
67	.035" Music Wire	10	ft	mcmaster.com 9666K27	130		130
68	.051" Music Wire	10	ft	mcmaster.com, 9666K3	130		130
69	Plastic Conduit	20	ft	mcmaster.com, 5181K1	260		260
76	1-1/4" Dia Plastic Propeller	2	ea	towerhobbies.com, Dum	26		26
77	1-3/4" Dia Plastic Propeller	2	ea	towerhobbies.com, Dum	26		26

Radio Kit

# of Kits Needed: **13**

	Amt	Unit	Source	# Total	# in Shop	Go Buy:
Standard Servo TS-53	3	ea	Tower Hobbies	39	40	0
Micro Servo HS-81	3	ea	Tower Hobbies	39	64	0
Small Battery, (Radio Reciever)	2	ea	Tower Hobbies	26	26	0
Large Battery, 2200mah 12V (DC motors)	2	ea		26	26	0
Radio Receiver	2	ea	Tower Hobbies	26	26	0
NOVAK "Reactor" Speed Controller	4	ea	out of production	52	47	5
NOVAK "Super Duty" Speed Controller	2	ea	Tower Hobbies	26	27	0
Large Brushed Motor	4	ea	?	52	86	0
Small Brushed Motor	2	ea	?	26	208	0

Bulk Fasteners

Only the following types and sizes of fasteners are allowed.
Any assortment may be used satisfying the following quantity constraints.
You may obtain these from the tool crib. If the one you want is not there, ask.

Screws:	60	pieces
Washers	50	pieces
Nuts:	50	pieces
Set Screws	20	pieces
Pop Rivets	50	pieces

SCREWS

Socket Cap Screws (Black Oxide)

Size:	Available Lengths:			
4-40		1/2"		
6-32	1/4"	1/2"	3/4"	1"
8-32	1/4"	1/2"	3/4"	1"
10-32	1/4"	1/2"	3/4"	1"
1/4-20		1/2"		

Flat Head Screws

Size	Available Lengths:			
4-40		1/2"		1"
6-32	1/4"	1/2"		1"
8-32	1/4"	1/2"		1"
10-32		1/2"		1"

WASHERS

#6
#8
#10
1/4"

NUTS

6-32
8-32
10-32
1/4-20

SET SCREWS

6-32	1/4"	3/8"	1/2"
8-32	1/4"	3/8"	1/2"
10-32	1/4"	3/8"	1/2"

POP RIVETS

1/8" Hole Aluminum Rivets, Lengths Unspecified

SPECIAL FASTENERS

Metric M2.5 and M3 cap screws in varying lengths are available for the exclusive use of attatching the motors, but will not count against the 60 screw total.

APPENDIX D.1: UNIVERSITY OF HOUSTON MECE 2361 DESIGN I SYLLABUS

MECE 2361: DESIGN I
Spring 2009 (INC)

Lecture: 10 AM to 12N; Monday
Studio: 9 AM to 12N; Wednesday

Instructor:
Richard Bannerot, Professor of Mechanical Engineering
Office: N231 D
The best way to reach me is by email: rbb@uh.edu.
Office phone: (713) 743-4511
Other class: MECE 4334 at 8:00 to 5:30 to 8:15 PM MW
Office Hours: whenever the door is open; suggestion: 1 PM to 5 PM Monday and Wednesday.

Recommended textbooks:

- *A Guide to Writing as an Engineer*, Beer and McMurrey, 2nd edition,. Copies are available at the UH Book Store (recommended for MECE 2361 and 4334; INDE 4334; and ECE 4334) and at the UH Writing and Communication Skill Center (for check out) at 217 AH. (We gave them about 25 copies three years ago, but the number on hand seems to decrease each year.)
- *Pocket Book of Technical Writing for Engineers and Scientists*, Finkelstein, 2nd edition. Copies are available at the UH Book Store (required for ENGI 2304)

PREREQUISITES

A knowledge of and ability in

- engineering graphics and freehand sketching (CNST [previously CIVT] 1331),
- software development (MECE 1331),
- business and introductory engineering software, e.g., WORD, EXCEL, POWERPOINT, PROJECT, etc., and
- the English language.

EXPECTATIONS

Communication is an essential part of the design process. (If you can not present your recommendations or results in a form that others are easily able to understand and want to learn about, what good is your work?) Students are expected to be able to communicate effectively in English, both orally and in writing, to produce and to read engineering drawings and to represent their ideas graphically as necessary. Unsatisfactory writing in any assignment could result in a failing grade for that assignment regardless of the "content." Written assignments are expected to be typed. Drawings and illustrations should be neat and self-explanatory. Formal engineering drawings are expected when appropriate. Should you have any questions about the form for an engineering drawing, there are many textbooks in the library on engineering graphics.

With prior approval, i.e., before the due date, and with an acceptable excuse (Email is best.), late work may be accepted without penalty. However, without prior approval grade penalties can be expected for work submitted late, normally 20% per day.

We are subject to the Academic Honesty Policy of the University of Houston. All work (including artifacts) is expected to be that of the submitter(s). Ideas, concepts, and information taken from the work of others should be properly acknowledged. Any text, table or figure that comes directly from another source, e.g., the internet, must be properly noted and referenced, e.g., quotations marks and/or citation. Any work performed on an artifact, other than that of the submitter(s), must be acknowledged. Failure to follow these simple rules could result in a violation of the UH Academic Honesty Policy. For policies related to academic honesty, as well as the academic calendar, religious holy days, and disabilities, search at http://www.uh.edu/provost/stu/stu_syllabsuppl.html

There may be a grade reduction for unexcused absences. An e-mail (preferred) or phone call to the instructor is required to receive prior permission for an “excused” absence. You are expected to acquire materials necessary to complete the projects. However, the essence of good design is creativity, one meaning of which in this course is to "maximize the quality of your work while minimizing the financial expenses." The plan is that you should not spend more for the course than the price of an average engineering textbook.

COURSE OBJECTIVES

The intent of most courses in science and engineering is to teach you how to analyze and evaluate given objects and systems and how to solve well-defined "classroom" problems. The objective of this course is to introduce the subjects of design and engineering design, which after all are the bases for the practice of engineering. You will be looking for solutions that satisfy goals subject to constraints rather than calculating the "right" answer to a well-defined and limited problem. In short, you will be addressing problems that have many solutions. We may not agree on whether your solution is appropriate. In fact, we shall seldom agree on which is the "best" solution for a particular problem. But that is what is interesting about design.

This course is about dealing with open-ended problems, the evaluation of work effort (both quantitative and qualitative), working effectively in a group, and learning to dig deep within your creative self.

RESOURCES

There is no textbook required for this course. Written materials will be supplied in class and through Blackboard, a College supported website: http://blackboard.egr.uh.edu/ . Links to other internet sites are listed on Blackboard. Teams or individuals may seek help with writing from peer consultants in the University of Houston Writing Center (UHWC). Contact the UHWC for details. The UHWC also presents a semester-long series of free workshops specifically for non-native speakers of English.

GRADING

(The grading weights could change if assignments change; see the ASSIGNMENT page for details.) Homework and projects are expected to be turned in on time. As noted above, late submissions will suffer a grade reduction. A good attendance record is expected, and attendance is taken at the beginning of class, i.e., tardiness equals an absence. If you anticipate missing a class or studio (illness, family emergency, etc.), please email the instructor before the scheduled class. If you unexpectedly miss a class, e.g., traffic accident, etc., please contact the instructor asap after the fact. As long as a pattern of missing classes does not develop, most of these absences will be “excused” (not counted against you). However, if the instructor is NOT contacted regarding an absence, the absence will be “un-excused”. If you anticipate a chronic problem with lateness, you are advised to discuss this issue with the instructor.

Individual Homework, Project and Exam: **70 %**

Two, closed book exams, a midterm (15%) and a final (25%), will cover the content of the lectures, the projects, shop tour, class handouts and homework.

Eight individual homework assignments, worth a total of 20%, are scheduled throughout the semester.

One individual projects will be worth 10%.

Deductions for excessive unexcused absences are possible.

Team Project: There will be one Team Project (four-person teams, to the extent possible): **30 %**

Peer Evaluations: Peer evaluations will be used to assess the level of the contribution of the individual team members to the four-person team project. Individual grades may be below or equal to the team grade (but rarely above) based on the peer evaluations, discussions with the team members, and the instructor's observations. Individuals may receive failing grades (for ineffective participation) for the team project even if the team grade is passing. Lack of participation and team dysfunctionality should be reported to the instructor as soon as possible.

Extra Credit: Up to 3% extra credit will be available for volunteer activity done during the semester (between September 1st and December 1st). Details will be given in class.

Important dates: The last day to drop a course without receiving a grade is Monday, Sept 8th. The last day to withdraw or drop a class is Tuesday, Nov 4th. (Note that Bannerot will be out of town from Oct 29th to Nov 10th.) The last day of classes is Saturday Dec 6th. The scheduled time for the Final Exam is Friday, Dec 12th from 5 PM to 8 PM. (the time for a 5:30 to 7 MW class)

APPENDIX D.2: UNIVERSITY OF HOUSTON MECE 2361 DESIGN 1 SCHEDULE

MECE 2361, Design I
Spring, 2009
CLASS SCHEDULE

date	lectures and assignments	assignment due
Jan 21	Intro to Course, Design Process I, HW#1 & HW#2	
Jan 26	Design Process II and Intro to Technical Communications Individual and Team Projects assigned	HW#1
Jan 28	Student talks; return HW# 1	HW#2 with student talks
Feb 2	Manufacturing and Shop Practice	HW#1 (resubmit)
Feb 4	Communications	
Feb 9	Design Process III, form teams	Individual Project (Draft)
Feb 11	Communications/ Team Issues; HW #3 in class	HW #3 (in class)
Feb 16	Machine Shop/Model Shop Tours (in groups)	
Feb 18	Machine Shop/Model Shop Tours (in groups)	
Feb 23	Design Process IV/Personality Issues	
Feb 25	Machine Shop/Model Shop Tours (in groups)	
Mar 2	Intellectual Property and Codes and Standards (HW#4)	Individual Project (Final)
Mar 4	Midterm Exam (closed book covering material delivered through Feb 25th)	Midterm Exam
Mar 9	Meet with Instructor in teams	
Mar 11	Initial Testing for Team Project	Initial Testing
Mar 16	SPRING BREAK	
Mar 18	SPRING BREAK	

Mar 23	Engineering Ethics (HW#5)	HW#4
Mar 25	Engineering Economics (HW #6)	
Mar 30	Sustainability and Design Constraints (HW#7 & #8)	HW#5
Apr 1	Meet with the Instructor in Teams	
Apr 6	Work in Teams	
Apr 8	Team Project Final Testing and submit device	Final Testing
Apr 13	TBD	HW#6
Apr 15	TBD	
Apr 20	Team Oral Presentations for Team Project	Oral Reports,
Apr 22	Team Oral Presentations for Team Project	Oral Reports, HW#7
Apr 27	Work in Teams	
Apr 29	Submit Team Written Report and Review for Final Exam	Team ext abs, HW# #8 Extra Credit Reports
May 4		
May 8?	Final Exam (closed book, comprehensive)	Final Exam (11 AM to 2 PM)

APPENDIX D.3: UNIVERSITY OF HOUSTON MECE 2361 DESIGN 1 PROJECT DESCRIPTION

January 21, 2009

MECE 2361: Design I
2009

Major Team Design Project

Form Teams:	February 18th
Initial Testing:	**March 11th**
Final Testing	April 14th
Device and Brochure Submission:	April 14th
Team Oral Presentation:	April 27th
Extended Abstract Due:	May 4th

PROBLEM STATEMENT

Design, fabricate and test a device that will autonomously sort up to ten golf balls from up to ten ping pong balls from an initially mixed state and a height (above the table on which it rests) of less than one inch (at the start of the process) and sequentially (all of one type followed by all of the second type) deliver them into an adjacent planter about 14.7 inches high and approximately 15.5 inches in diameter. The planter will be provided by the instructor and will be available for inspection in class at selected times, but shall not be available for team "practice." All other materials and the objects are to be provided by the team. The "Testing" of the device will take place at normal class times in the normal classroom. (Initial Testing on March 11th and Final Testing on April 14th) The device shall weigh less than ten pounds for both tests (the lighter the better for the Final Testing). There is no restriction on the type of energy used, but there can be no external energy source, i.e., the energy source is part of the device. Designs using gravitational energy will be viewed more favorably than those using other forms of energy. If multiple forms of energy are used, the greater the proportion of gravitational energy used the better. Batteries are allowed. Devices that use "excessive" energy, e.g., produce excessive velocities, will be penalized. Safety is of utmost importance, both to the people constructing and operating the device, and to those observing its operation. "Unsafe" devices will be disqualified, and "safe" devices will be rated higher than those judged to be less safe.

Teams must submit their devices immediately after the Final Testing for evaluation. Both written and oral reports are required. Further information on the constraints, goals and evaluation processes are given in this document.

TEAMS

Teams of four students each (to the extent possible) will be formed on February 18th. Each team shall declare a name and establish a spirit that should be demonstrated in the esthetics of the device, the presentations and the reports. Team names may be changed at any time with the consent of the instructor.

THE DEVICE

The "device" is defined as all items brought to the testing area except the balls and the tools used for assembly. Under no circumstance shall the device in any way cause harm to the operators or the audience or damage or disfiguration to the room or its contents. The device shall weigh less than ten pounds for all testing and be designed so that it may be weighed on a simple “pedestal scale” (available for inspection upon request). A device weighing more than ten pounds will not be tested. For the Final Testing, the lighter the device the better, as quantified by the Figure of Merit defined in Eqn. (1) in the Final Testing Section of this document.

The "mechanical" subsystems of the device should be constructed by members of the team (Any exceptions must be noted before Testing.) but may contain prefabricated mechanical components such as gears, hinges, pulleys, wheels, bearings and shafts. Gear “sets” may be purchased; however, no other “kits” are allowed. “Vehicles” must be constructed from individual parts, e.g., wheels and axle parts, i.e., not from kits or toys. Normal, simple fasteners such as screws, nails, bolts, rivets, tape, glue, etc. may be utilized. Fabricated commercial parts (components and assemblies) can not be used “for their intended purpose” in the device, but may (with the instructor’s specific approval) be incorporated into the device if they are NOT being used for their intended purpose. All questionable components should be submitted to the instructor before being incorporated into the device. A team that uses an unauthorized or illegal component or subsystem will be given a "failure" for the test or run in which this component or subsystem is utilized.

No “sticky materials” (e.g., tape or glue) or clamps are allowed to hold the device in place, although suction cups and “friction” mats are acceptable (and counted as part of the device, i.e., included in its “weight”). Nothing is allowed to penetrate the table, e.g., tacks. No damage (either physical or esthetic) shall be inflicted on the table, the floor, the rug, the room or its contents.

BALLS

The balls are to be selected and supplied by the team and are NOT counted as part of the weight of the device during the testing. The only restrictions on the balls are that they must be “someone’s” official golf or ping pong balls.

OPERATIONS

The planter and the device may be located anywhere on the provided table. The maximum distance between the table top and bottom of each ball is one inch. The balls must be completely mixed (not separated in any way) at the start of test. For both the Initial Testing and the Final Testing, at the direction of the instructor or his designate, a team member will be instructed to initiate the operation of his/her device. The initiation shall be in the form of a simple “release”, during which only the device is touched (not any of the balls), and no energy is transferred to the device or the balls. Only one hand may be utilized in the release process, e.g., the device can not be held with one hand while the other hand releases the balls. For the Final Testing, at least, it is expected that some thought will be given to using an innovative release mechanism. During the testing, parts of the device may extend beyond the edges of the table, but may not touch the floor. If any part of the device touches the floor, the test is a failure. Balls may touch the floor. The testing ends when twenty seconds has elapsed, when the team signals the termination of its run, or when the instructor determines that the attempt has been completed.

The objective is for the device to "perform" in as creative and interesting a way as possible. The desired attributes of "creative" performance are:

- to demonstrate innovative concepts to initiate the process, to maintain the process, and to control the process, and
- to keep the attention and interest of the audience.

TIMES AND PLACES FOR THE TESTING AND PRESENTATION

The Initial Testing will take place in the regular Wednesday class meeting room beginning at 9:00 AM on March 11th. The Final Testing will take place in the regular Wednesday meeting room on April 14th beginning at 9:00 AM as described above. Teams should be prepared to test beyond the normal class times, if necessary. The testing and evaluation criteria for both the Initial Testing and the Final Testing are discussed in the next two sections. Team presentations for the project will be in the regular Wednesday meeting room during the regular meeting times during the week of April 27th.

INITIAL TESTING

The requirement for the Initial Testing is to successfully move three balls into the planter from an initial position less than an inch from the table top. Only three balls may be "loaded" into the device. Each ball must remain in the planter, i.e., not bounce out, to be counted. The order of testing will be determined by the instructor and announced at the beginning of the testing session. There will be up to four rounds of testing with each team allowed one test per round in the order designated. Each team shall have two minutes to set up and perform any "practice" attempts. Once a team is "successful" (propelling three balls into the planter), it will no longer be allowed to test and may leave. Initial Testing could extend beyond 12 noon, and teams not yet successful will be expected to stay.

Each team will be given two testing opportunities or rounds (if necessary) in the Initial Testing for full credit. Two additional testing opportunities will be allowed (for less credit, see the Grading Section on page 6) for those devices that are unsuccessful in both of the first two tests. Teams unsuccessful in meeting the stated requirements after four tests (total) will receive zero points for Initial Testing.

Any team not present and ready to test at 9:00 AM could be disqualified for the Initial Testing, i.e., treated as if it failed all four tests as discussed above. After one team has removed its device, the clock starts for the deployment of the next device. There is a limited time for deployment (two minutes) and removal (thirty seconds), and a team will be disqualified for that attempt or test should it not comply.

FINAL TESTING

For the Final Testing, the device shall operate autonomously to place as many as ten of one type of ball (call it "Ball A".) into the planter before propelling any of the other type of ball (Call it "Ball B".) into the planter with at least a one second interval between the placement of the last Ball A and first Ball B. The balls must initially be mixed and within one inch of the table top. Each ball must remain in the planter, i.e., not bounce out, to be counted. During the "run" no intervention with the device, the balls, the planter, or the table will be permitted. **The requirement for a successful Final Testing is to place at least three of each type of ball, as described above, into the planter within 20 seconds, i.e., three or more of type A followed by three or more of type B (without either sequence interrupted), with at least a one second internal between ball sequences with a device weighing less than ten pounds.** The balls must initially be mixed and within one inch of the table top. Ideally, the device will place ten of type A balls followed by ten of type B balls from an initially mixed state and from within one inch of the table top into the planter, as **slowly** as possible (within 20 seconds). Teams may "load" the device with any number of balls up to a maximum of 20 (ten of each kind). If a type A ball enters the planter first, then all type A balls entering sequentially thereafter will be counted until a type B ball interrupts the sequence. (Note due to the required one-second delay between type A and type B balls, only the type B balls entering one second after the last type A ball will be counted.) Then this type B ball and the subsequent type B balls will be counted sequentially until a type A ball interrupts the sequence, the devices runs out of balls, the time runs out, the team indicates the run is over, or the instructor declares the run over.

The Final Testing will take place on April 14th starting at 9:00 AM in the regular classroom. Teams must be present with their devices at 9:00 AM to be eligible for the Final Testing. Based on the Final Testing, Teams will score points according to the Figure of Merit (Equation (1) below) which favors devices that are effective, consistent, light-weight and slow. At their scheduled times, teams will bring their devices to the common testing area and will be allowed three minutes to set up and practice. If a device is not able to perform after the three-minute set up time or can not be removed from the testing area within 30 seconds, it is disqualified for that round of testing.

The goal is to propel, within 20 seconds, ten of each ball type sequentially into the planter, as fast as possible. Specifically, the goal is to maximize the Figure of Merit, FM, defined as

$$FM = 2*(N_g + N_p) - M + 3*(10 - W_d) + t_1 + 2*t_2) \quad (1)$$

where

N_g is the total number of golf balls sequentially propelled into the planter (that remain in the planter) during the run. ($3 \leq N_g \leq 10$).

N_p is the total number of ping pong balls sequentially propelled into the planter (that remain in the planter) during the run. ($3 \leq N_p \leq 10$).

M is the total number of balls initially "loaded" into the device. ($6 \leq M \leq 20$)

W_d is the weight of the device in pounds ($W_d \leq 10.00$).

t_1 is the total time for the run in seconds ($t \leq 20.0$)

t_2 is the time delay in seconds between the time that the last Ball A enters the planter and the time the first Ball B enters the planter.

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A Figure of Merit will be determined only for devices achieving successful Final Testing as defined above.

The testing order will be assigned at the beginning of each testing session. Teams will be allowed to participate in two rounds of testing with the higher Figure of Merit counting. Teams that fail to achieve a successful test in either the first or second round will be allowed to participate in up to two additional rounds under the conditions described above. However, the resulting Figures of Merit will be reduced by 25% per round, and the device will not be eligible for bonus points. (See the Grading Section.) The order of testing shall remain the same for the third and fourth rounds of testing. Devices that are unsuccessful after four rounds will receive no credit (zero) for Final Testing. Repairs and substitutions are allowed between rounds, and if significant changes are made to the device and/or significant material is added or removed, the device shall be reweighed.

At the conclusion of the Final Testing teams are responsible for transferring their devices to a location as directed by the instructor. **A written description of how the device operates in the form of a one page, two-sided, sales brochure should be left with the device** (possibly folded twice into a six-page brochure**).** The team must be identified on the brochure and an electronic copy should be sent to the instructor at rbb@uh.edu on or before April 14th. (Name the file: "brochure for Team X", where X is the team number.) Drawings/photographs of the device along with appropriate discussions indicating the various aspects of the design would be advisable. Special attention should be given in the discussion to the outstanding design features of the device. The device needs to be "sold." The devices should be left in "operating" condition so that the instructor can evaluated their operation. Devices that are not successfully demonstrated during the Final Testing will be evaluated but will be penalized in the "Design Evaluation" (See Grading Section). For example, a zero will be given for "robustness" and very little credit would be given for "creativity in executing the concept". The devices may be retrieved after 3 PM the same day and must be retrieved by noon the next day (Thursday).

REPORTING

Presentation

Each team will have up to twelve minutes the during the week of April 27th during the normal class periods to present a description of its "solution". (The schedule will be posted by April 20th ; some teams will present on the 27th and the rest on the 29th.) The presentation should have an attention-getting beginning and a structured conclusion. Descriptions of noteworthy successes and failures in the design and construction processes are usually effective in holding the audience's attention. All team members are expected to participate equally in the presentation. Teams are expected to make a PowerPoint or equivalent presentation. The presentation shall be submitted electronically to the instructor by 6 AM the day of the presentation. Files should be labeled to indicate the team number, e.g., "presentation by Team 7". **(Please "compress" your photographic images before inserting them into the electronic presentation. The presentation file will hopefully be less than a couple of MBs.)** You are invited to attend all the presentations on both days, but are expected to attend the session in which you present and to remain for the entire class period. You will be invited to participate in the discussions of the devices after each presentation. (Note: When preparing an oral presentation practice makes perfect!). If your presentation requires special software to run, you may prefer to run it on your personal computer (or submit it early so the instructor can "try it out"). If you plan to use your own computer, let the instructor know before 6 AM on the day of the presentation. Your presentation will be moved to the end of the period so any "problems" in a computer change over will not adversely effect others. You should try out your "special" presentation using the projector in the classroom prior to the 27th, since not all projectors are capable of running all software.

Extended Abstract

The Extended Abstract is due at the beginning of class on May 2nd. Submit both a **hard copy** to the instructor and an **electronic copy** as an attachment to an email to rbb@uh.edu. Label the file "Ext Abs from Team X" (X is your team's number.)

The Extended Abstract consists of a single 8½ by 11 inch page (at least one-inch margins on all sides) with text (single, one-and-a-half, or double spaced Times New Roman – 12 or equivalent (Try to "fill" the page.)) on the front side and tables and figures (usually four or less) on the back (Try to "fill" the page.). These figures and tables should be numbered, titled, and referenced in the text. The document is similar in content to the "abstract" associated with a technical document, but it is longer. It should contain more details and, of course, the figures and tables that are not permitted in a report abstract. The text page of the Extended Abstract should have a header that includes the project title, semester, team name and number and the names of the team members. More information and examples will be made available.

GRADING

	points
Initial Testing *	10
Final Testing §	35
Presentation	13
Design Evaluation #	30
Extended Abstract	12

*A device that is successful in either of its first two attempts at the Initial Testing receives 10 points. Devices successful in their third attempt receive 6 points; in their fourth attempt, 3 points.

§ For the Final Testing, "Testing Points" awarded will be determined by the following formula:

Testing Points = Figure of Merit + Bonus Points

Figure of Merit is determined by Eqn. (1)

Bonus points will be awarded to the successful devices as follows:

- The largest values for the entire class of N_g, N_p, $(10 - W_d)$, and (20-t): 5 points each
- The next largest values: 4 points each
- The next largest values: 3 point each
- The next largest values: 2 point each
- The next largest values: 1 point each
- For a device that uses only gravity: 5 points (for each device, regardless of the number that qualify)

The values of these parameters, N_g, N_p, $(10 - W_d)$, and (20-t) are taken as defined when used in Eqn. (1). In cases of ties, the bonus points will be averaged (except for use of gravity). That is, if the three devices propelled ten golf balls each, i.e., N_g=10 for all three devices, all three of the devices receive (5+4+3)/3 = 4 bonus points.

The score for the Final Testing will be awarded on a linear scale. The device with the most "Testing Points" will receive full credit, 35 points (or possibly more if the device significantly outperforms all others). The scores for the other devices will be determined by the fraction of their "Testing Points" to what the instructor determines to be the "highest expected value of Testing Points" (the highest number of testing points scored or a lesser value). That is, a team whose "Testing Points" are 80% of the "highest" will receive 80% of 35 or 28 points.

For the Design Evaluation the following rubric will be used:

- Concept selection (20%): As much as half credit may be lost for not using gravity as a source of energy to "drive" any function of the device. Otherwise, the quality of the concept selection, the uniqueness of the concept (i.e., is it like everyone else's), and the probability of success will be assessed.
- Creativity in executing the concept (25%): How was the concept implemented? Was it <u>not</u> like everyone else's? Was it likely to work? Did it show good thinking?
- Craftsmanship and esthetics (20%): How does it look? How much care was exercised to make look good? Does it represent the "spirit" of the team name? Does it <u>look</u> like it works?
- Robustness (15%): Does its operation require special care or could anyone just walk up and operate it? Would it work for a few days or just during the testing period.
- Sales Brochure (20%): What's overall quality and content? Does it make good use of graphics and/or photographs? Photographs or quality drawing with text notes are particularly effective.

Normally, each team member receives the team grade. However, as part of the final exam each team member shall submit a completed form (provided by the instructor) indicating his/her estimate of the extent to which other members of the team fulfilled their responsibilities for the project. The instructor will take these completed forms and his own observations during the semester into account when assigning each student's grade for the project.

Cost

It is suggested that the total material cost should not exceed $100; however, there is no penalty for spending more. You should provide an itemized list of the materials, their sources and costs, in the Final Report. Cost estimates should be included for borrowed, donated, and/or other "free" items.

Some Final Comments

Ideas and designs shall be original and construction should be performed by team members. Exceptions should be noted in the Final Report and may affect the team grade. It is suggested that the team discuss this issue with the instructor at the time the work is done. No pre-constructed assemblies are permitted in the design. Devices may change at any time, e.g., between the Initial Testing and Final Testing, since new ideas may emerge after seeing the solutions of others. "Ruggedness" is usually an important feature of most successful designs.

All rules are subject to interpretation by the instructor and may even be changed should circumstances merit such action.

APPENDIX E.1, E.2: VILLANOVA UNIVERSITY SYLLABUS AND SCHEDULE

VILLANOVA UNIVERSITY

DEPARTMENT OF MECHANICAL ENGINEERING

ME 2505 – ME Analysis and Design - Lab Fall – 2005

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Laboratory Overview and Objectives

The primary objectives of this lab are to provide a hands-on introduction to the design process, and to provide the opportunity to learn a variety of basic skills that will form the foundation for future mechanical engineering courses. The secondary objectives are to emphasize the role that engineering design plays in contemporary society, to impart a sense of the creativity and innovation inherent in mechanical engineering design, and to provide the opportunity to develop the ability to function as part of a design team. Project results are communicated through written and oral reports, emphasizing the fact that communication skills are extremely important for practicing engineers.

Each laboratory session is 2 hours and 45 minutes long. Do not expect to get out early. Attendance and participation at all laboratory sessions is **mandatory.**

Attendance and Participation

Tardiness, and/or lack of participation will affect the final grade.

Grading

50% of the grade for ME 2505 will be based on laboratory performance. The laboratory grade will be the average of the grades for each laboratory assignment with some of the multiple week assignments counting double or triple.

Academic Conduct

You are encouraged to discuss your assignments with other students and to help each other to learn the work. *However any work you submit for grading must be your own or if it is a group assignment you must have contributed your fair share.*

Some Excerpts from the Villanova University Code of Academic Integrity

> Students shall not falsify, invent, or use in a deliberately misleading way any information, data, or citations in any assignment.
>
> Students shall not help or attempt to help others to commit an act of academic dishonesty.
>
> Students shall not rely on or use someone else's words, ideas, data, or arguments without clearly acknowledging the source and extent of the reliance or use.
>
> When doing out-of-class projects, homework, or assignments, students must work individually unless collaboration has been expressly permitted by the instructor. Students who do collaborate without express permission of their instructor must inform the instructor of the nature of their collaboration. If the collaboration is unacceptable, the instructor will determine the appropriate consequences (which may include treating the situation as an academic integrity violation.)

Learning Support Services

Students with disabilities who require academic accommodations should schedule an appointment to discuss specifics with me. It is the policy of Villanova to make reasonable academic accommodations for qualified individuals with disabilities. You must present verification and register with the Learning Support Office by contacting 610-519-5636 or nancy.mott@villanova.edu . Registration is needed in order to receive accommodations.

Lecture	Class Topic	Weekly Lab Session
1	Introduction, What is M.E.	**Intro, Hands-On, Testing & Revising, Design, Mathcad**
2	Systems of Units and Unit Conversions	
3	Accuracy, Precision, Significant Figures	**Hands-On, Testing & Revising, Design, Mathcad**
	NO CLASS – Labor Day	
4	Problem Solving 1	
5	Bearings 1	
6	Bearings 2	
7	Types of Gears	**Product Dissection – Bearings, Gears, Motors**
8	Gear Train Analysis	
9	DC Motors	**Lego Cars – Gears, Motors and Power**
10	AC Motors	
11	IC Engine Theory 1	**Robot**
12	IC Engine Theory 2	
	NO CLASS – Fall Break	Fall Break
	NO CLASS - Fall Break	
13	IC Engine Performance 1	**Matlab – Bearing Loads**
14	IC Engine Performance 2	
15	Statistics 1	**Engine Dissection**
16	Statistics 2	
17	Statistics 3	**Engine Dissection**
18	Statistics 4	
19	Design Process 1	**Statistics, Collect & Analyze Data, Mathcad, Matlab**
20	Design Process 2	
21	Heat Transfer 1	**Labview - Introduction**
21	Heat Transfer 2	
23	Curve Fitting - Linear	**Labview – Heat Transfer**
	NO CLASS – Thanksgiving	
24	Curve Fitting - Irregular	
25	Root Finding 1	**Robot Testing and Competition**
26	Root Finding 2	
27	Presentation Skills 1	**Oral Presentations**

28	Presentation Skills 2	

APPENDIX F: QFD WEIGHTING

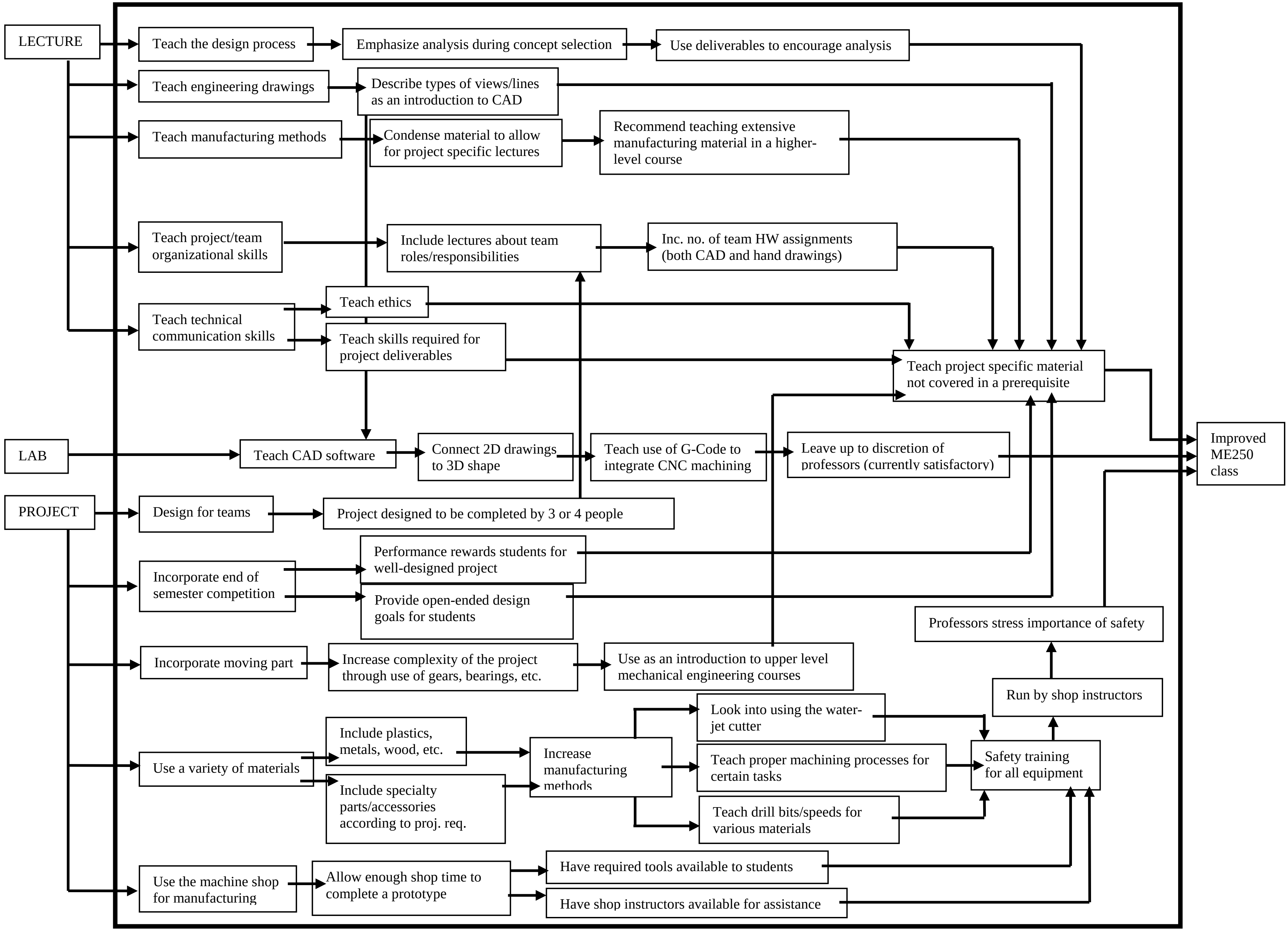
	Have a competition between prototypes at the end of the semester.	Include moving parts (gears, bearings, etc.)	Use a wider variety of tools	Use a wider variety of materials	Allow for students to express creativity when desiging prototypes	Have a better connection between lecture materials and the project	Allot a reasonable amount of time for completion of the project	Keep the cost for prototype creation to a minimum	Ensure the safety of each student	Provide new educational tools to help students effectively work in team	Redesign class schedule to accommodate increased difficulty	Create a challenging enviornment for the students	Weight (sum of row)
Have a competition between prototypes at the end of the semester.	X	0	1	1	0	0	0	1	0	1	1	0	5
Include moving parts (gears, bearings, etc.)	1	X	1	1	0	0	0	1	0	1	1	0	6
Use a wider variety of tools	0	0	X	0	0	0	0	1	0	1	0	0	2
Use a wider variety of materials	0	0	1	X	0	0	0	1	0	1	0	0	3
Allow for students to express creativity when desiging prototypes	1	1	1	1	X	1	0	1	0	1	1	1	9
Have a better connection between lecture materials and the project	1	1	1	1	0	X	0	1	0	1	0	0	6
Allot a reasonable amount of time for completion of the project	1	1	1	1	1	1	X	1	0	1	1	1	10
Keep the cost for prototype creation to a minimum	0	0	0	0	0	0	0	X	0	1	0	0	1
Ensure the safety of each student	1	1	1	1	1	1	1	1	X	1	1	1	11
Provide new educational tools to help students effectively work in teams	0	0	0	0	0	0	0	0	0	X	0	0	0
Redesign class schedule to accommodate increased difficulty	0	0	1	1	0	1	0	1	0	1	X	0	5
Create a challenging enviornment for the students	1	1	1	1	0	1	0	1	0	1	1	X	8

APPENDIX G: QFD

#	Technical Requirement	1	2	3	4	5	6	7
1	Amount of time to design							
2	Amount of time to build/manufacture	-						
3	Amount of time to test	-	-					
4	Cost (per group) of prototype							
5	Number of materials available				+			
6	Time in lecture pertaining to project specific knowledge							
7	Competition Equipment Size				+			

#	Customer Needs	Customer Weights	Kano Type	Amount of time to design	Amount of time to build/manufacture	Amount of time to test	Cost (per group) of prototype	Number of materials available	Time in lecture pertaining to project specific knowledg	Competition Equipment Size	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
				Technical Requirements							**Customer Opinion Survey**				
1	Have a competition between prototypes at the end of the semester.	5		1	1	3	1	1		9	A				BC
2	Include moving parts (gears, bearings, etc.)	6		9	9	3	3	1	9		A				BC
3	Use a wider variety of tools	2		3	9		1	3	3				A		
4	Use a wider variety of materials	3		3	3		9	9	9		A				BC
5	Allow for students to express creativity when desiging prototypes	9		9	9	9	3	3	9	3			A	BC	
6	Have a better connection between lecture materials and the project	6			1				9			A			
7	Allot a reasonable amount of time for completion of the project	10		9	9	9			1			A	B		C
8	Keep the cost for prototype creation to a minimum	1					9	9	3	3			BC		A
9	Ensure the safety of each student	11			3	1	1			3					ABC
10	Provide new educational tools to help students effectively work in teams	0		1									ABC		
11	Redesign class schedule to accommodate increased difficulty	5		1			1		9						
12	Create a challenging enviornment for the students	8		3	3	3	3	3		3					
13															
14															
15															
		Raw score		274	320	239	128	104	280	132					
		Scaled		0.856	1	0.747	0.4	0.325	0.875	0.413					
		Relative Weight		19%	22%	16%	9%	7%	19%	9%					
		Rank		3	1	4	6	7	2	5					
		Direction		↑	↑	↑	↓	↑	↑	T					
	Technical Requirement Units			Weeks	Weeks	Weeks	Dollars	Number of	% of Lectures	Square Feet					
	Technical Requriement Targets			8	4	2		5	75%	18					

APPENDIX H: FUNCITONAL DECOMPOSITION



APPENDIX I: FULL LIST OF CONCEPT GENERATION

CONCEPT	DESCRIPTION	THEME	GOALS	COMPLEXITY	SAFETY CONCERN
American Gladiators	A game requiring the movement of a robot between platforms in the quickest time.	multifunctional	maneuverability, speed	M	
Battle Boats	Boats attempting to detroy each other	multifunctional	buoyancy, maneuverability, sustainability	H	X
Battle Bots	Robots attempting to destroy each other	multifunctional	sustainability	H	X
Block Moving	Robot translating the location of blocks in the shortest time	multifunctional	force, maneuverability, speed	M	
Boat Wars	Boats destroying an opponent's "city" before they destroys yours	multifunctional	accuracy, buoyancy, maneuverability	H	X
BRD (beverage retrieval device)	A robot that retrieves and opens a beverage	multifunctional	maneuverability	H	X
Monkey (climber)	A robot that climbs a post to retrieve objects	multifunctional	maneuverability	M	
Paperbot	A robot throws objects at targets while moving in a straight line	multifunctional	accuracy, maneuverability	H	X
Rock'em Sock'em Robots	Based off of the popular child's toy	multifunctional	force, speed	H	X
Snow Plow	A robot that moves blocks (snow) out of the way of other objects	multifunctional	force, maneuverability, speed	M	
Soccer/Foosball	Robots maneuver a course with a ball to score in the opponent's goal	multifunctional	maneuverability	M	X
Sumo-Wrestling	Attempt to pull the opposing robot out of a ring	multifunctional	force	E	
Tank Wars	Destroy an opponent's "city" before they destroy yours	multifunctional	accuracy, maneuverability	H	X
Treasure Hunting	Robot digs to find hidden items	multifunctional	maneuverability	M	
Battleship	Action version of the classic children's game	other	accuracy	M	X
Catcher	Robot catches falling/thrown objects	other	accuracy	E	
Dropping	Accurately hit a target from a given elevation	other	accuracy	M	X
Fishing Pole	Engineer a fishing pole to be used in a fishing competition	other	accuracy	M	
Gap Jump	Create a machine that can cross a sizeable gap	other	accuracy	M	
Hungry Hungry Hippos	Recreation of a classic children's game	other	accuracy, speed	M	
Jumping	Create a robot that can launch highest into the air	other	accuracy	M	
Parachute	Similar to dropping, ability of a machine to release a parachute and drop to a given location	other	accuracy	E	
Pong	Mechanized version of the original video game	other	accuracy, force	H	
Rube Goldberg	Creation of a series of events that ultimately complete a given task	other	speed	H	
Solar Panel	Design a machine that can capture the most solar power	other	efficiency	H	
Catapult	Create a catapult to accurately launch objects at a target	projectile	accuracy	E	
Cornhole	Create a machine that will accurately toss a beanbag into the hole of a cornhole apparatus	projectile	accuracy	M	
Dart Shooter	Redesign/build a dart shooter to play darts	projectile	accuracy	M	
Duck Hunt	A robot that senses and shoots objects that fly by	projectile	accuracy	H	
Field Goal	A robot that can accurately kick a field goal	projectile	distance, force	M	
Golf Club Swing	Create a machine that can swing a golf club and hit aw ball the greatest distance	projectile	distance, force	M	
Putt Putt Golf	Similar to gold club swing, create a machine that can accurately putt and complete and miniature golf hole	projectile	accuracy	M	
Ring Toss	Create a machine that tosses rings over bottles as in the classic carnival game	projectile	accuracy	M	
Boat	Design a boat to drive an "out and back" course in the quickest time	race	buoyancy, maneuverability, speed	M	
Dragster	Create a car that will drive quickly and deploy a parachute to stop	race	speed	E	
Labyrinth	Maneuver a maze avoiding holes	race	maneuverability	H	
Mario Kart	Similar to the video game, create a car that will survive a course with multiple obstacles/opponents	race	speed	H	
Rainbow Road	Design a car to maneuver an elevated course with no side rails	race	maneuverability	H	
Carry Weight Up a Height	Design a machine to lift a given weight up to a certain height	strength	force, speed	E	
Crane	Create the truss structure of a crane to lift the most weight	strength	force	E	
Hammer/Nails	Engineer a machine to quickly hammer nails into a board	strength	accuracy	E	
Karate Chop	A mechanism that creates a force large enough to break the most boards	strength	force	E	
Tug-O-War	Apply a force at the end of a rope to attempt to move the opposing team	strength	force	E	
World's Strongest Man (lifter)	Robot vertically lifts something placed on top of it	strength	force	M	
Cliff Dive	The ability for a mechanism to fall off a cliff and survive	survival	force	M	X
Egg Crash Car	A vehicle that can roll down a hill and hit a wall without breaking an egg enclosed in the car	survival	force, sustainability	M	

APPENDIX J: PUGH CHART

	DATUM	1	2	3	4	5
Customer Needs	Old ME 250	American Gladiators	Soccer Foosball	Tank Wars	Catapult	Karate Chop
Competition	0	1	1	1	1	1
Moving Parts	0	1	1	1	1	1
Variety of Tools	0	0	0	0	0	0
Variety of Materials	0	1	1	1	1	1
Creativity	0	1	0	1	0	0
Connection with Lecture	0	1	1	1	1	1
Reasonable Time	0	0	0	0	0	0
Cost	0	-1	-1	-1	-1	-1
Safety	0	-1	-1	-1	-1	-1
Teamwork Tools	0	1	1	1	1	1
$\Sigma+$	+0	+6	+5	+6	+5	+5
$\Sigma-$	-0	-2	-2	-2	-2	-2
Σ	0	4	3	4	3	3

Appendix K: Improved Lecture Schedule

Week	Date	Topic	Content
1	Sept. 8	Introduction	Introduce lecture syllabus, lab information, safety training
	Sept. 10	Project Introduction	Introduce competition, material kit, timeline, final deliverables
2	Sept. 15	Orthographic/3D Drawings	Relate 2D and 3D views for simple objects, layout/line conventions
	Sept. 17	Orthographic/3D Drawings	Relate 2D and 3D views for complex objects
3	Sept. 22	Concept Generation and Teaming	Teamwork and roles, Gantt chart, design evaluation tools, TEAMS: concept gen
	Sept. 24	Customer Requirements	Translate customer requirements to specifications, QFD
4	Sept. 29	Sectional Views	Line conventions for sections, relating views to 2D and 3D drawings
	Oct. 1	Dimensions and Tolerances	Use of GD&T on drawings, labeling styles, TEAMS: develop concepts with GD&T
5	Oct. 6	Gears and Springs	Governing equations for gears and springs, use in project
	Oct. 8	Electrical Motors	Motor basics, electrical and mechanical components, use in project
6	Oct. 13	Project Analysis	Stress, force, velocity and momentum analysis for designs
	Oct. 15	Project Materials	Use of provided materials and parts, TEAMS: analyze designs and choose best
7	Oct. 20	Fall Study Break	
	Oct. 22	Exam 1 Review	
8	Oct. 27	Exam 1	
	Oct. 29	Project Manufacturing	Equipment for project, feeds, speeds, drill bits, TEAM: manufacturing plan
9	Nov. 3	Machining Processes	Teach various industrial machining processes
	Nov. 5	Machining Processes	Teach various industrial machining processes
10	Nov. 10	Polymer Shaping Processes	Teach various industrial polymer shaping processes, TEAMS: begin manufacturing
	Nov. 12	Polymer Shaping Processes	Teach various industrial polymer shaping processes
11	Nov. 17	Metal Forming Processes	Teach various industrial metal forming processes
	Nov. 19	Metal Forming Processes	Teach various industrial metal forming processes
12	Nov. 24	Technical Communication	Discuss final deliverables, format of paper and presentation

	Nov. 26	Thanksgiving Break	
13	Dec. 1	Rapid Prototyping	Teach process of rapid prototyping and use in industry
	Dec. 3	Micro/Nano-Fabrication	Teach research and applications of micro and nano-fabrication
14	Dec. 7	Prototype Due	
	Dec. 8	Exam 2 Review	
	Dec. 10	Exam 2	
15	Dec. 16	Paper Due	

Appendix L: Ideal Lecture Schedule

Week	Date	Topic	Content
1	Sept. 8	Introduction	Introduce lecture syllabus, project, safety training
	Sept. 10	Teaming	Team roles, respecting other backgrounds and learning styles
2	Sept. 15	Design Process	Concept generation/selection, final concept, prototype, and design evaluation tools
	Sept. 17	Orthographic/3D Drawings	Relate 2D and 3D views, layout/line conventions, TEAMS: start concept gen
3	Sept. 22	Sectional Drawings	More complex 2D/3D views, line conventions for sections
	Sept. 24	Dimensions/Tolerances	GD&T on drawings, tolerances in manufacturing, TEAMS: develop concepts
4	Sept. 29	Gears	Governing equations, sizes, forces, use in project
	Oct. 1	Bearings	Governing equations (roller and journal bearings), use in project
5	Oct. 6	Springs	Equations for forces (linear and torsional), use in project
	Oct. 8	Electric Motors	Motor basics, use in project, TEAMS: develop concepts with technical info
6	Oct. 13	Project Materials	Use of provided materials and parts, introduce CES
	Oct. 15	Forces and Projectiles	Force/velocity/momentum analysis needed to prove firing mechanism
7	Oct. 20	Fall Study Break	
	Oct. 22	Stress Analysis	Basis stress and failure equations, TEAMS: analyze concepts and choose best
8	Oct. 27	Exam 1 Review	
	Oct. 29	Exam 1	
9	Nov. 3	Manufacturing Introduction	Introduce available machines/processes, shop safety, TEAMS: Manufacturing plan
	Nov. 5	Basic Equipment	Drill press/band saw uses/feeds and speeds/drill bits, hand tools
10	Nov. 10	CNC Manufacturing	Mill/lathe, feeds and speeds, bits, part placement, TEAMS: begin manufacturing
	Nov. 12	Fastening	Welding, screws, other joining methods available
11	Nov. 17	Assembly and Finishing	Logical assembly order, sanding/painting and affect on tolerances
	Nov. 19	Prototype Testing	Testing equipment and set-up, safety, techniques to respond to feedback
12	Nov. 24	Technical Communication	Discuss final deliverables, format of paper and presentation

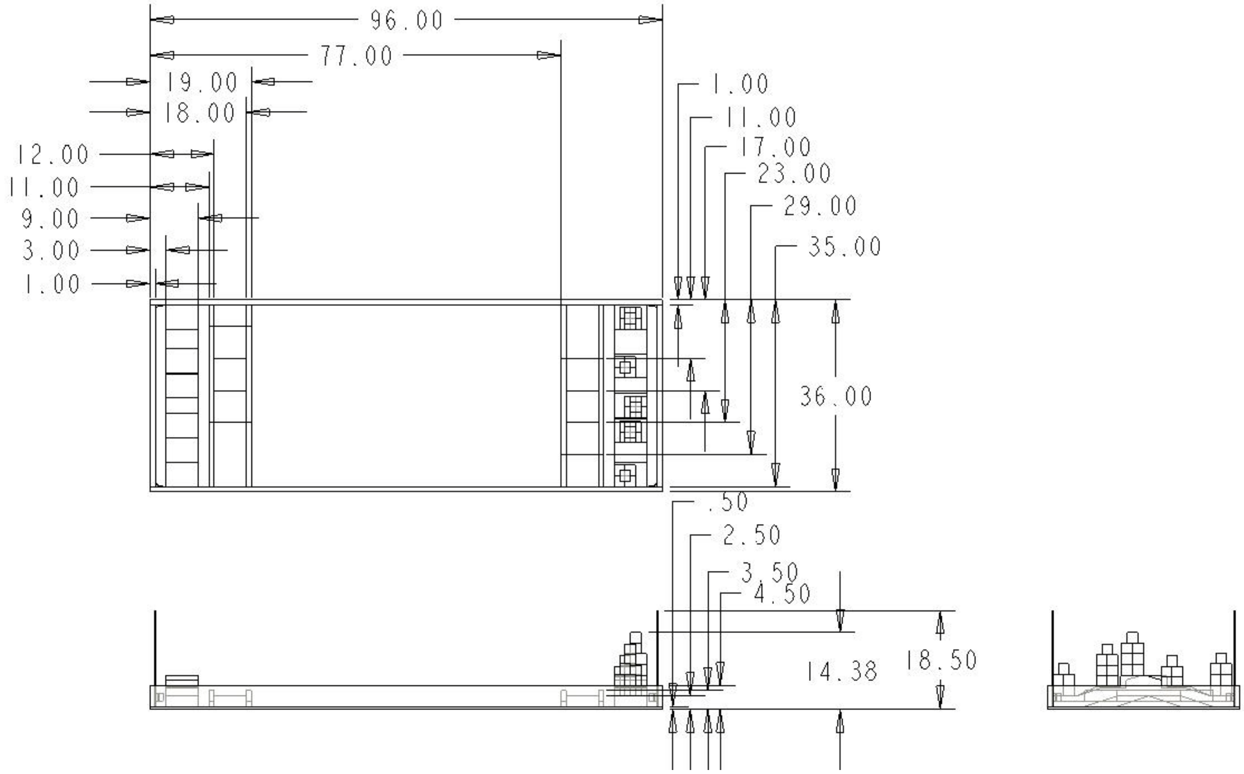
	Nov. 26	Thanksgiving Break	
13	Dec. 1	Open Shop/Testing	No lecture, professor office hours
	Dec. 3	Open Shop/Testing	No lecture, professor office hours
14	Dec. 7	Prototype Due	
	Dec. 8	Exam 2 Review	
	Dec. 10	Exam 2	
15	Dec. 16	Paper Due	

Appendix M: Improved Lab Schedule

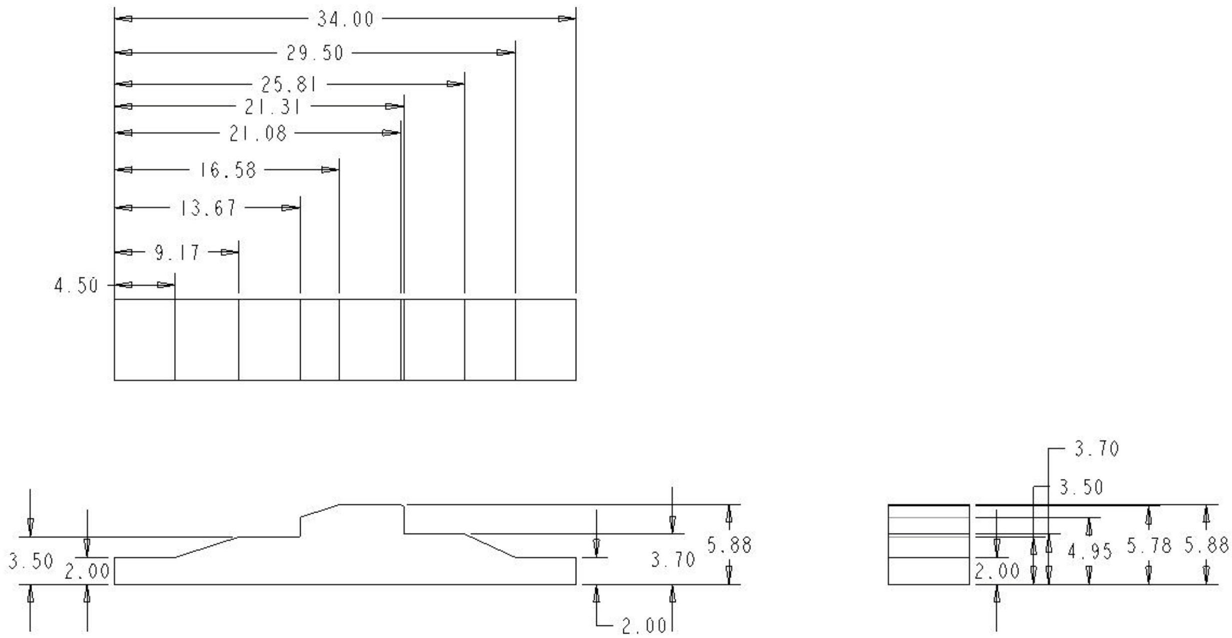
This schedule is to be used with both the improved and ideal lecture schedules.

Week	Date	Topic	Content
1	Sept. 9	No Lab First Week	
2	Sept. 14	Lab Introduction	Lab syllabus, form teams
	Sept. 16	2D CAD Drawings	Simple 2D CAD drawings
3	Sept. 21	2D CAD Drawings	Advanced 2D CAD drawings
	Sept. 23	3D CAD Drawings	Simple 3D CAD drawings
4	Sept. 28	3D CAD Drawings	Intermediate 3D CAD drawings
	Sept. 30	3D CAD Drawings	Advanced 3D CAD drawings
5	Oct. 5	Orthographic/Sectional	Orthographic and sectional views for 3D
	Oct. 7	Assemblies	Assemble multiple 3D objects
6	Oct. 12	Interoperability	STEP function for different CAD software
	Oct. 14	CES	CES to select/evaluate materials
7	Oct. 19	Fall Study Break	
	Oct. 21	CNC Lathe Tool-path	Convert CAD to G-code for CNC lathe
8	Oct. 26	CNC Mill Tool-path	Convert CAD to G-code for CNC mill
	Oct. 28	Candlestick	Teach use of CNC mill and lathe
9	Nov. 2	Candlestick	Students use CNC mill
	Nov. 4	Candlestick	Students use CNC lathe
10	Nov. 9	Open Shop	Students manufacture prototype
	Nov. 11	Open Shop	Students manufacture prototype
11	Nov. 16	Open Shop	Students manufacture prototype
	Nov. 18	Open Shop	Students manufacture prototype
12	Nov. 23	Open Shop/Testing	Students manufacture and test prototype
	Nov. 25	Open Shop/Testing	Students manufacture and test prototype
13	Nov. 30	Open Shop/Testing	Students manufacture and test prototype
	Dec. 2	Open Shop/Testing	Students manufacture and test prototype
14	Dec. 7	Prototype Due	
	Dec. 9	Project Presentations	
15	Dec. 14	Project Presentations	
	Dec. 16	Paper Due	

APPENDIX N.1: ENGINEERING DRAWING OF BATTLEFIELD



APPENDIX N.2: ENGINEERING DRAWING OF HILL WITH PLATFORMS



APPENDIX O: BALL-BLOCK IMPACT CALCULATIONS

Determining Velocity of ball at Impact
Known values

$$m_{ball} = 0.0045\ kg$$
$$m_w = 0.0145\ kg$$
$$\mu_w = 0.5$$
$$\Delta x = 0.0508\ m\ (2\ in.)$$

Determining foam ball coefficient of restitution

The foam ball was dropped from heights of 12, 24, and 36 in. The resulting bounce back height was measured.

Table 1: Bounce heights of foam ball. All values in inches.

Height	Bounce Height 1	Bounce Height 2	Bounce Height 3	Bounce Height 4
36	11	10	11	11
24	9	8	8	8
12	4	4	4	4

$$C_R = \sqrt{\frac{bounce\ height}{drop\ height}}$$

Taking all the values, and averaging them, the coefficient of restitution was determined.

$$C_R = 0.57$$

Equations solving for necessary velocity
A rough estimate determined that only half of the energy is transferred from the ball to the block at impact.

$$\frac{1}{2} m_{ball}\, v_{ball}{}^2 = \frac{1}{2} m_{ball}\, v'_{ball}{}^2 + Energy\ necessary\ to\ knock\ block\ off$$
$$v'_{ball} = \frac{m_{ball}\, v_{ball} + m_{block}\, C_R(-v_{ball})}{m_{ball} + m_{block}}$$
$$v'_{ball} = -.198 v_{ball}$$

$$Energy\ to\ knock\ block\ off = f * \Delta x = \mu m_w g * 0.0508\ (energy\ to\ knock\ block\ 2")$$
$$Energy = 0.0145 * 9.81 * 0.5 * 0.0508 = 0.0036\ N$$
$$.00216 v_{ball}{}^2 = 0.0036\ N$$
$$v_{ball} = 1.29\ \frac{m}{s}$$

Determining Effect of Drag on the Ball
Known values

$$m = 0.0045\ kg\ (mass\ of\ ball)$$
$$\rho = 1.204\ kg/m^3$$
$$A = \pi r^2 = \pi * 0.0225^2 = 0.0016\ m^2$$

$$C_d = 0.5$$

$$v_f = v_{ball} = 1.29\ \frac{m}{s}$$

Equations solving for initial velocity

$$F_d = -\frac{1}{2}\rho A C_d v^2$$

$$F = ma = F_d = -\frac{1}{2}\rho A C_d v^2$$

$$m\frac{dv}{dt} = -\frac{1}{2}\rho A C_d v^2$$

$$\frac{dv}{v^2} = -\frac{1}{2m}\rho A C_d dt$$

$$\int_{v_i}^{v_f} \frac{dv}{v^2} = \int_0^t -\frac{1}{2m}\rho A C_d dt$$

$$-\frac{1}{v_f} + \frac{1}{v_i} = -\frac{1}{2m}\rho A C_d t$$

$$v_i = (-\frac{1}{2m}\rho A C_d t + \frac{1}{v_f})^{-1}$$

$$v_i = 1.6\frac{m}{s}\ (time\ is\ calculated\ when\ the\ integral\ equals\ 2m, 1.4\ seconds)$$

APPENDIX P: COMPRESSION SPRING TANK CALCULATIONS

Determining the Initial Velocity

The basic equations of projectile motion for constant acceleration are used with the assumption that the maximum velocity is at 45º to find the maximum initial velocity needed.

Known Values

$$g = 9.81\ \frac{m}{s^2}\ (gravitational\ acceleration)$$
$$x = 2\ m\ (horizontal\ length\ the\ ball\ travels)$$
$$\theta = 45°\ (maximum\ angle)$$

Equations and Calculations

$$t_x = 2t_y$$
$$v_{xi} = v\cos\theta$$
$$v_y = v\sin\theta$$

$$v_{xi} = v\cos\theta = (-\frac{1}{2m}\rho AC_d t + \frac{1}{v_{xf}})^{-1}$$

Since the firing and hitting height are the same, drag for the vertical direction is neglected since the effect it has on the ball becomes zero. (The effect when V>0 is equal and opposite the effect when V<0)

$$v_y = v\sin\theta = \frac{1}{2}gt^2$$

$$v\cos\theta = (-\frac{1}{2m}\rho AC_d * \sqrt{\frac{2v\sin\theta}{g}} + \frac{1}{v_{xf}})^{-1}$$

When firing with an initial velocity of 4.43 m/s, it provides an impact velocity of 2.44 m/s. This is acceptable because the velocity is higher than the necessary velocity to knock a block off the platform. This also allows for the possibility to knock more than one block off if the impact is not perfect.

Determining the Spring Constant

The spring constant is calculated from the properties of the purchased spring, assuming that it is made of hard drawn spring steel.

Known Values

$$OD = 0.5\ in = 0.0127\ m\ (outer\ spring\ diameter)$$
$$d = 0.054\ in = 0.00137\ m\ (wire\ diameter)$$
$$N_t = 12\ (total\ turns\ of\ spring)$$
$$G = 79.3 *\ 10^9\ \frac{N}{m^2}\ (material\ constant)$$

Equations and Calculations

$$N_a = N_t - 2$$
$$N_a = 10\ (active\ turns)$$

$$D = OD - d$$
$$D = 0.446\ in = 0.0113\ m\ (mean\ coil\ diameter)$$

$$k = \frac{d^4 G}{8D^3 N_a}$$
$$k = 2420\ \frac{N}{m}$$

Determining the Compression Distance
The compression distance is calculated using conservation of energy between the compressed spring and the initial motion of the ball, using the velocity and spring constant previously calculated. It is assumed that all energy is transferred from the spring to the rack and ball, and that the rack and ball move at the same velocity.

Known Values

$$m_{ball} = 0.0045\ kg$$
$$m_{rack} = 0.0097\ kg$$
$$v = 4.43\ \frac{m}{s}$$
$$k = 2420\ \frac{N}{m}$$

Equations and Calculations

$$\frac{1}{2}kx^2 = \frac{1}{2}(m_{ball} + m_{rack})v^2$$
$$x = \sqrt{\frac{(m_{ball} + m_{rack})v^2}{2k}}$$
$$x = 7.61\ mm$$

Determining the Firing Motor Torque
The torque on the servo motor is calculated using the radius of the gear attached to the motor, and the force that gear must apply to the spring.

Known Values

$$d_g = \frac{9}{16}\ in = 0.0143\ m\ (gear\ diameter)$$
$$k = 2420\ \frac{N}{m}$$
$$x = 0.00761\ m$$

Equations and Calculations

$$T_{motor} = \frac{1}{2}d_g F_{spring}$$
$$T_{motor} = \frac{1}{2}d_g kx$$
$$T_{motor} = 0.132\ Nm$$

Determining the Aiming Motor Torque
The torque on the aiming motor is calculated using the mass of the body, mass of the barrel, and mass of the firing motor because they are the most massive components. It is assumed that this

mass is centered 3 in. away from the aiming motor, which is the connection between the body and barrel.

Known Values

$$m_{body} = 0.087\ kg$$
$$m_{barrel} = 0.092\ kg$$
$$m_{motor} = 0.056\ kg$$
$$x = 3\ in = 0.0762\ m$$

Equations and Calculations

$$T_{aiming} = gx(m_{body} + m_{barrel} + m_{motor})$$
$$T_{aiming} = 0.176\ Nm$$

APPENDIX Q: PITCHING MACHINE TANK CALCULATIONS

RPM Calculation

This was used to determine the minimum RPM our selected motor must generate.

$$V = r\dot{\theta}$$

$$\dot{\theta} = \frac{V}{r}$$

$$60 * \frac{\dot{\theta}}{2\pi} = RPM$$

$$RPM = \frac{30V}{\pi r}$$

For the spinning wheels r=1 in. (.0254 m). V is estimated at 5 m/s.

$$RPM = 1880$$

Torque Calculation

To simplify the calculations, all of the mass of the wheel is assumed on the edge of the wheel. This assumption will ensure that our torque calculation is larger than the minimum torque actually required. This will also ensure that the added torque when launching a foam ball is acceptable. This torque is necessary to ensure that the torque requirement when selecting a motor is correct.

$$\tau = mgr$$

$$\tau = 0.0887\ kg * 9.81 * .0254\ m$$

$$\tau = 0.0221\ Nm$$

APPENDIX R: DESIGN ANALYSIS

1) The first component selected for material selection was the top plate of the pitching machine tank. This part must be able to support a 1kg load that is applied at its center. This will allow for sufficient support of the two motors attached to the plate. The maximum deflection acceptable is 3mm. We determined a minimum Young's Modulus of 2 GPa. We also set the constraints to ensure that the material would be a good thermal and electrical insulator. This will prevent issues arising from an electrical wire slipping off of the motor. The other constraint is that the material is cost effective. From the constraints, we were given 5 possible materials. They are Polyvinylchloride (PVC), Polyethylene terephthalate (PET), Phenolics, Polystyrene (PS) and Polylactide (PLA). Our final choice was PVC. This was readily available, cheap, and met all of the necessary requirements.

The second component was the pinion for the compression spring tank. This part must be purchased and then manufactured down to the appropriate number of teeth. To ensure the accuracy of the part, and to reduce manufacturing time, the part must be soft and easily machined. It must also have a low cost. Based on this, we set our constraints on CES. We said that the cost needed to be less than $10 per kilogram. We also said that the material had to be very easy to machine and form. Finally, we said that it needed to have a Vickers hardness of less than 75. Based on these constraints, there were several suggestions. The suggestions were brass, bronze, copper, cast Al-alloys, and age-hardening wrought Al-alloys. We chose brass because it fit our requirements, and was the cheapest available for purchase. The lower hardness level allows a purchased spur gear to be filed to the proper number of teeth as a sector gear.

2) For the first component, with a size of 10 in. by 7 in. by 0.25 in., and a density of 0.047 lb/m^3, the total mass of the material necessary is 0.82 lbs of PVC. For the second component, the mass was measured to be 25g. Using these two masses, we were able to use SimaPro to determine the environmental effects of the parts, as seen in Figure R.1 through R.5.

Based on the results, the brass pinion has a greater effect on the environment. Though the PVC uses a large amount of water in the Raw materials, the amount of waste generated by the pinion is of much greater issue. Because of this, the pinion has the larger effect. The PVC does not have any significant impact with the Econindicator 99 damage classifications, while the brass pinion only has an impact on minerals. Because of these minimal impacts, the selections of the two materials are proven acceptable.

3) The plate involved in the pitching machine will have a very small production volume. It is used in student prototypes, and thus is tailored to the specifics needs of each tank prototype. Because of this, the production volume is estimated at 100 if the project were to be implemented in other Universities. Since the batch size is small, and the manufacturing process is cutting holes and shapes, CES suggested several processes. The best process to use for this was abrasive jet machining and cutting. The piece does not need more than the cutting process this provides, and this will perform the task fast and accurately.

For the pinion involved in the compressed spring tank, it is again a piece that is specifically tailored to the tank prototype. Because of this it will also have an estimated production volume of 100 or less. Using this, along with the fact that the machining necessary is the removal of material, the best machining process suggested from CES was milling. This will allow the part to quickly be machined down to the appropriate number of teeth to get a proper compression when used.

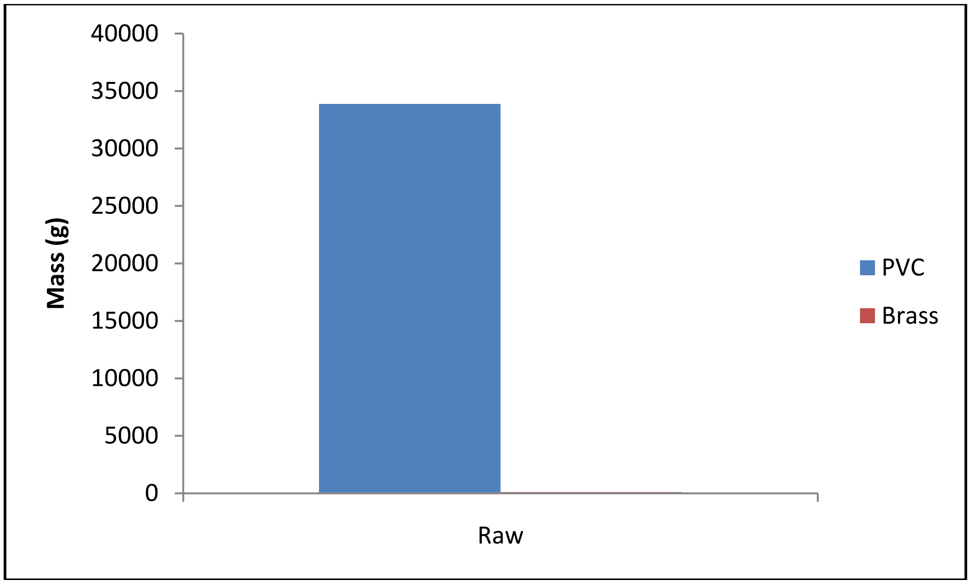


Figure R.1: Comparison of mass of PVC and brass needed

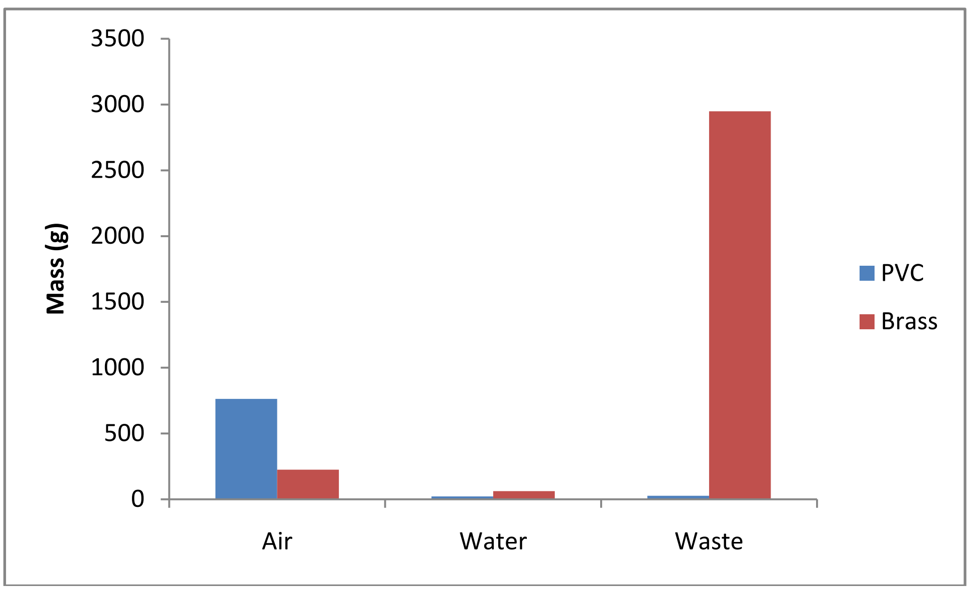


Figure R.2: Comparison of waste material produced while manufacturing PVC and brass

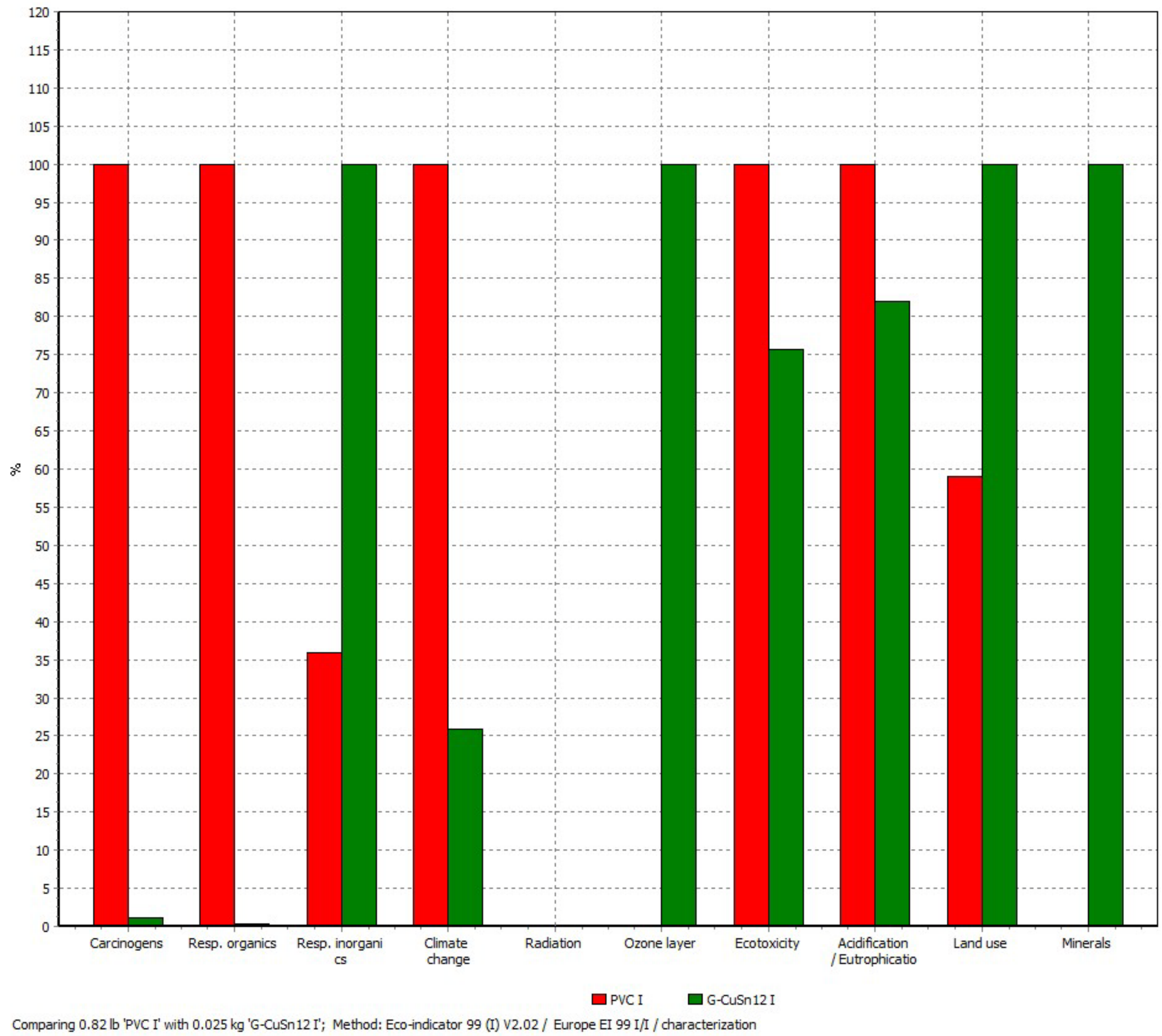


Figure R.3: Environmental impact characterization for PVC and brass

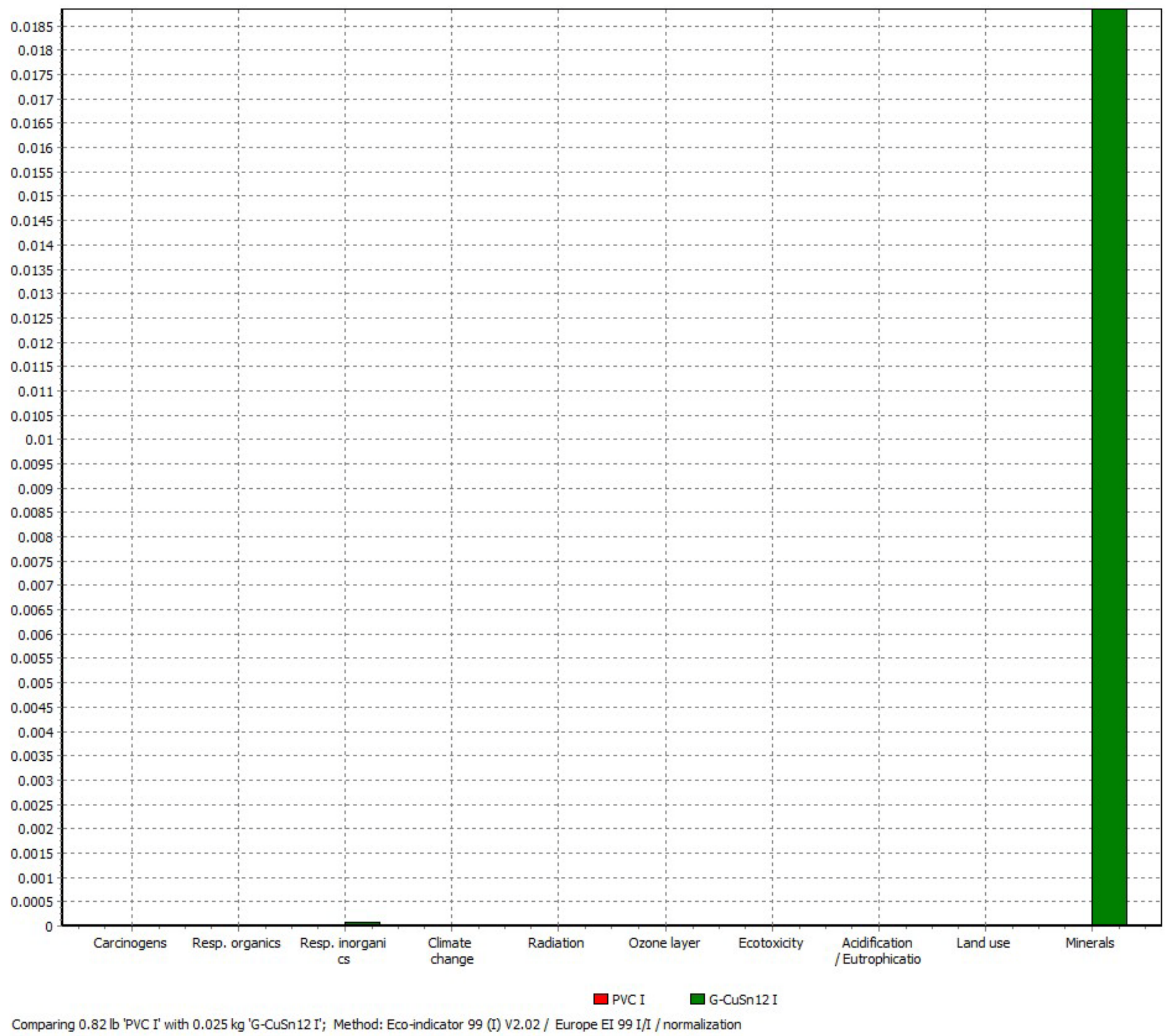


Figure R.4: Environmental impact normalization for PVC and brass

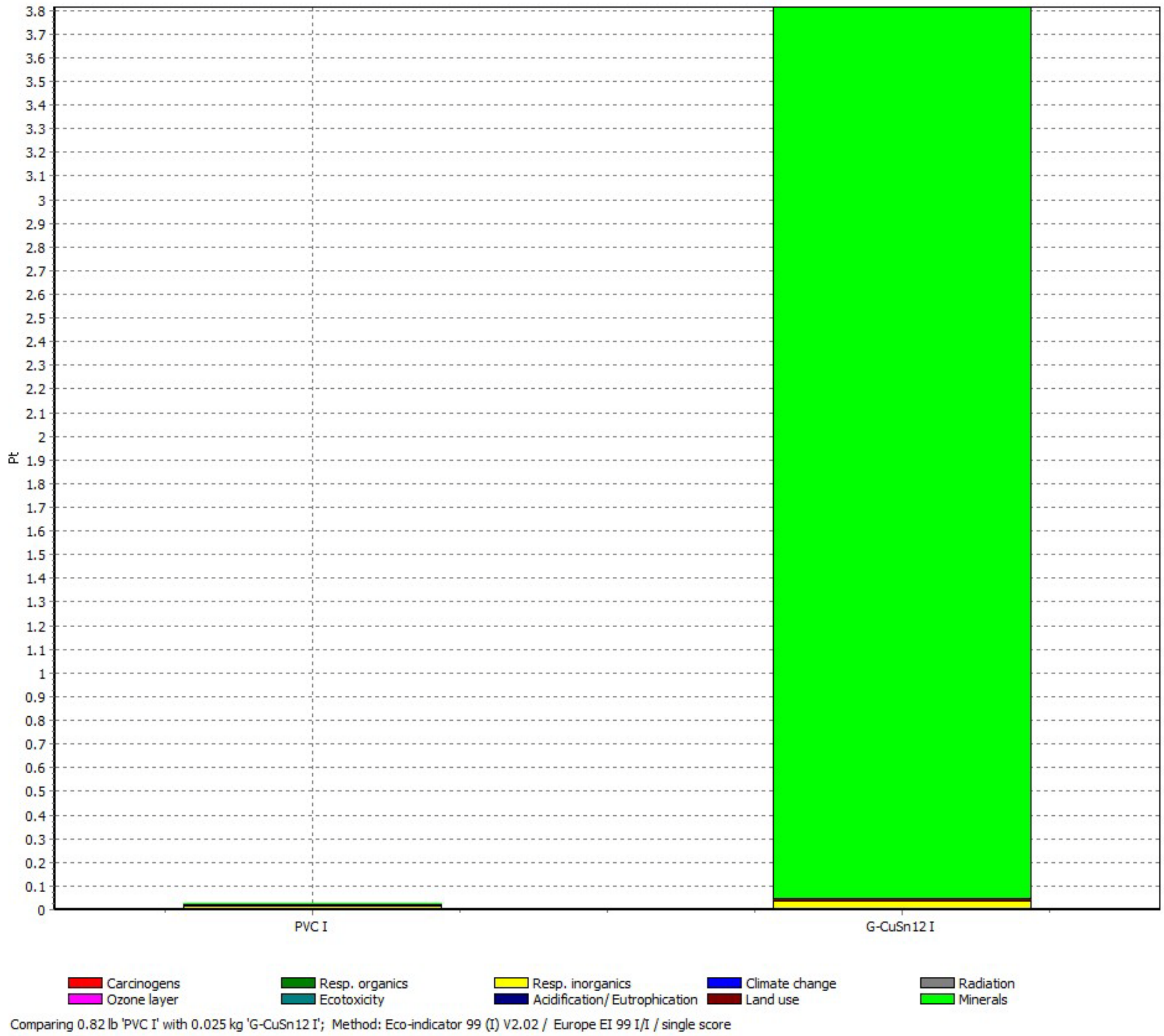
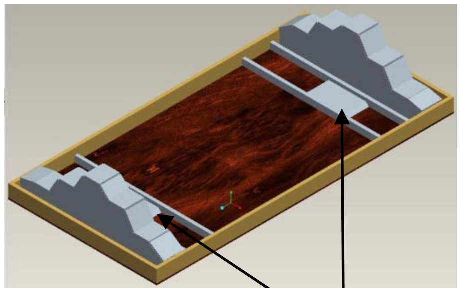


Figure R.3: Environmental impact single score for PVC and brass

APPENDIX S: DESCRIPTION OF ENGINEERING CHANGES SINCE DESIGN REVIEW #3

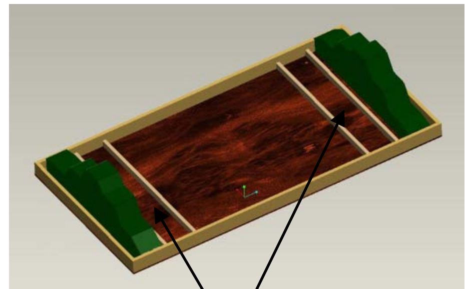
Battlefield

WAS:



Battlefield with Ramps

IS:



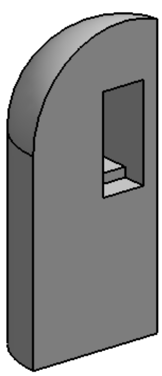
Battlefield without Ramps

Notes:
Removed ramps from each end of the battlefield because the driving motors would hit the ramp as the tank drove onto it.

Team 6	
Project: ME 250 Redesign	
Ref Drawing: Battlefield	
Change Made By: Stephanie Klosek	4/13/2009
Authorized By: Stephen Oldham	4/13/2009

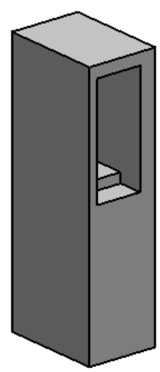
Compression Spring Tank Prototype

WAS:



6” x 2.765” x 2”

IS:

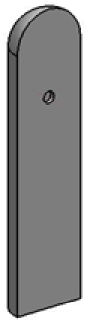


5.322” x 1.382” x 2”

Notes:
Removed all unnecessary materials to reduce weight on tank platform. Unable to machine curve due to inability to use the CNC Mill.

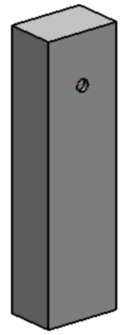
Team 6	
Project: ME 250 Redesign	
Ref Drawing: Aiming Servo Motor Column	
Change Made By: Christopher Liang	4/13/2009
Authorized By: Leah Gussenbauer	4/13/2009

WAS:



6” x 1.5 “ x 0.75”

IS:



5.385” x 1.5” x 1”

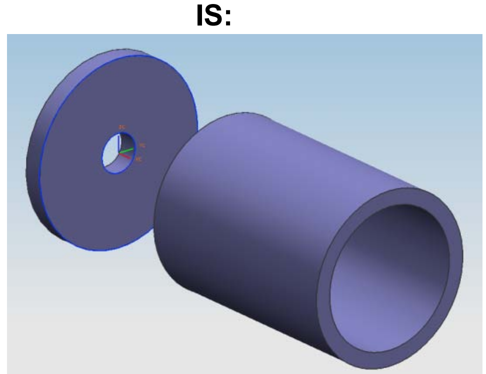
Notes:
Unable to machine curve due to inability to use the CNC Mill.

Team 6
Project: ME 250 Redesign
Ref Drawing: Aiming Support Column
Change Made By: Christopher Liang 4/13/2009
Authorized By: Leah Gussenbauer 4/13/2009

WAS:

3” x 2.2” x 1.8”

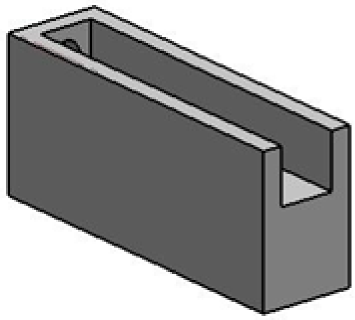
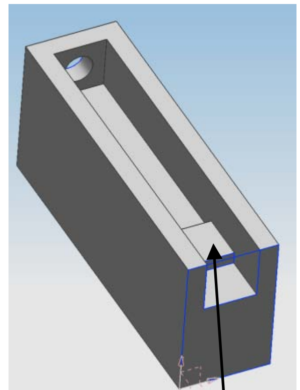
IS:



Barrel: 2.75” x 2.375” x 2”
Barrel End Cap 0.25” x 2.375” x 0.50”

Notes:
Purchased PVC Pipe rather than manually lathe the barrel. Attached a 2.375” x 2.375” square PVC piece to purchased PVC pipe and used dremel to remove excess material. drilled a .50” hole in the center of the barrel end cap.

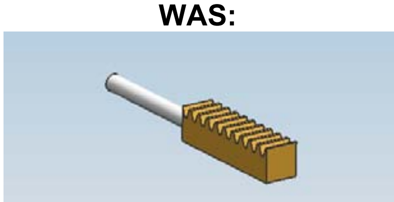
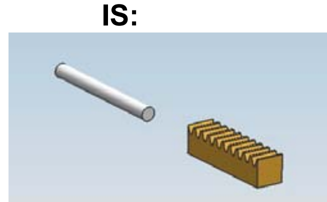
Team 6
Project: ME 250 Redesign
Ref Drawing: Barrel
Change Made By: Leah Gussenbauer 4/13/2009
Authorized By: Christopher Liang 4/13/2009

WAS:	**IS:**
	

0.125” x 0.56” x 0.5” PVC piece

Notes:
Inserted PVC piece to stop the rack from shooting out of the barrel

Team 6	
Project: ME 250 Redesign	
Ref Drawing: Body	
Change Made By: Leah Gussenbauer	4/13/2009
Authorized By: Christopher Liang	4/13/2009

WAS:	**IS:**
	

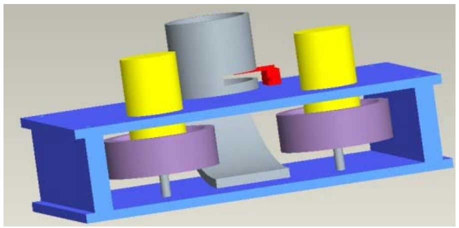
Replaced dowel pin with size 10 bolt and attached 0.50” washer to size 10 nut. Fastened washer/nut to size 10 bolt. Press fit brass rack into 1/4”-20 brass nut. Rack bolt are not attached to each other

Notes:
Rack was too small to drill a hole and insert a dowel pin. Instead, replaced dowel pin with size 10 bolt and kept bolt and rack separate. Attached washer and size 10 onto bolt to hold spring. Press fit brass rack into 1/4”-20 brass nut to stop rack from shooting out of the barrel

Team 6	
Project: ME 250 Redesign	
Ref Drawing: Rack Assembly	
Change Made By: Leah Gussenbauer	4/13/2009
Authorized By: Christopher Liang	4/13/2009

Pitching Machine Tank Prototype

WAS:



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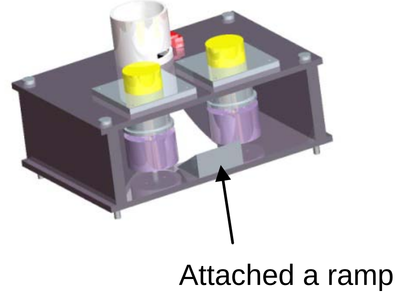
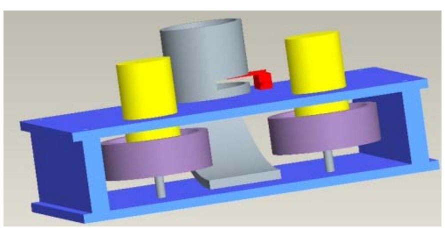


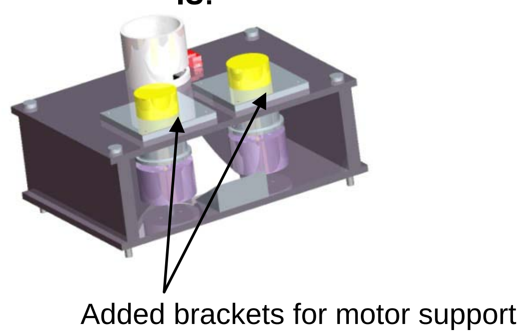
Notes:
Ramp was attached to launch the foam ball at an angle when fired.

Team 6	
Project: ME 250 Redesign	
Ref Drawing: Pitching Machine Tank Prototype	
Change Made By: Stephanie Klosek	4/13/2009
Authorized By: Stephen Oldham	4/13/2009

WAS:



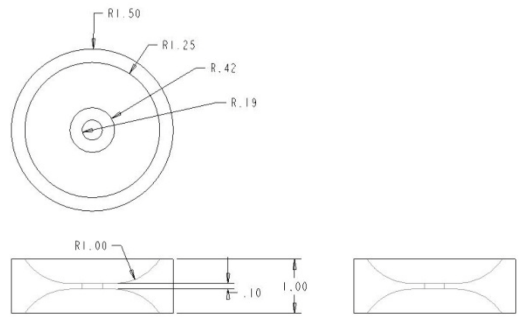
IS:

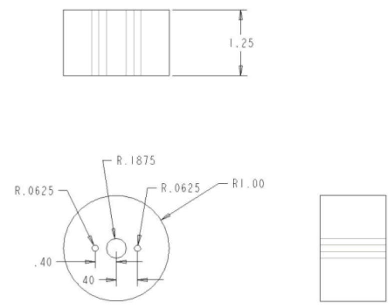


Notes:
Brackets were added to support the motors and keep them from rotating.

Team 6	
Project: ME 250 Redesign	
Ref Drawing: Pitching Machine Tank Prototype	
Change Made By: Stephen Oldham	4/13/2009
Authorized By: Stephanie Klosek	4/13/2009

WAS: **IS:**

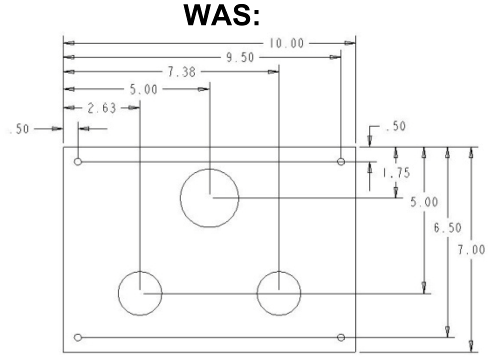


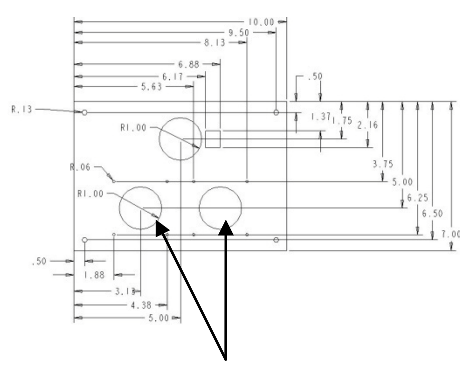


Notes:
Wheels are now solid 2" diameter
instead of material removed and 3" diameter.

Team 6	
Project: ME 250 Redesign	
Ref Drawing: Spinning Wheels	
Change Made By: Stephanie Klosek	4/13/2009
Authorized By: Stephen Oldham	4/13/2009

WAS: **IS:**



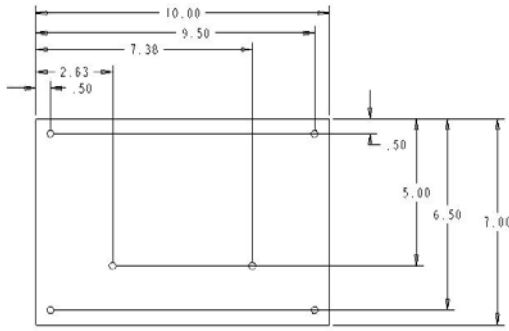


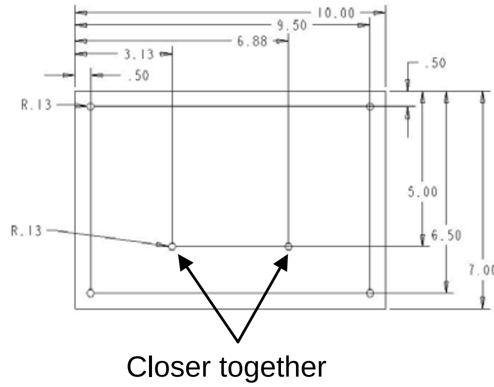
Larger radius

Notes:
Radius increased to 1" to allow the
motor bracket to fit and account for smaller
wheels.

Team 6	
Project: ME 250 Redesign	
Ref Drawing: Top Plate	
Change Made By: Stephen Oldham	4/13/2009
Authorized By: Stephanie Klosek	4/13/2009

WAS: **IS:**





Notes:
Holes were positioned closer together
to account for the smaller wheels.

Team 6	
Project: ME 250 Redesign	
Ref Drawing: Base	
Change Made By: Stephen Oldham	4/13/2009
Authorized By: Stephanie Klosek	4/13/2009

APPENDIX T: TANK WARS HANDOUT

ME 250 Fall 2009 Project
Tank Wars

1. Objective

To gain experience designing and manufacturing a prototype according to provided specifications. As a part of the project you will learn the design process from the concept generation phase, to a final design, to a manufactured prototype. You will also gain experience with CAD software (UG, ProE or Catia) and tools such as the CNC mill, CNC lathe, band saw and drill press. Finally you will apply theoretical knowledge from other classes to analyze your design and prove its functionality.

2. Tank Wars

You will be a part of a team with 3-4 other students. Your team will design and manufacture a tank prototype with a firing mechanism that launches foam balls. Your tank prototype will attach to a tank platform which includes motors and wheels for driving, and an Arduino control system which moves your motors. Your team will also be required to write the Arduino code to drive your motors as desired.

At the end of the semester, your tank prototype will compete against all other teams in the Tank Wars competition. The goal of the competition is to destroy all of your opponent's buildings (represented by stacked balsa wood blocks) before your opponent destroys your buildings. During this competition you will attach your tank prototype to a tank platform, connect all motors to Arduino, load your program into Arduino, and attach the wireless transmitter/receiver into a laptop to control your tank's movements remotely. You will then place your tank on the battlefield shown in Figure 1 and compete using the rules listed below.

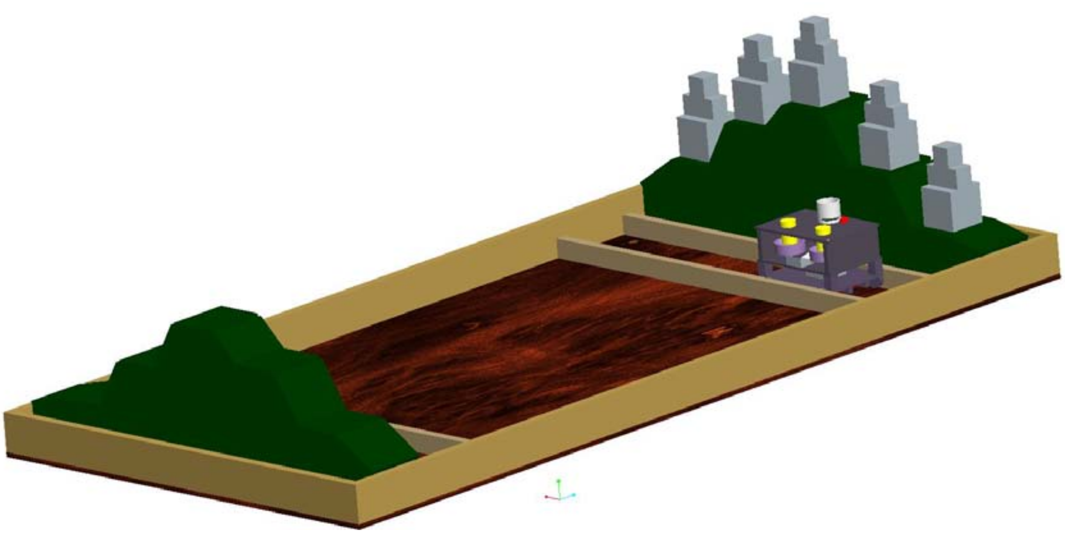


Figure 1: Battlefield with buildings and example tank

Competition Rules

1. Safety glasses must be worn during play
2. Time to attach tank prototype to tank platform and load Arduino code must not exceed 3 minutes
3. Time to remove tank prototype from tank platform must not exceed 2 minutes

4. Manual interaction with tank prototype or platform during play is limited to loading the tank
5. Teams alternate turns (load, aim, fire), firing one ball per turn
6. Teams may only aim at objects on the battlefield (opponent's tank or buildings)
7. A single knocked off block denotes a destroyed building
8. Team with the most destroyed buildings at the end of the match wins
9. Match time limit is 10 minutes (with an even number of turns)
10. First tie-breaker: team with the most total blocks knocked off during the match wins
11. Second tie-breaker: center building is reset, team with the most blocks knocked off wins (with even turns)

3. Tank Prototype Specifications

Your team is provided with the following specifications for your tank prototype. Your design will be graded on how well it complies with these specifications.

1. Assembled tank prototype must fit inside a 7 in. x 6 in. x 6 in. space. However it can expand during play.
2. Tank prototype (without tank platform) has a weight limit of 3 kg.
3. The foam ball is 1.75 in. in diameter and weighs 4.5 g.
4. The foam ball must be fired a horizontal distance of 6 ft, and must hit buildings on platforms ranging from 5 to 15 in. in height.
5. Tank prototype is limited to 2 servos and either 2 DC motors or 1 stepper motor to control its motion. More motors cannot attach to the Arduino motor shield.
6. If motors draw more than 0.6 A of continuous current or 1.2 A peak current, and they need specific controls, they must be attached to an H-Bridge that can support their current load.
7. If motors draw more than 0.6 A of continuous current or 1.2 A peak current, but do not need specific controls, a MOSFET may be used to act as a switch to control the motors.
8. The Arduino supplies 5 V, if more voltage is needed the tank prototype must include a battery to supply that voltage.
9. Motors and other moving parts should be protected from opponent's shots. If your tank is damaged during play you may not repair it.
10. The tank prototype may not rapid fire; only one ball may be loaded and fired at once.
11. Explosives, fire or compressed air tanks may not be used in firing mechanisms.
12. Design must be approved by a GSI/Professor before manufacturing

4. Manufacturing

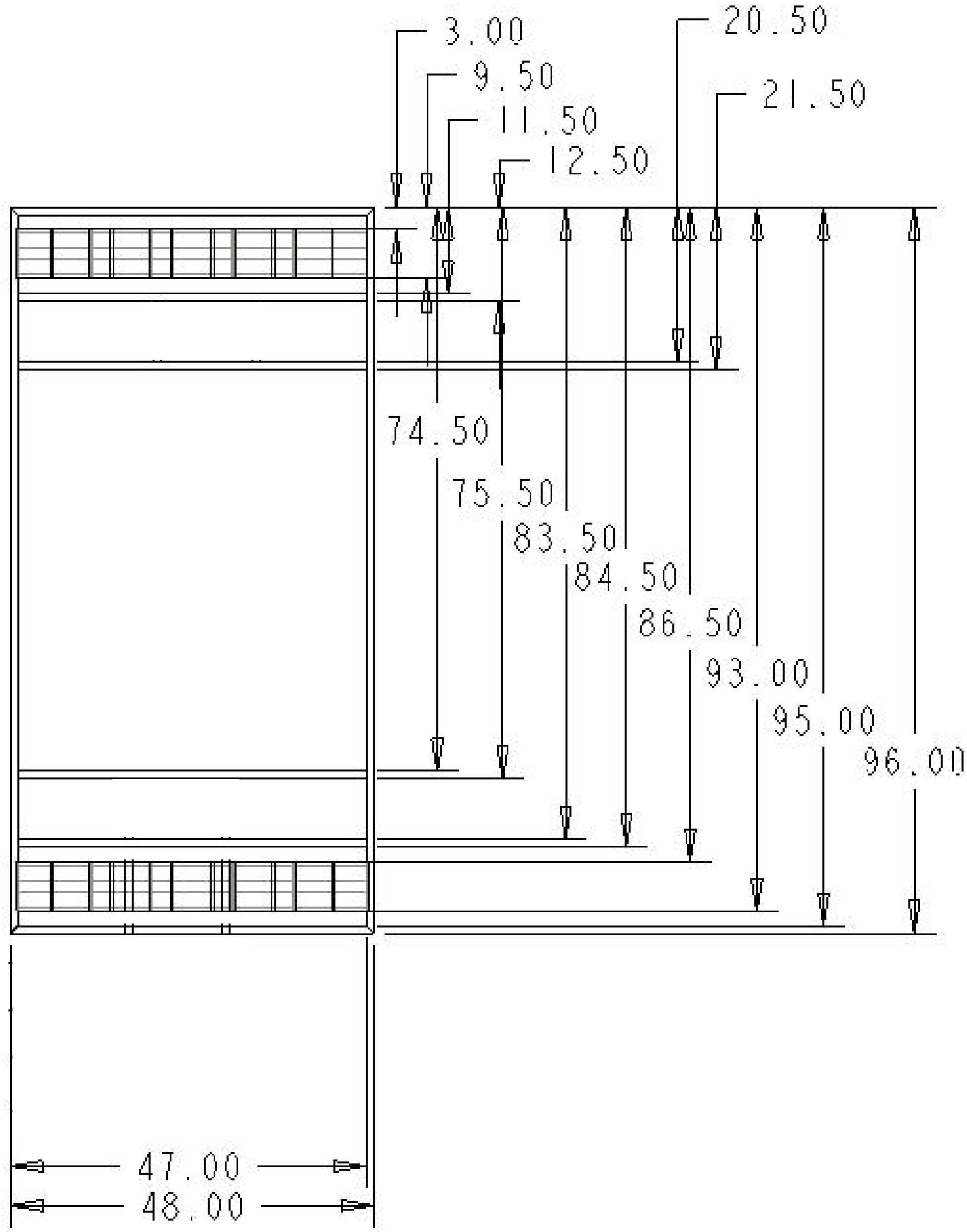
Your team will be provided with a list of materials chosen to cover a wide range of potential launching mechanisms. The following types of materials will be available. Within each category there will be objects with a variety of specifications. An additional budget will be available to your team if you need components or sizes of objects not included in this list. However all purchases must be approved by the GSI/Professor.

1. Raw materials (PVC, wood, sheet metal, wax blocks)
2. Motors (DC, servo, stepper)
3. Gears (rack, pinion)
4. Springs (linear, torsional)
5. Bearings (roller, sleeve)
6. Fasteners (nuts and bolts, screws, epoxy)

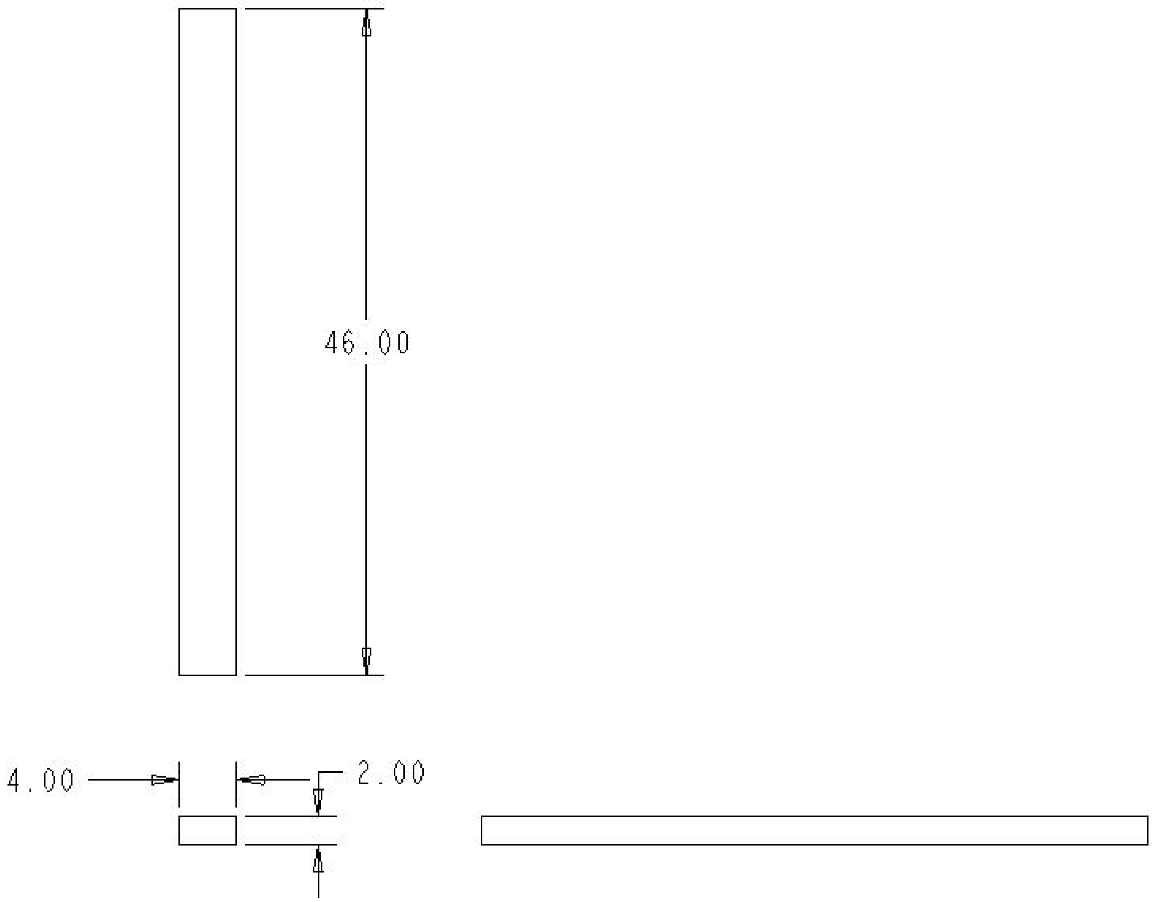
The following tools will be available for you to use while manufacturing and assembling your prototype. A variety of size bits will be available for each of these tools.

1. CNC mill
2. CNC lathe
3. Band saw
4. Drill press
5. Other hand tools as needed

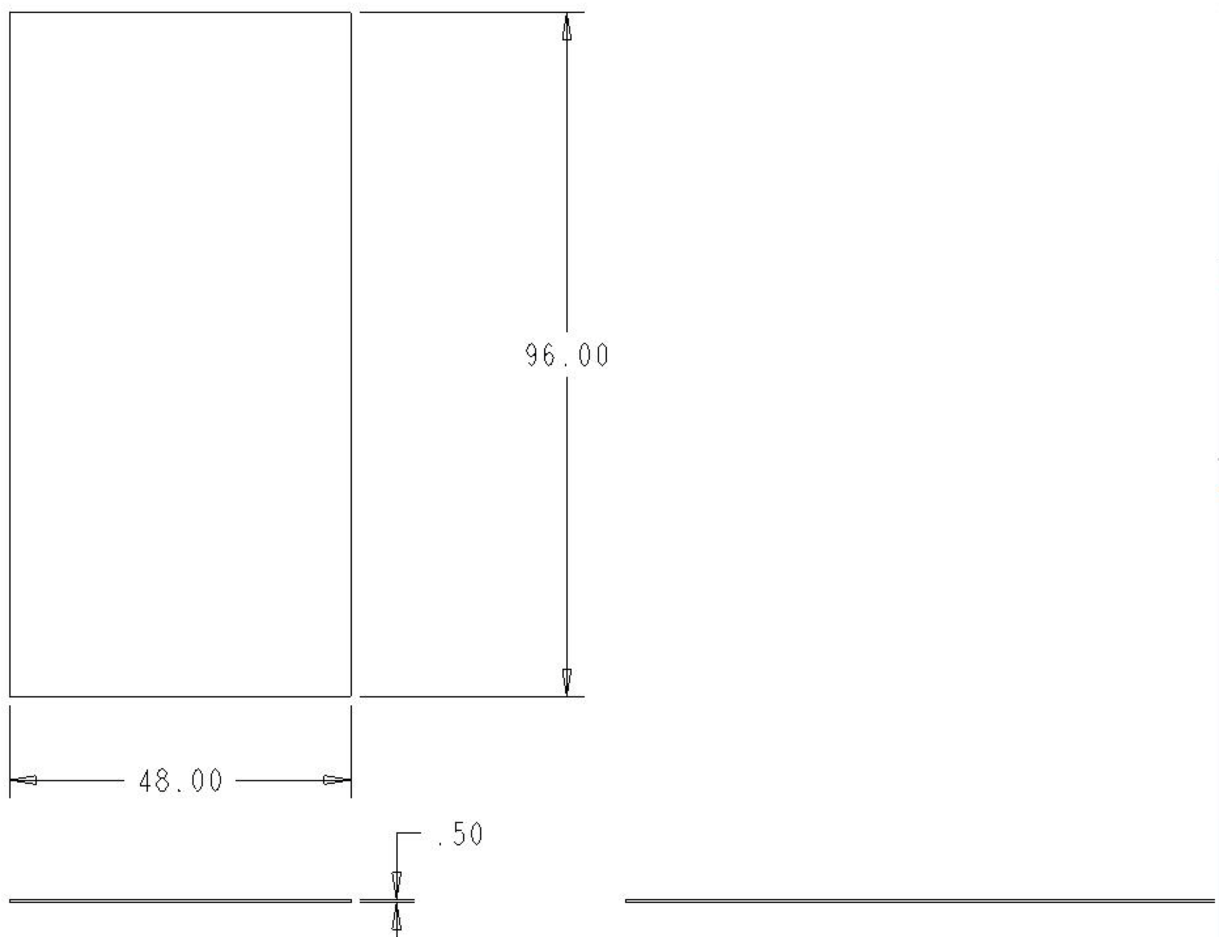
APPENDIX U.1: BATTLEFIELD DIMENSIONS – ASSEMBLED BATTLEFIELD



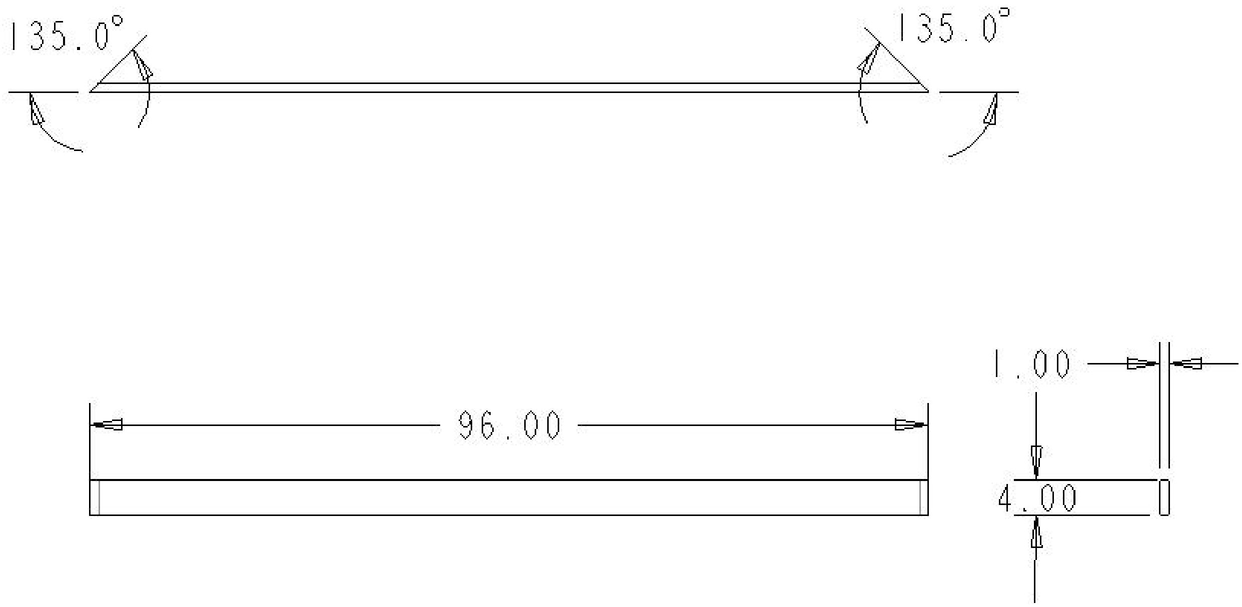
APPENDIX U.2: BATTLEFIELD DIMENSIONS – HILL SUPPORT 2X4 BOARD



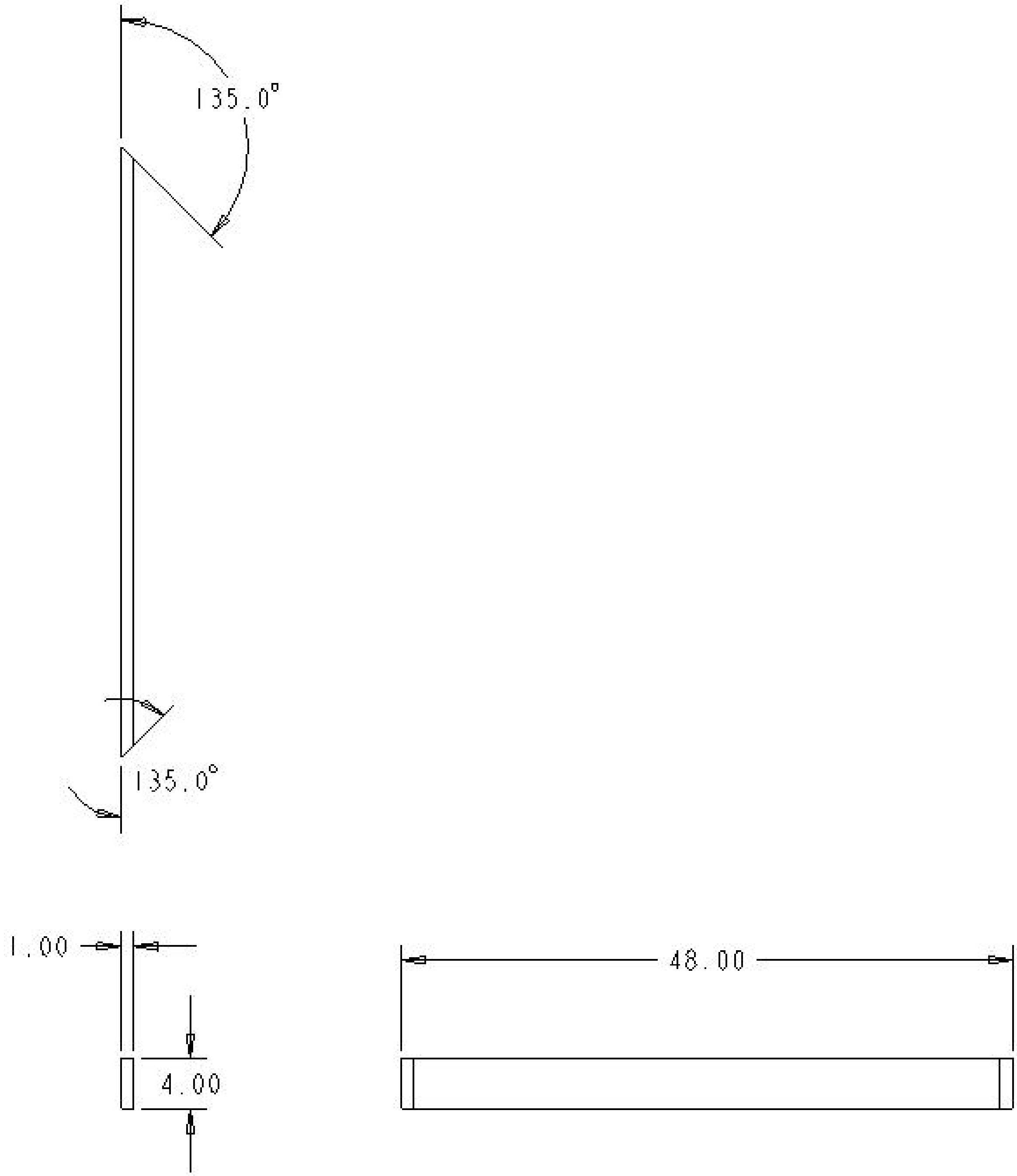
APPENDIX U.3: BATTLEFIELD DIMENSIONS – BATTLEFIELD BASE



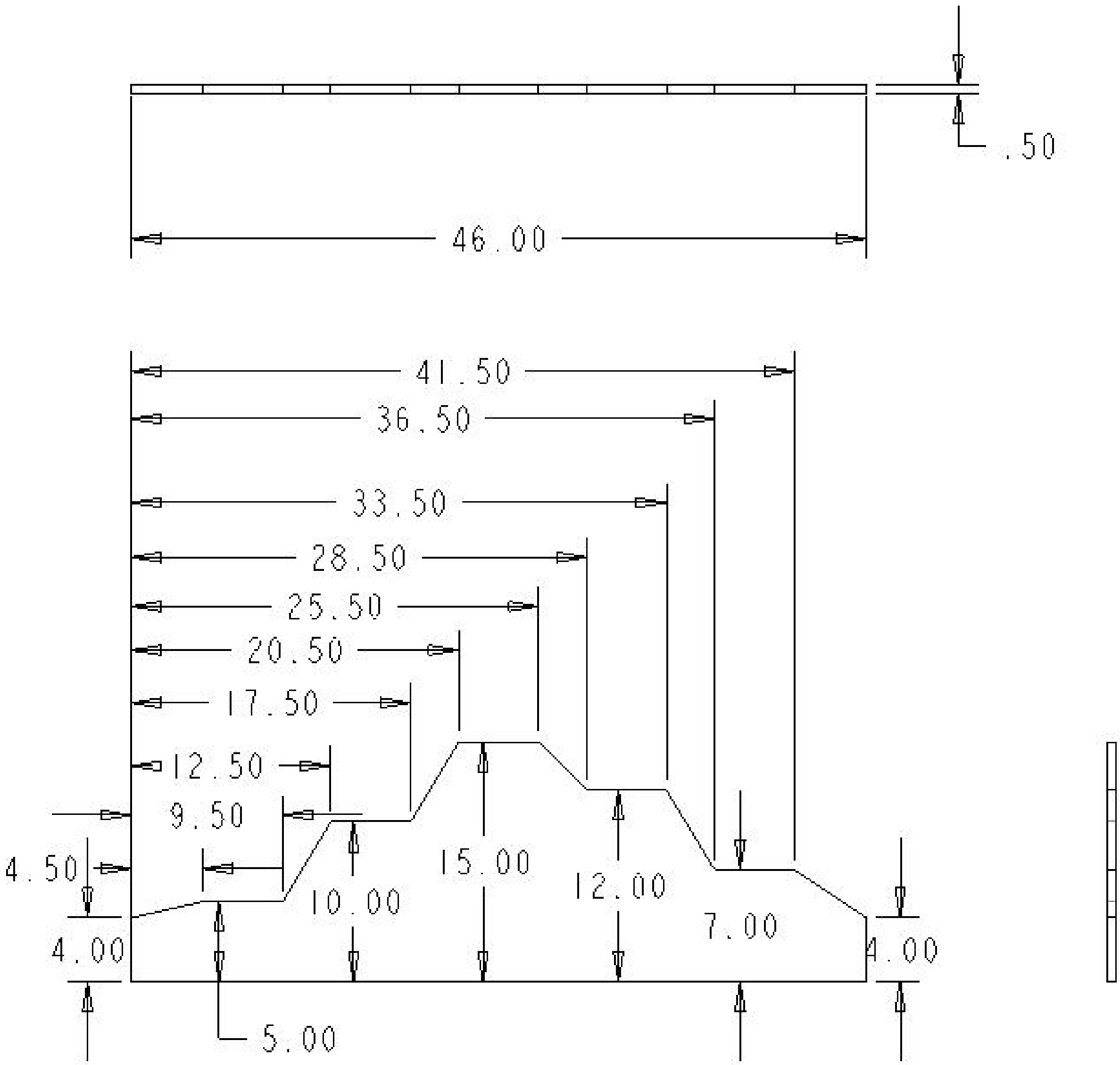
APPENDIX U.4: BATTLEFIELD DIMENSIONS – LONG BATTLEFIELD WALL



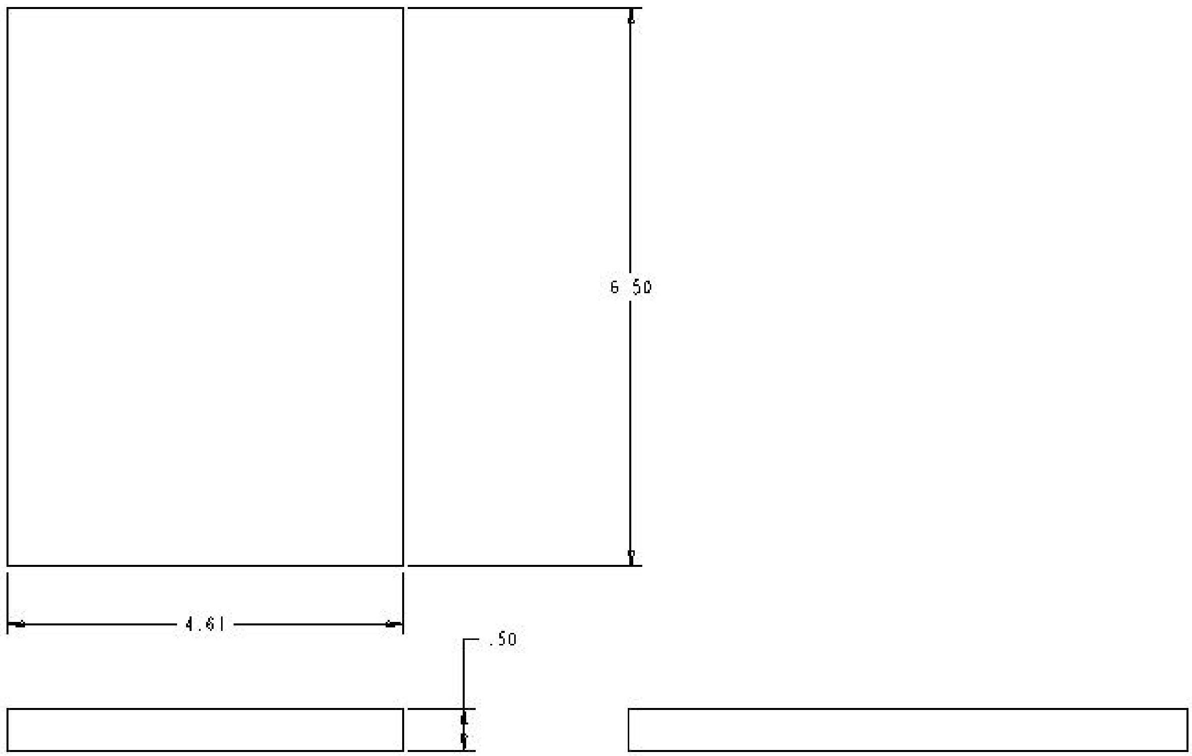
APPENDIX U.5: BATTLEFIELD DIMENSIONS – SHORT BATTLEFIELD WALL



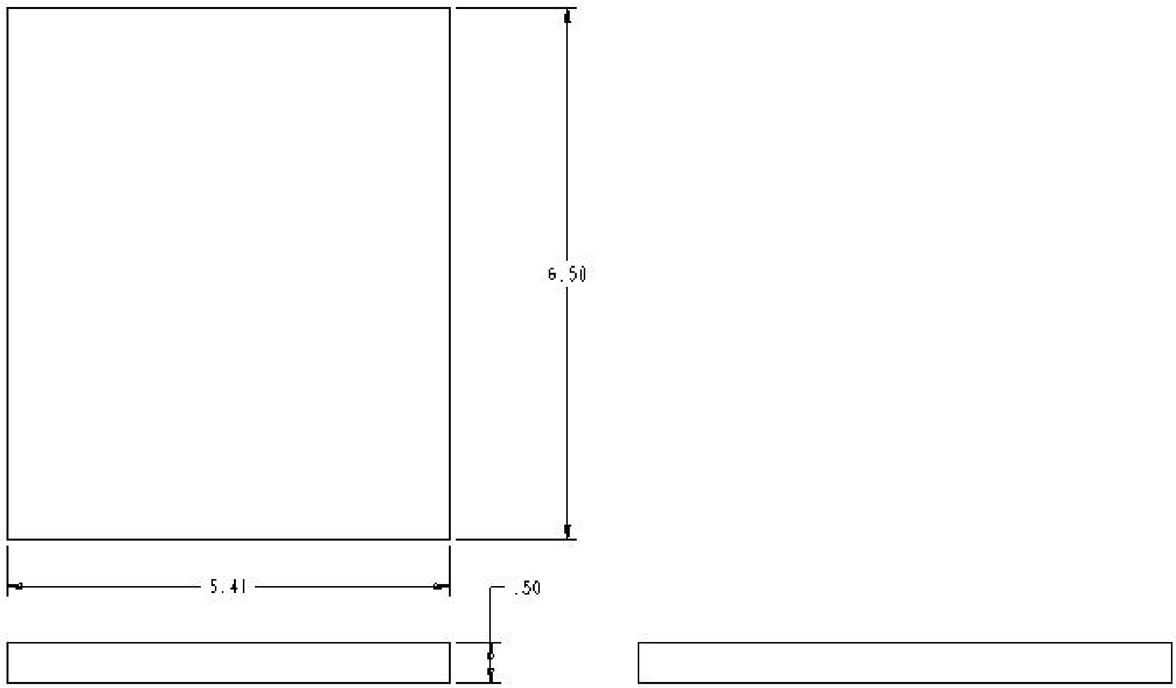
APPENDIX U.6: BATTLEFIELD DIMENSIONS – HILL



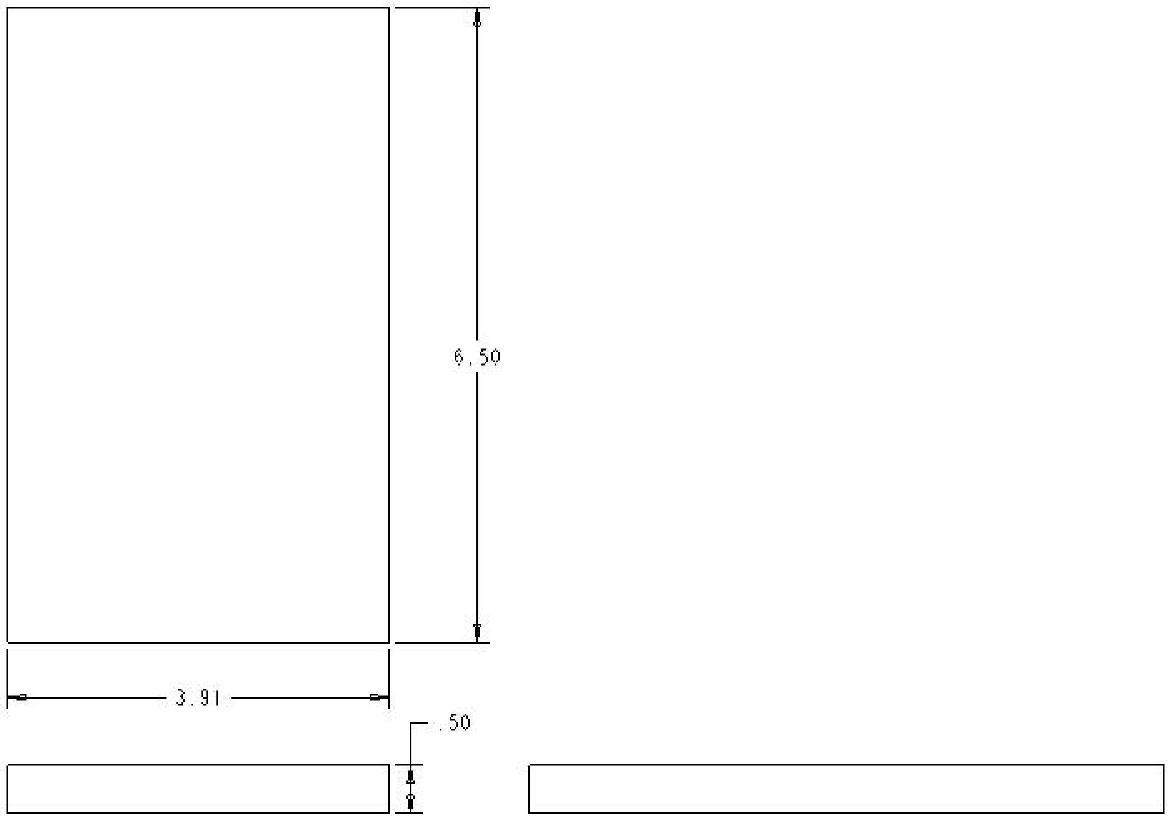
APPENDIX U.7: BATTLEFIELD DIMENSIONS – ANGLED HILL PLATFORM 1



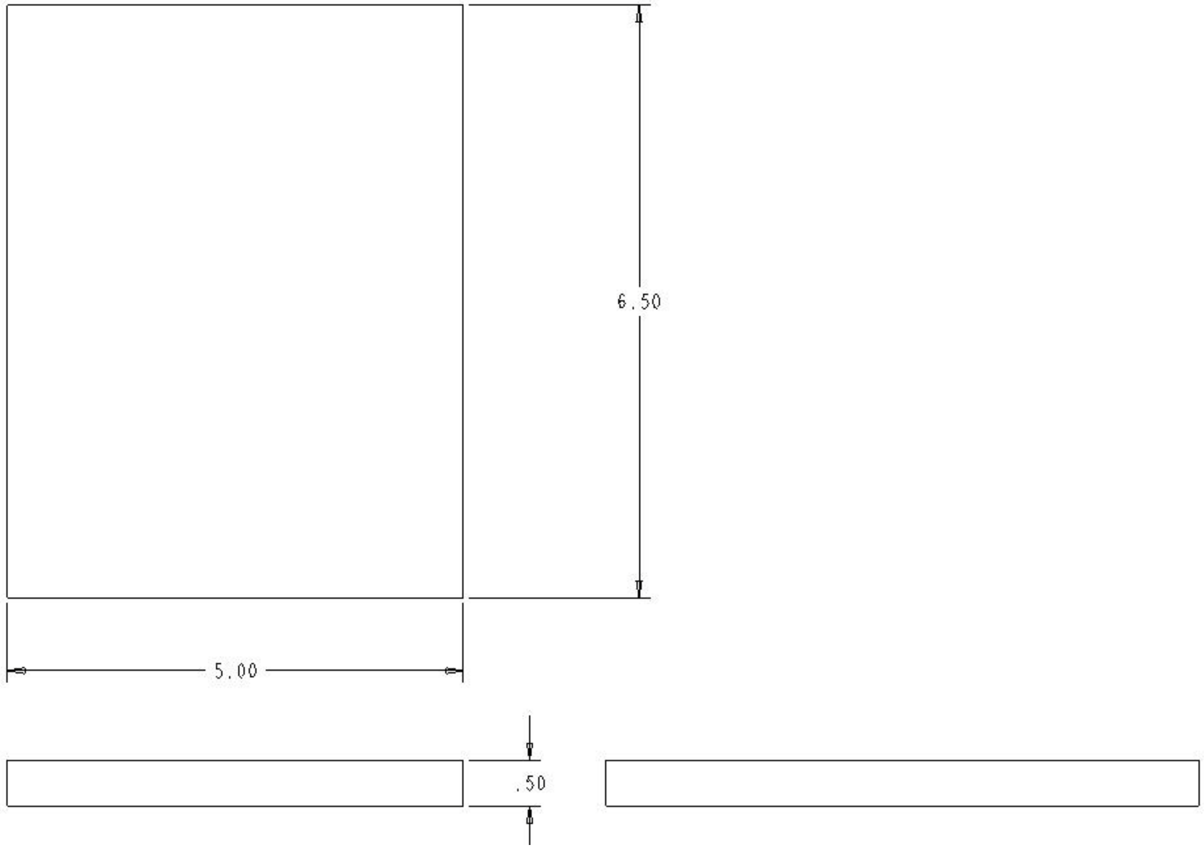
APPENDIX U.8: BATTLEFIELD DIMENSIONS – ANGLED HILL PLATFORM 2



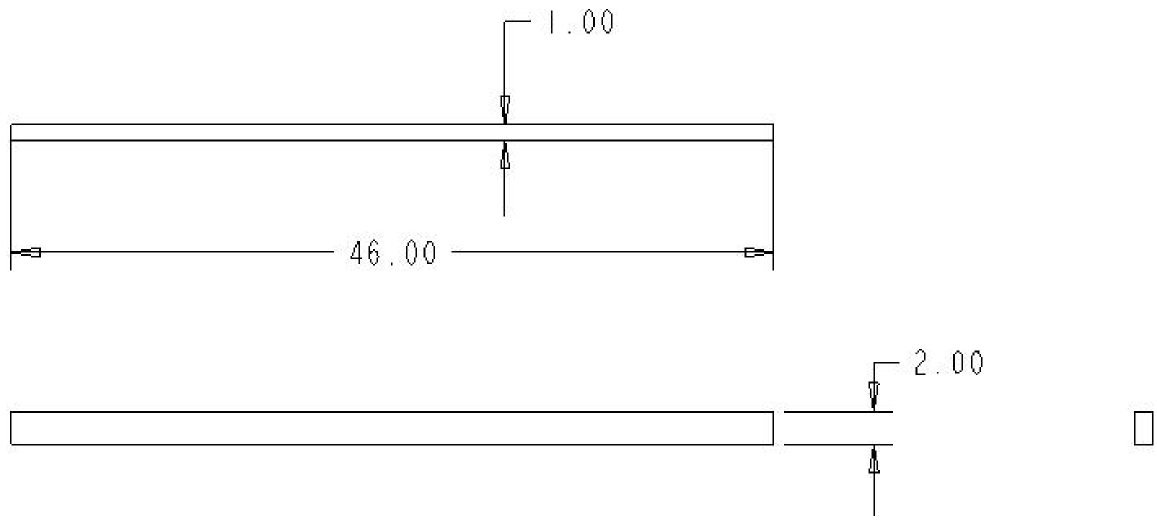
APPENDIX U.9: BATTLEFIELD DIMENSIONS – ANGLED HILL PLATFORM 3



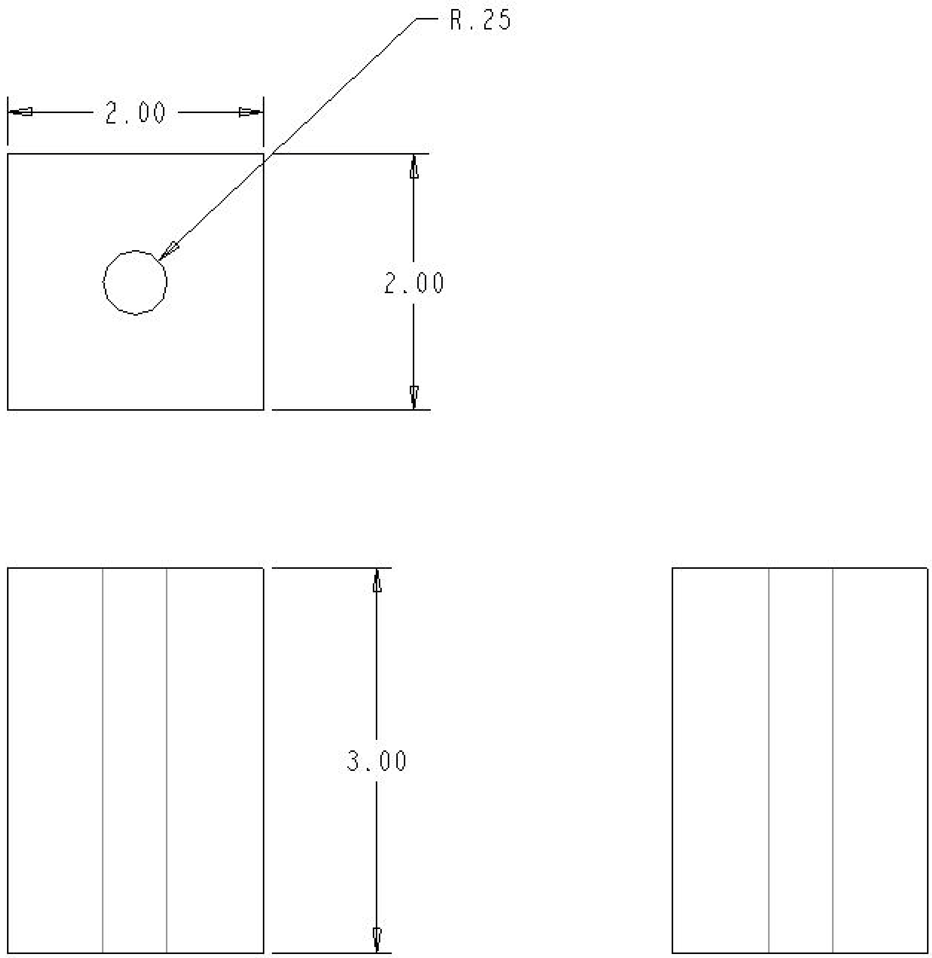
APPENDIX U.10: BATTLEFIELD DIMENSIONS – HORIZONTAL HIL PLATFORM



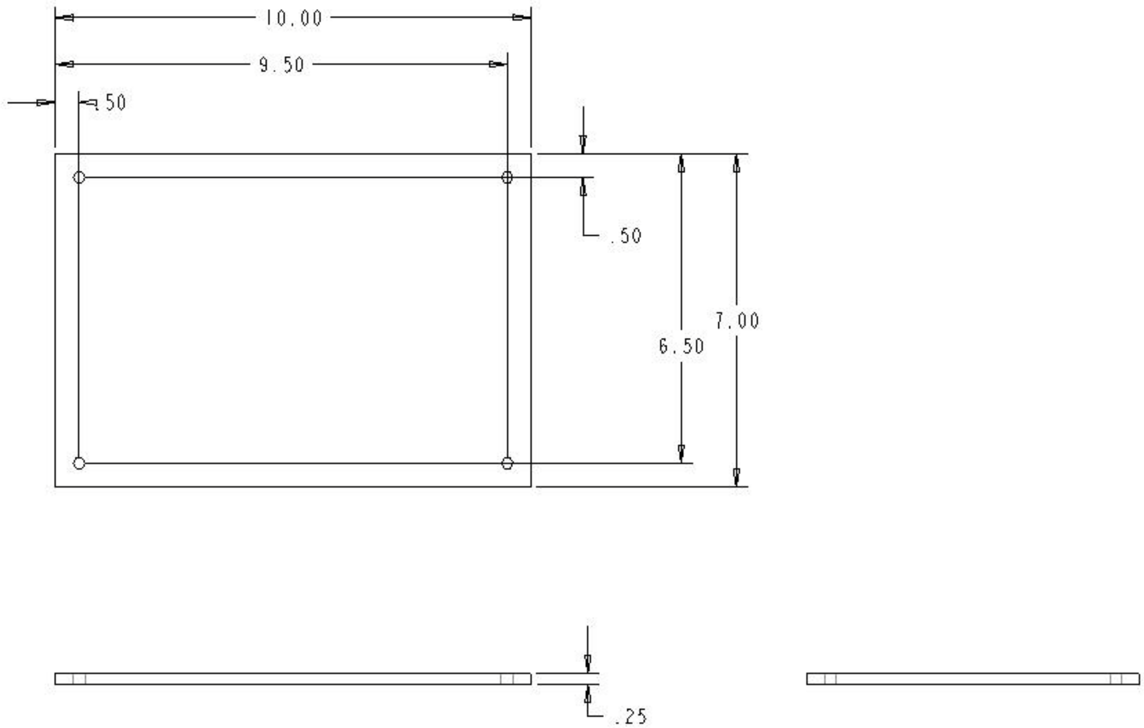
APPENDIX U.11: BATTLEFIELD DIMENSIONS – ROAD BARRIER



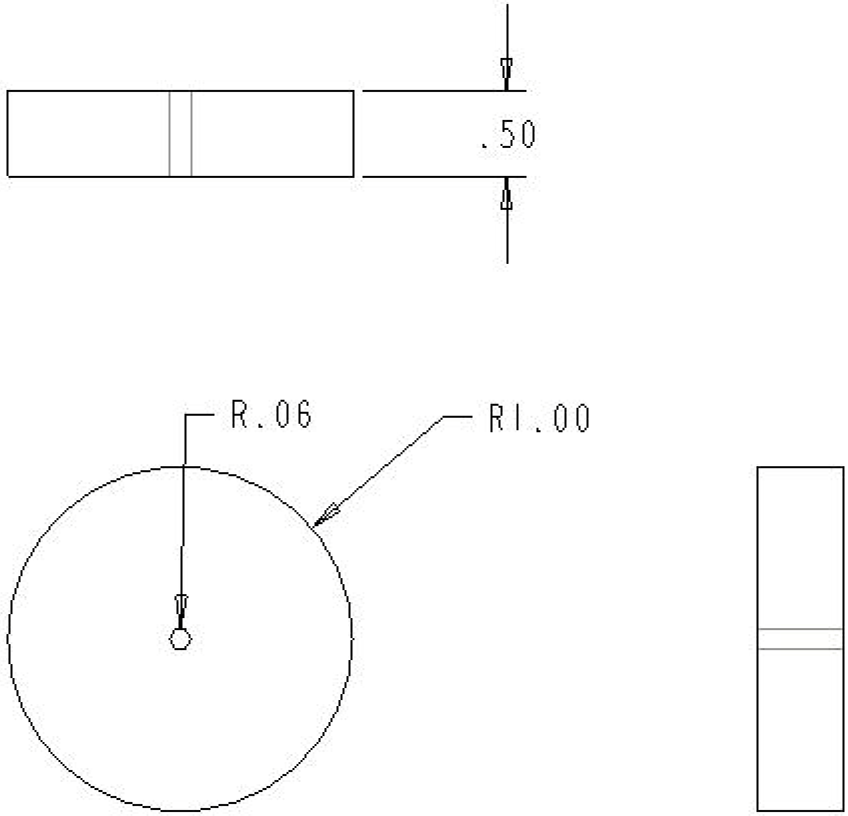
APPENDIX U.12: BATTLEFIELD DIMENSIONS – NET SUPPORTS



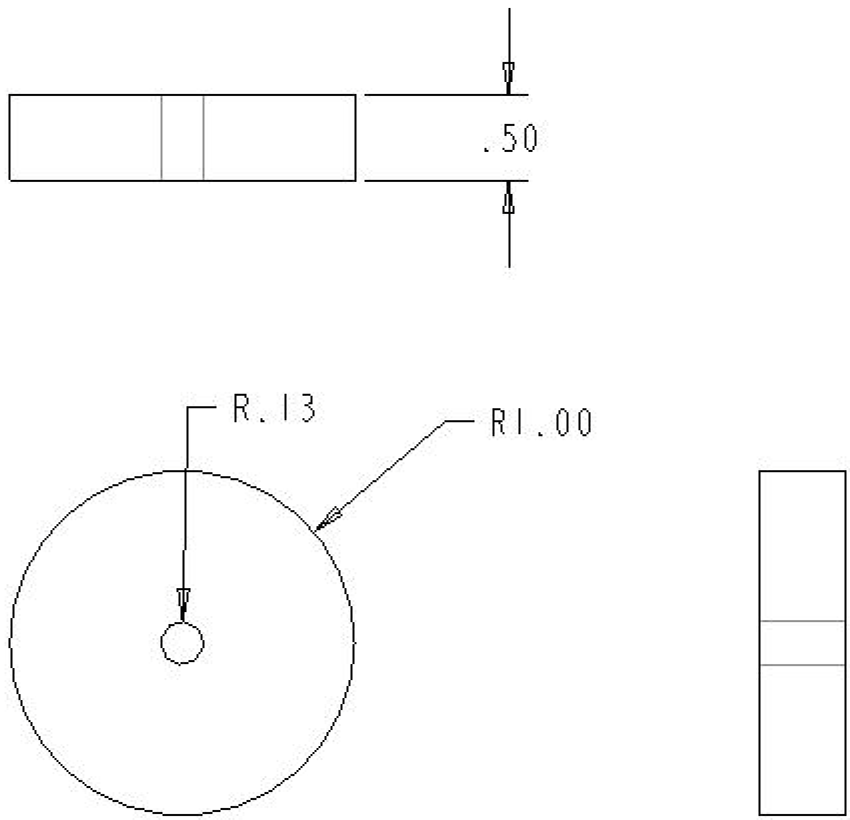
APPENDIX V.1: TANK PLATFORM DIMENSIONS – BASEPLATE



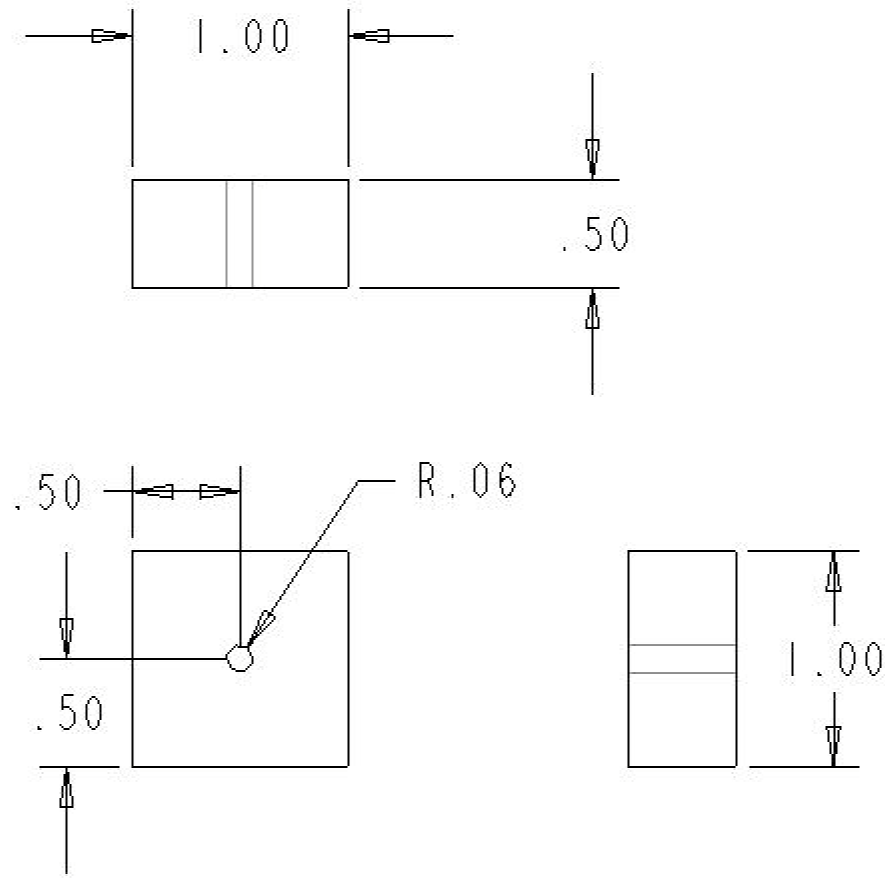
APPENDIX V.2: TANK PLATFORM DIMENSIONS – REAR WHEEL



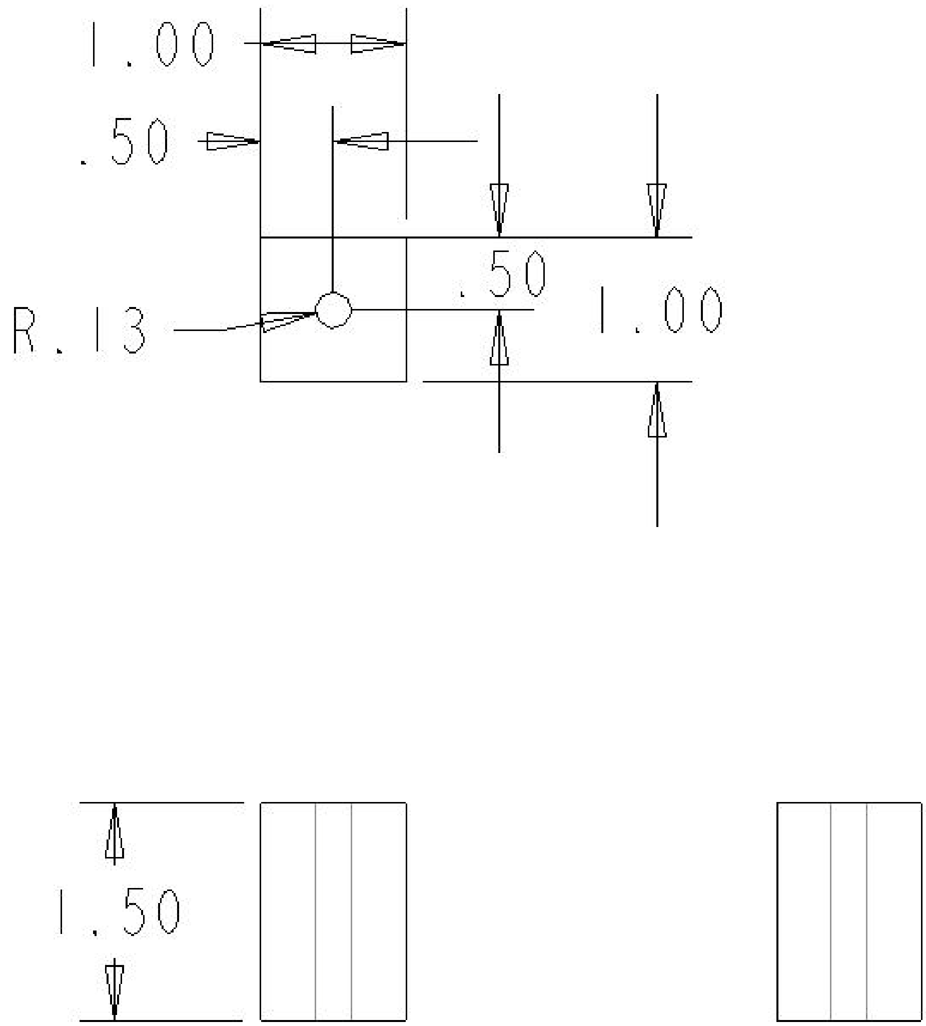
APPENDIX V.3: TANK PLATFORM DIMENSIONS – FRONT WHEEL



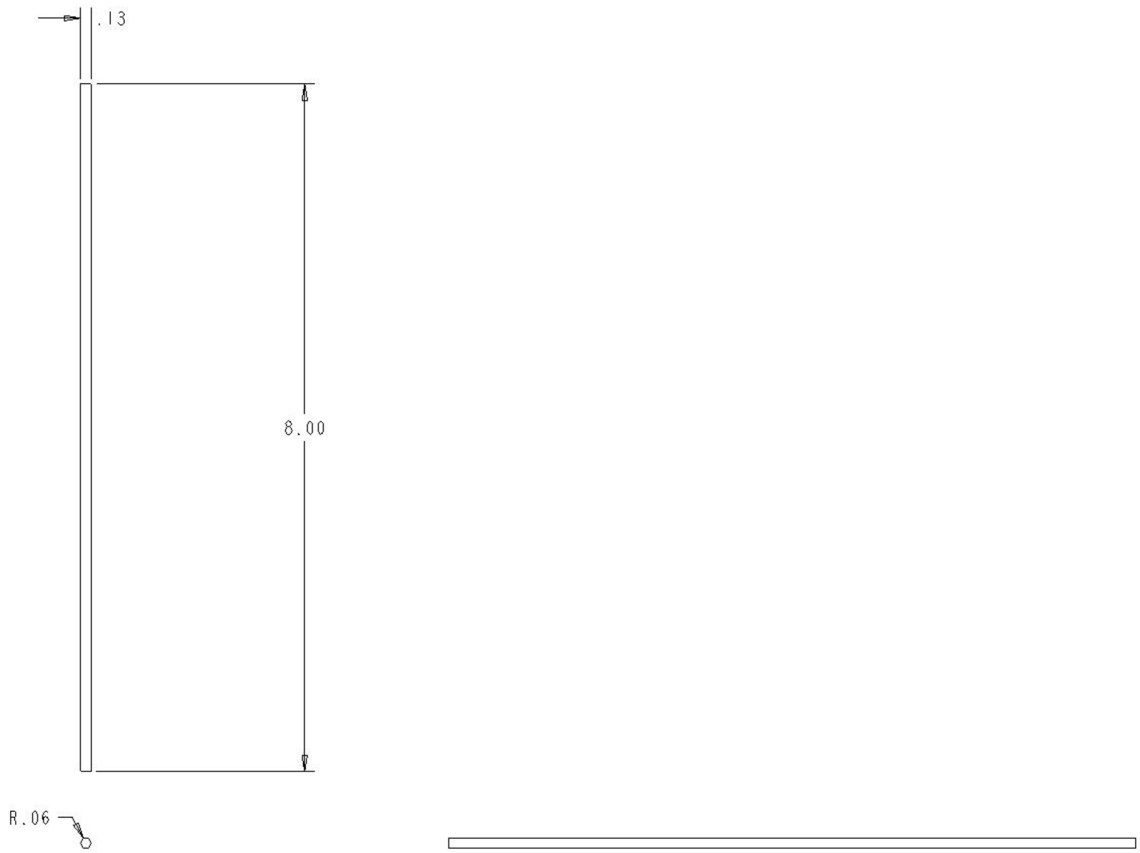
APPENDIX V.4: TANK PLATFORM DIMENSIONS – AXLE BRACKET



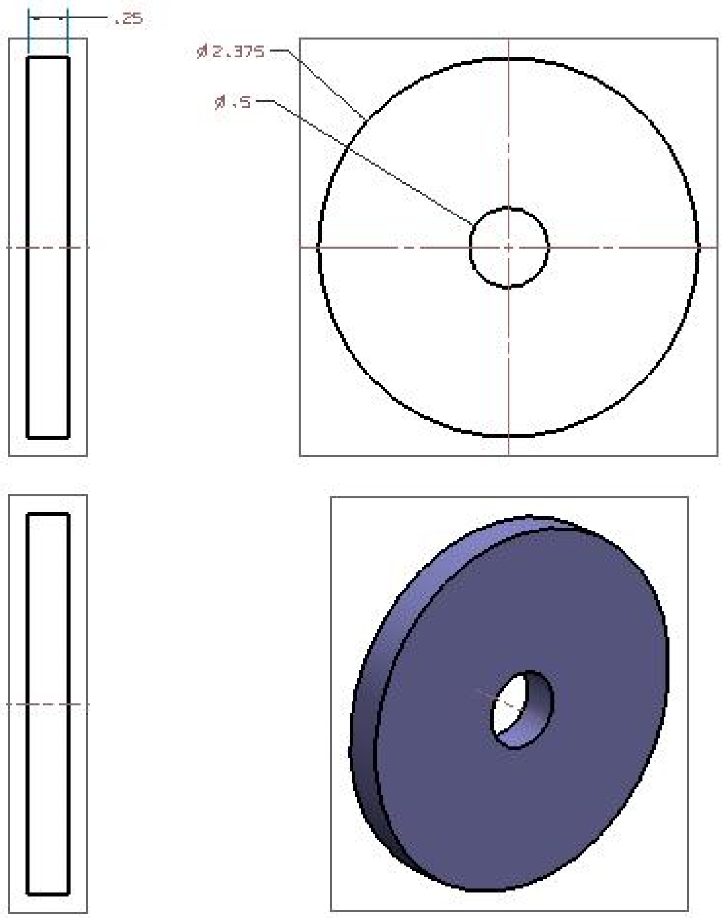
APPENDIX V.5: TANK PLATFORM DIMENSIONS – SPACER BLOCK



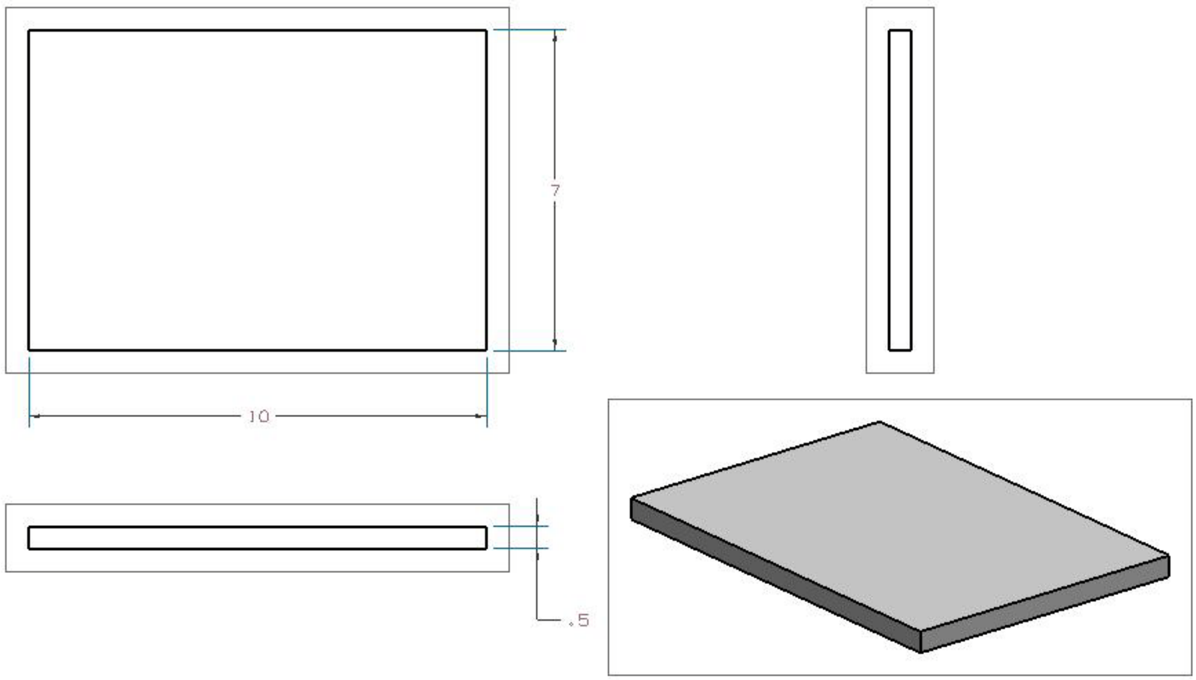
APPENDIX V.6: TANK PLATFORM DIMENSIONS – REAR AXLE



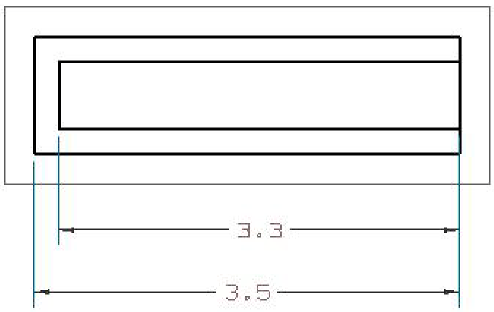
APPENDIX W.1: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS – BARREL END CAP

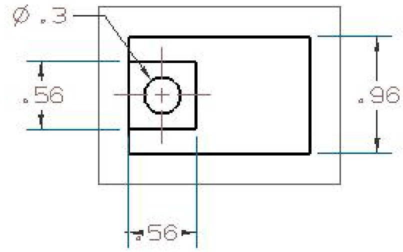


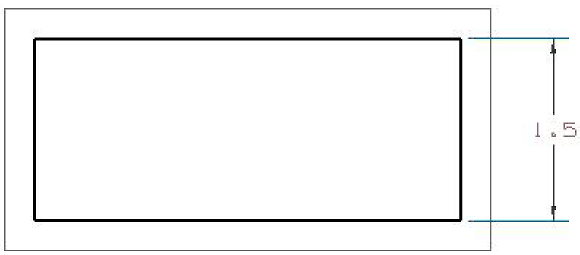
APPENDIX W.2: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS - BASE

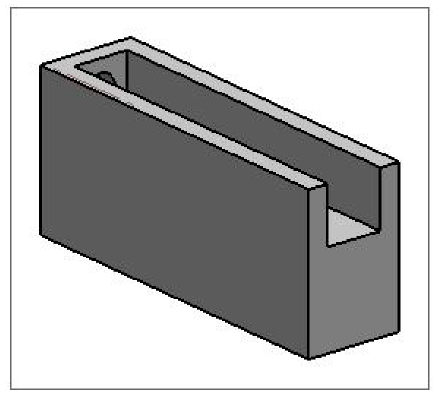


APPENDIX W.3: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS - BODY

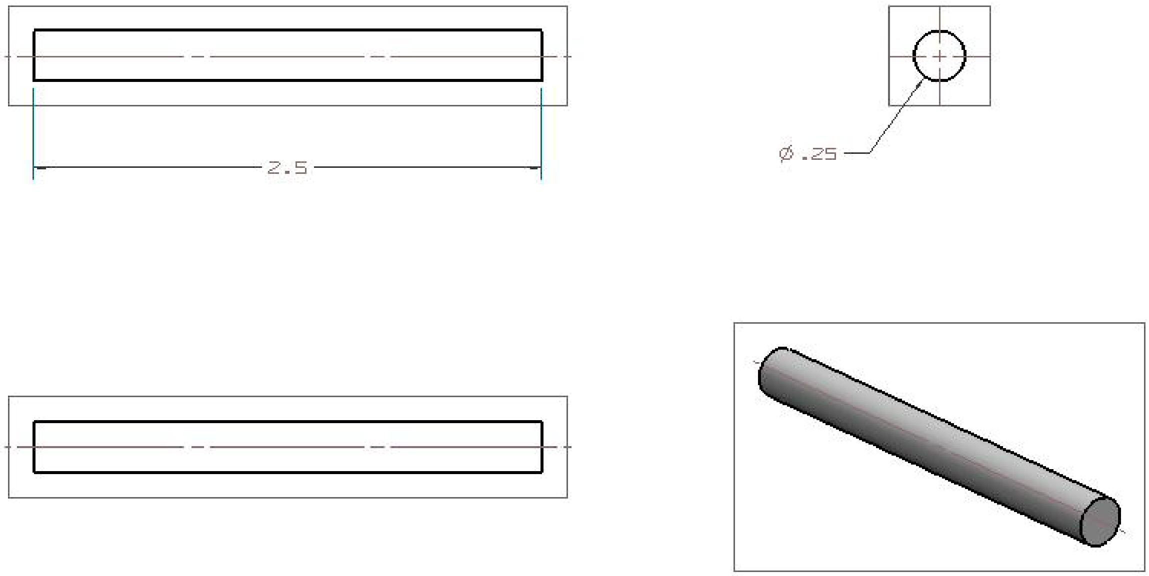




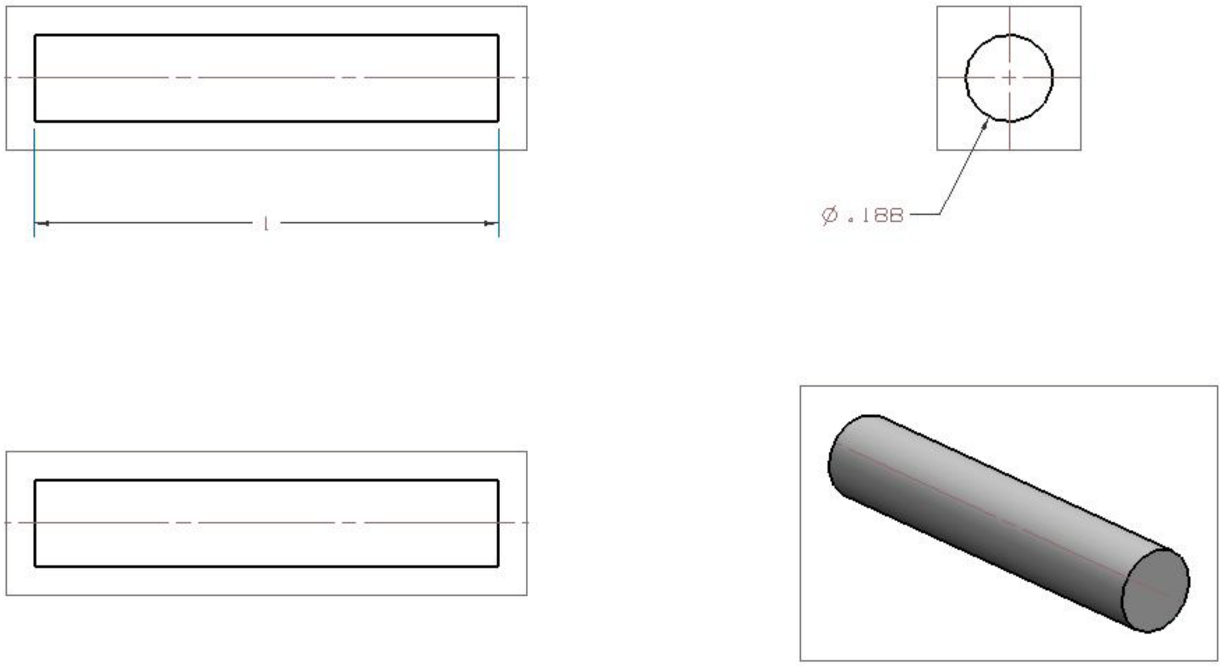




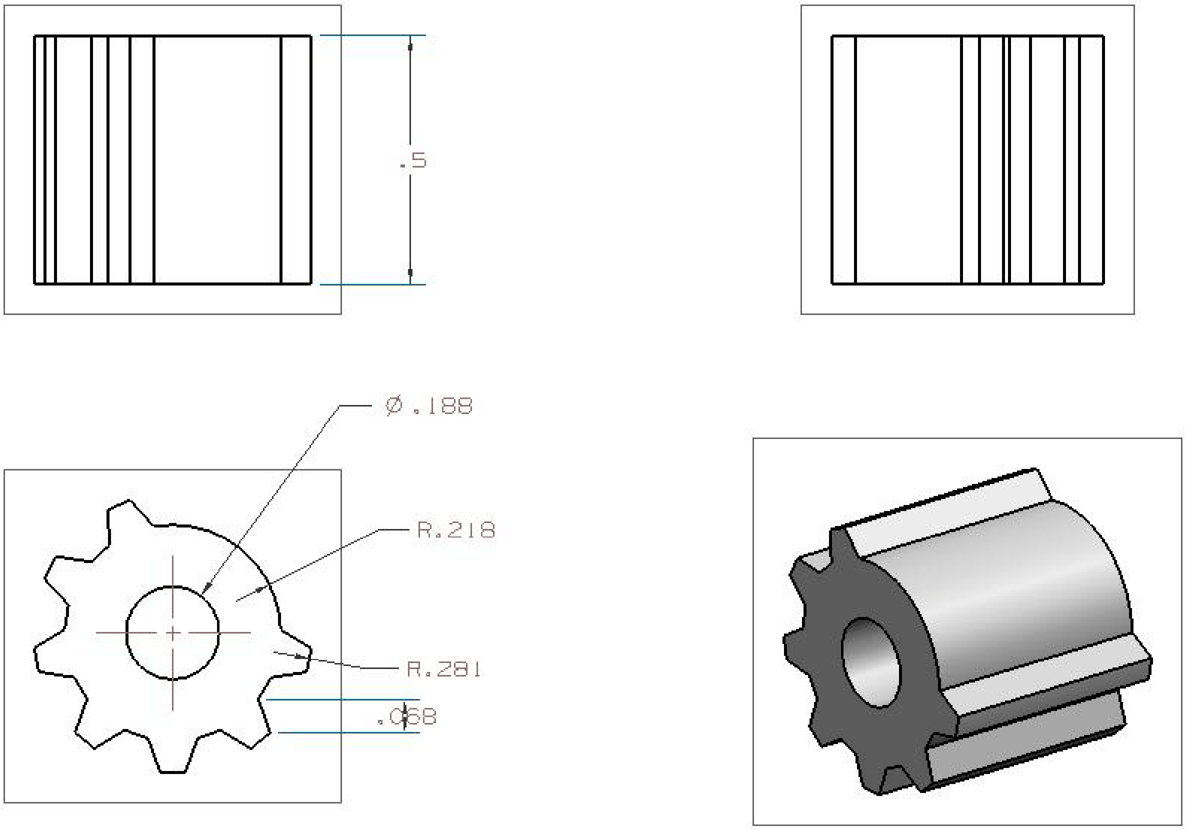
APPENDIX W.4: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS – DOWEL PIN



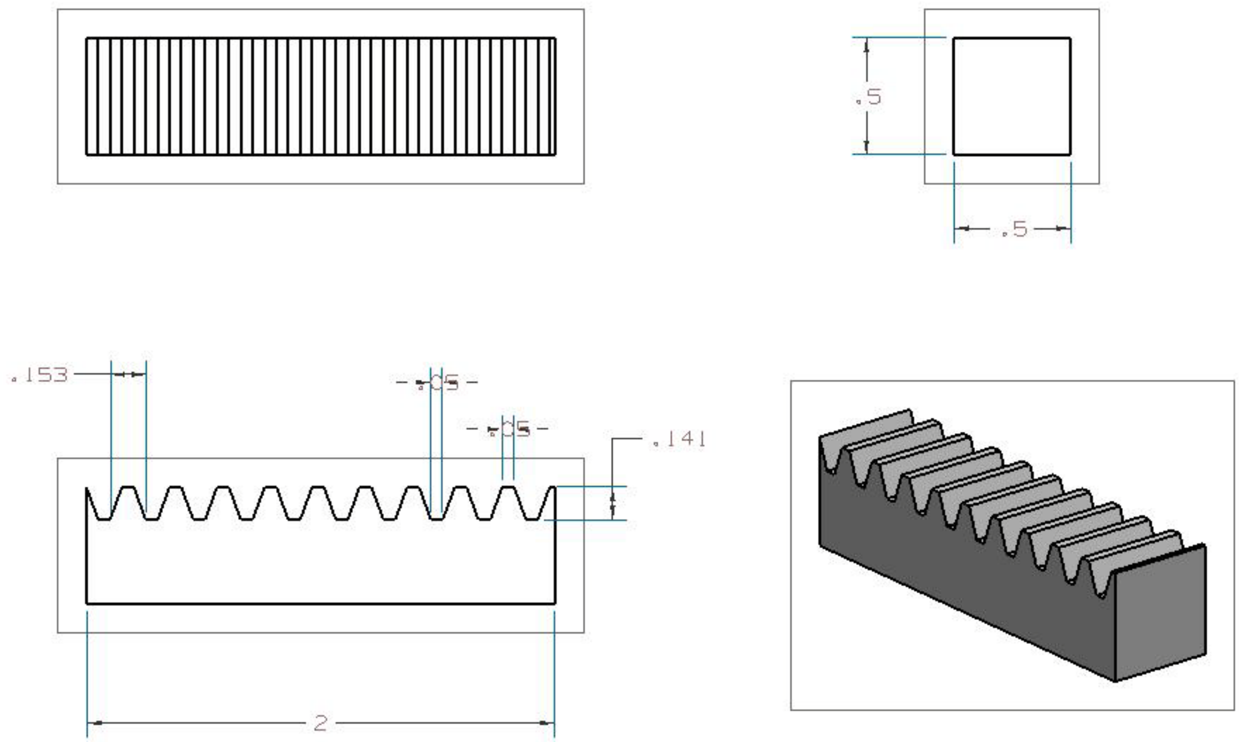
APPENDIX W.5: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS – DOWEL PIN (SHORT)



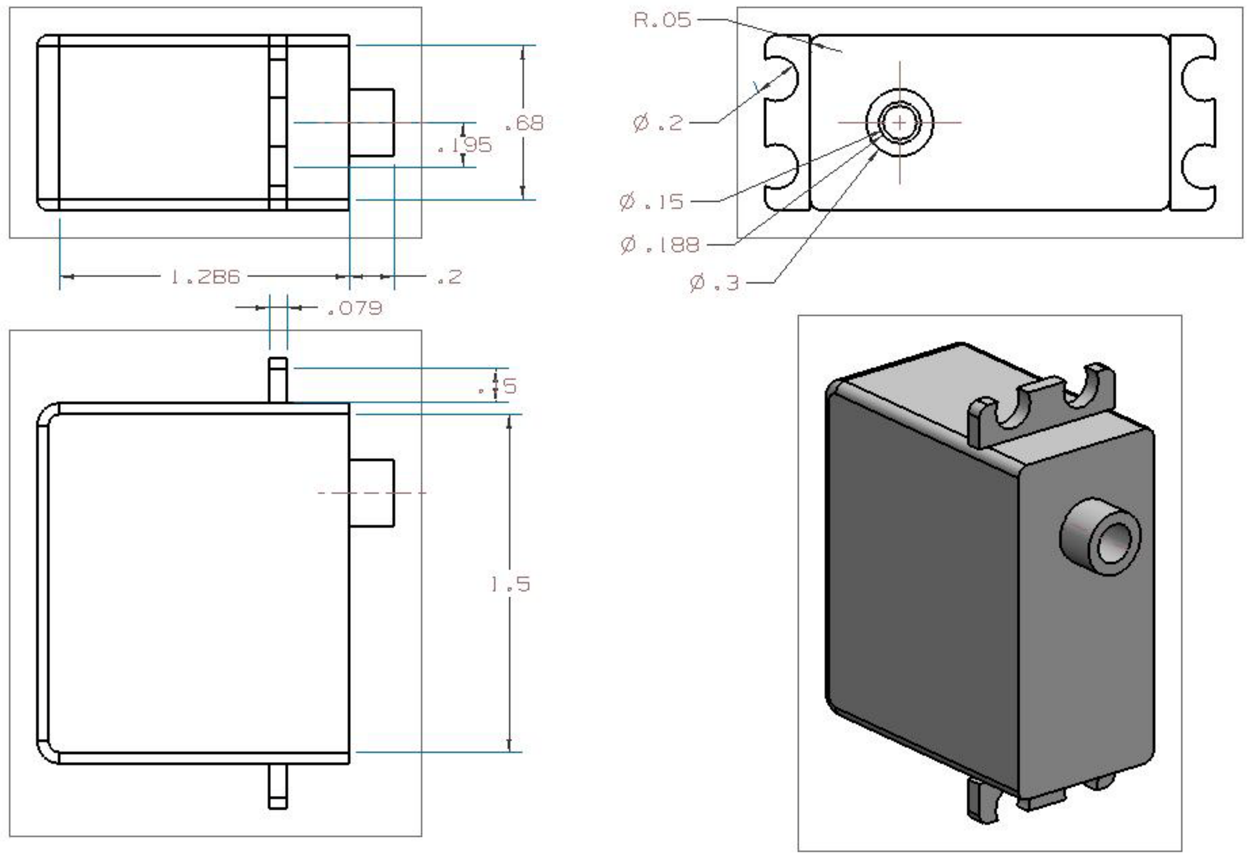
APPENDIX W.6: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS – SECTOR GEAR



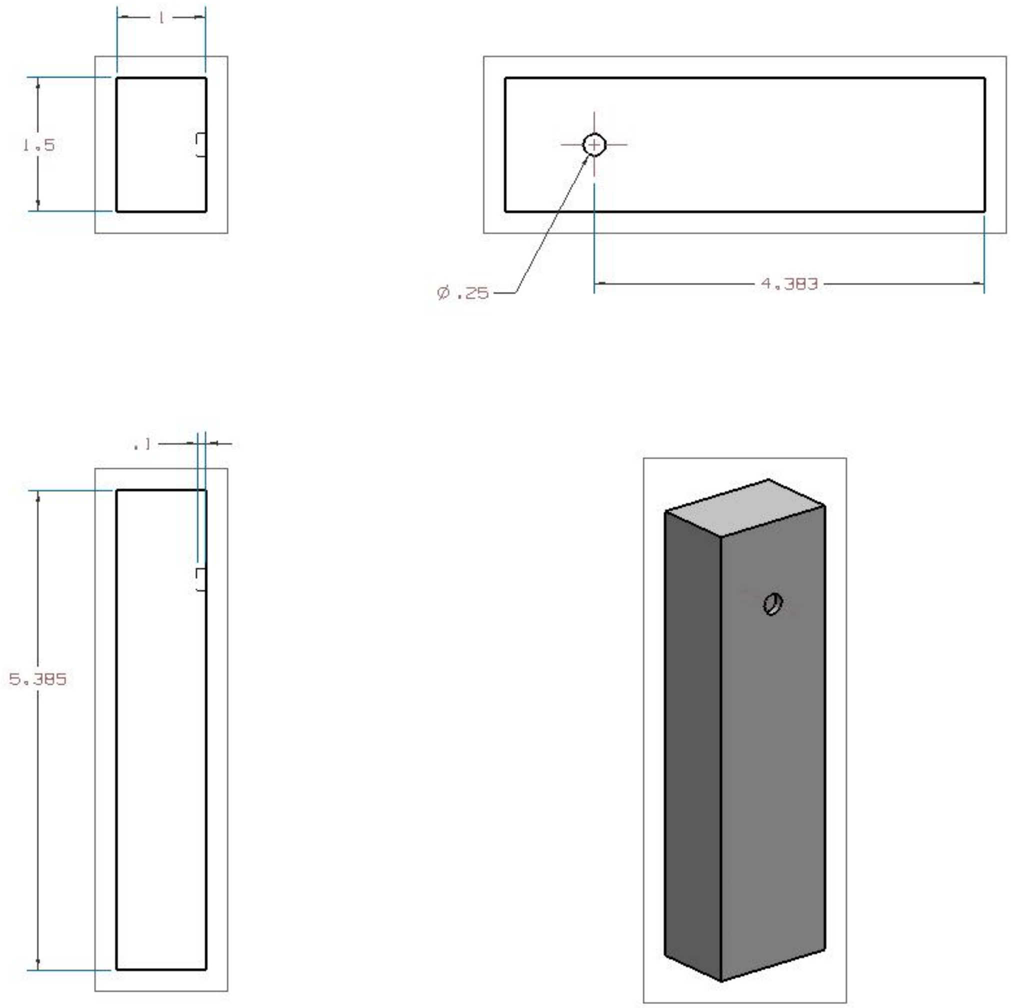
APPENDIX W.7: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS - RACK



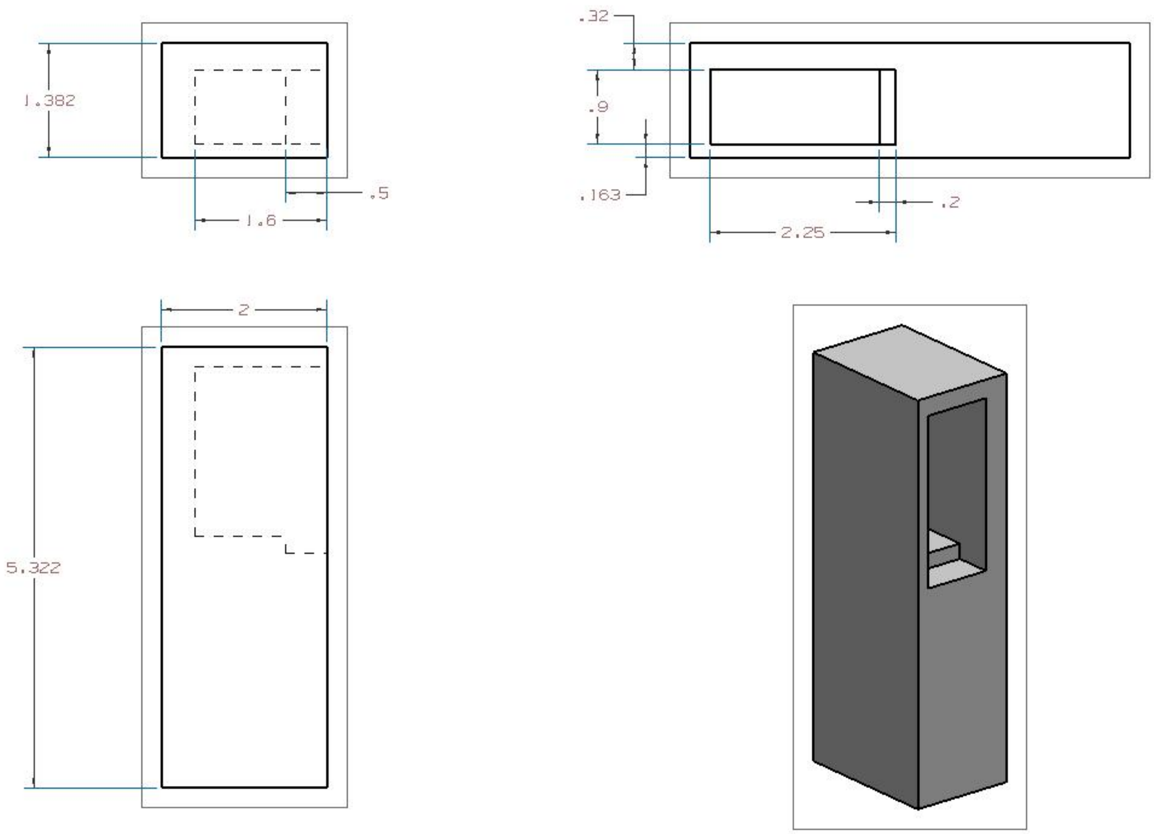
APPENDIX W.8: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS – SERVO MOTOR



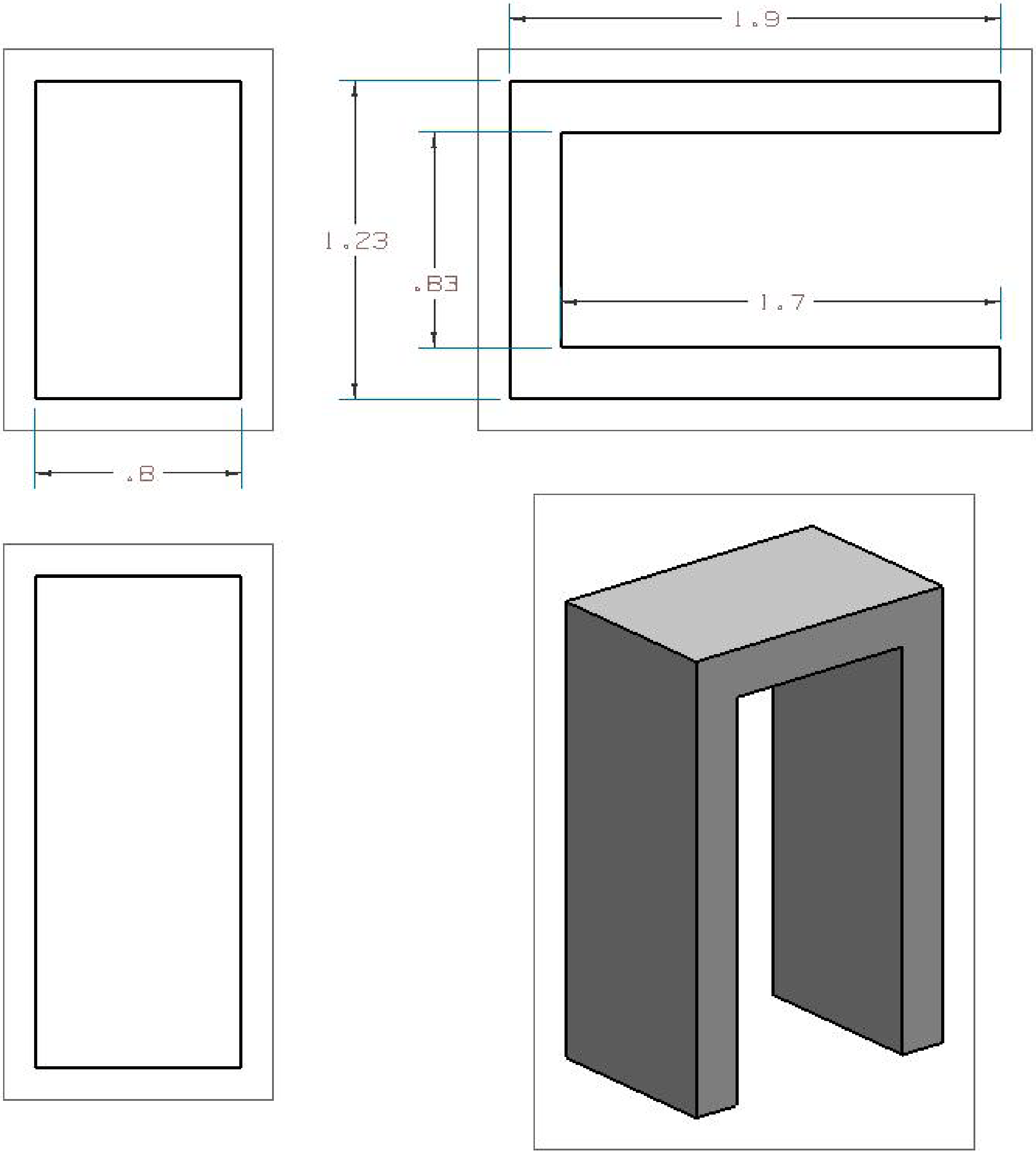
APPENDIX W.9: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS – SUPPORT COLUMN



APPENDIX W.10: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS – SUPPORT COLUMN (SERVO MOTOR HOUSING)



APPENDIX W.11: COMPRESSION SPRING TANK PROTOTYPE DIMENSIONS – SERVO MOTOR BRACKET

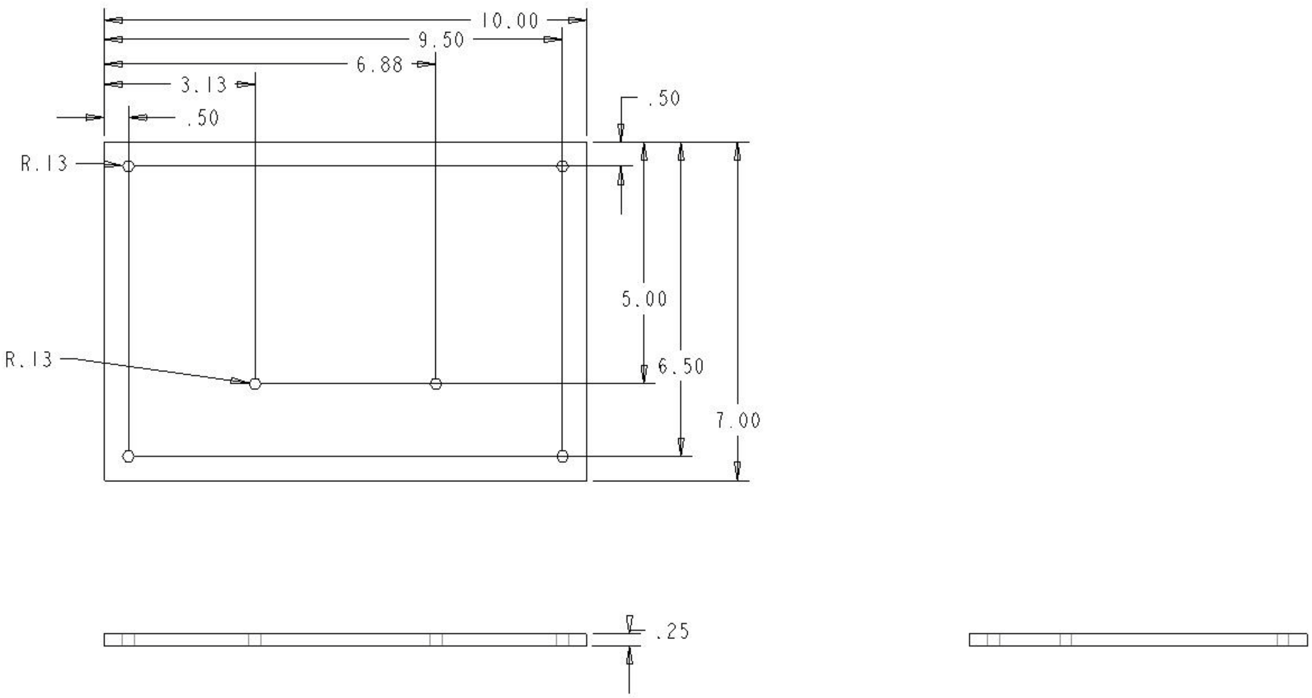


APPENDIX X: ARDUINO CODE FOR THE COMPRESSION SPRING TANK

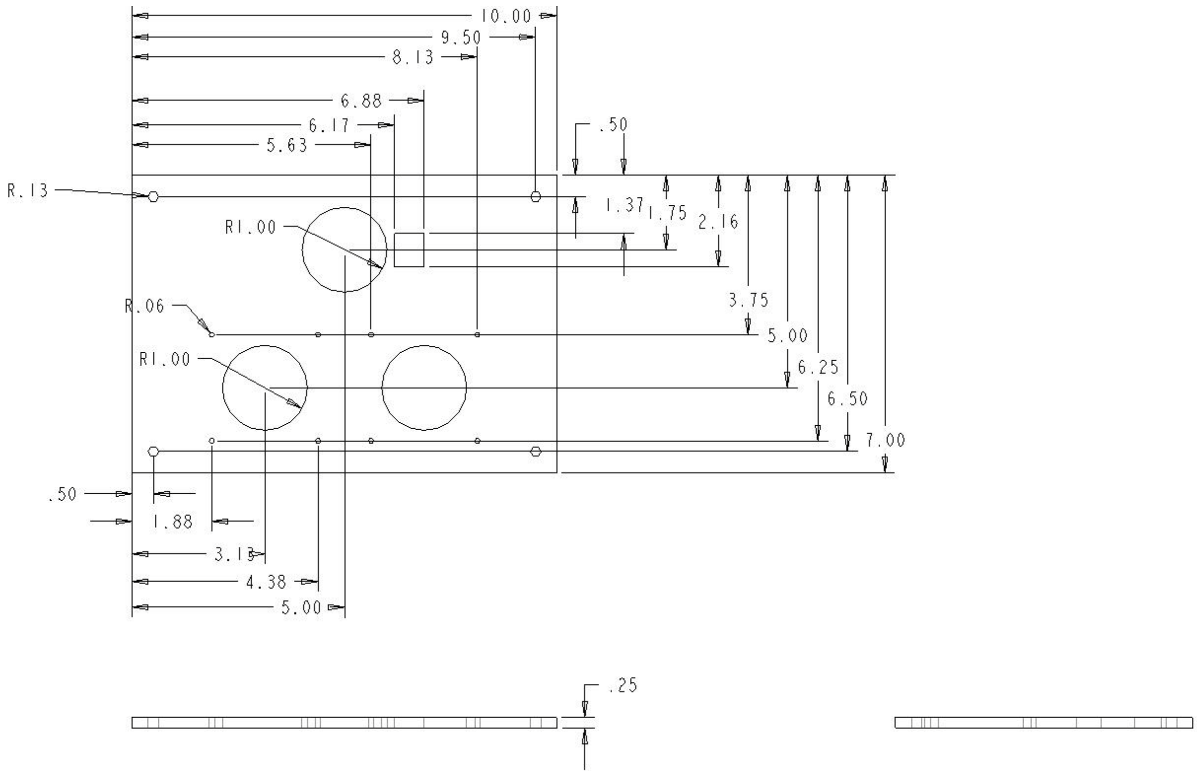
```
#include <ServoTimer1.h>
#include <AFMotor.h>
// Driving
AF_DCMotor motor1(1, MOTOR12_1KHZ);
AF_DCMotor motor2(2, MOTOR12_1KHZ);
int upswitch = 14;
int downswitch = 15;
// Aiming
ServoTimer1 servo1;
int aimup = 16;
int aimdown = 17;
int pos = 185;
// Firing
int firing = 18;
int firemotor1 = 5;
int firemotor2 = 6;
void setup() {
 // Driving
 Serial.begin(9600);
 motor1.setSpeed(200);
 motor2.setSpeed(200);
 pinMode(upswitch, INPUT);
 pinMode(downswitch, INPUT);
 // Aiming
 Serial.begin(9600);
 pinMode(aimup, INPUT);
 pinMode(aimdown, INPUT);
 servo1.attach(10);
 // Firing
 pinMode(firing, INPUT);
 pinMode(firemotor1, OUTPUT);
 pinMode(firemotor2, OUTPUT);
}
void loop() {
 // Driving
 if (digitalRead(upswitch) == LOW)
 {
   motor1.run(FORWARD);
   motor2.run(BACKWARD);
 }
 else if (digitalRead(downswitch) == LOW)
 {
   motor1.run(BACKWARD);
   motor2.run(FORWARD);
 }
```

```
 else
 {
   motor1.run(RELEASE);
   motor2.run(RELEASE);
 }
 // Aiming
 delay(20);
 pos = constrain(pos,135,185);
 if (digitalRead(aimup) == LOW)
 {
   servo1.write(pos++);
 }
 else if (digitalRead(aimdown) == LOW)
 {
   servo1.write(pos--);
 }
 // Firing
 if (digitalRead(firing) == LOW)
 {
   digitalWrite(firemotor1, LOW);
   digitalWrite(firemotor2, HIGH);
 }
 else
 {
   digitalWrite(firemotor1, LOW);
   digitalWrite(firemotor2, LOW);
 }
}
```

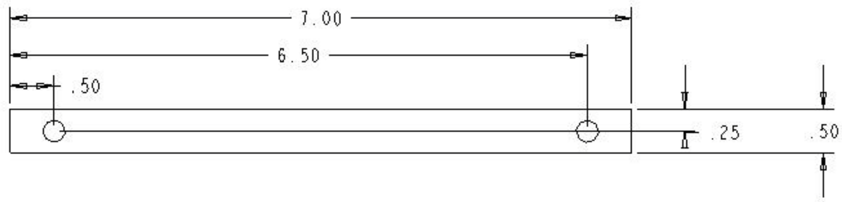
APPENDIX Y.1: PITCHING MACHINE TANK DIMENSIONS – BASE

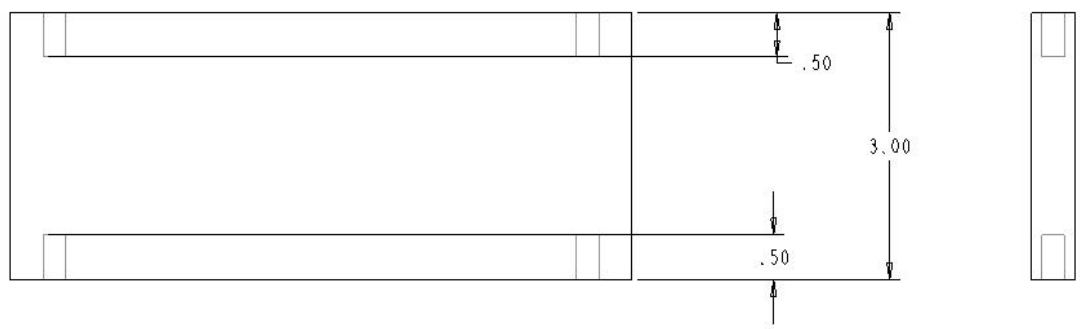


APPENDIX Y.2: PITCHING MACHINE TANK DIMENSIONS – TOP PLATE

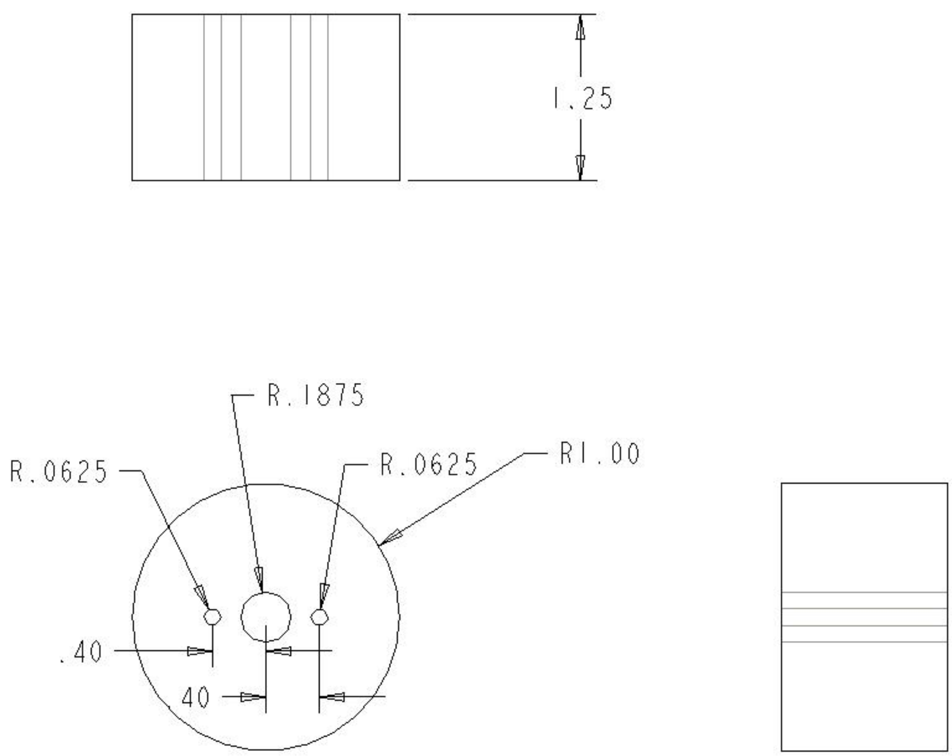


APPENDIX Y.3: PITCHING MACHINE TANK DIMENSIONS – SUPPORT

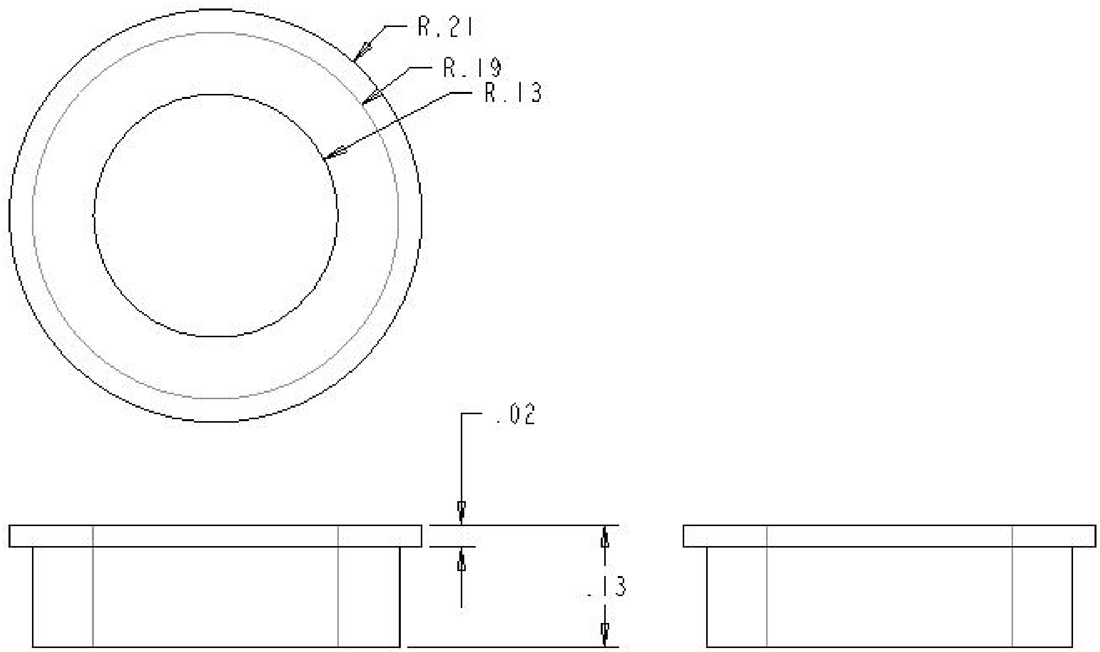




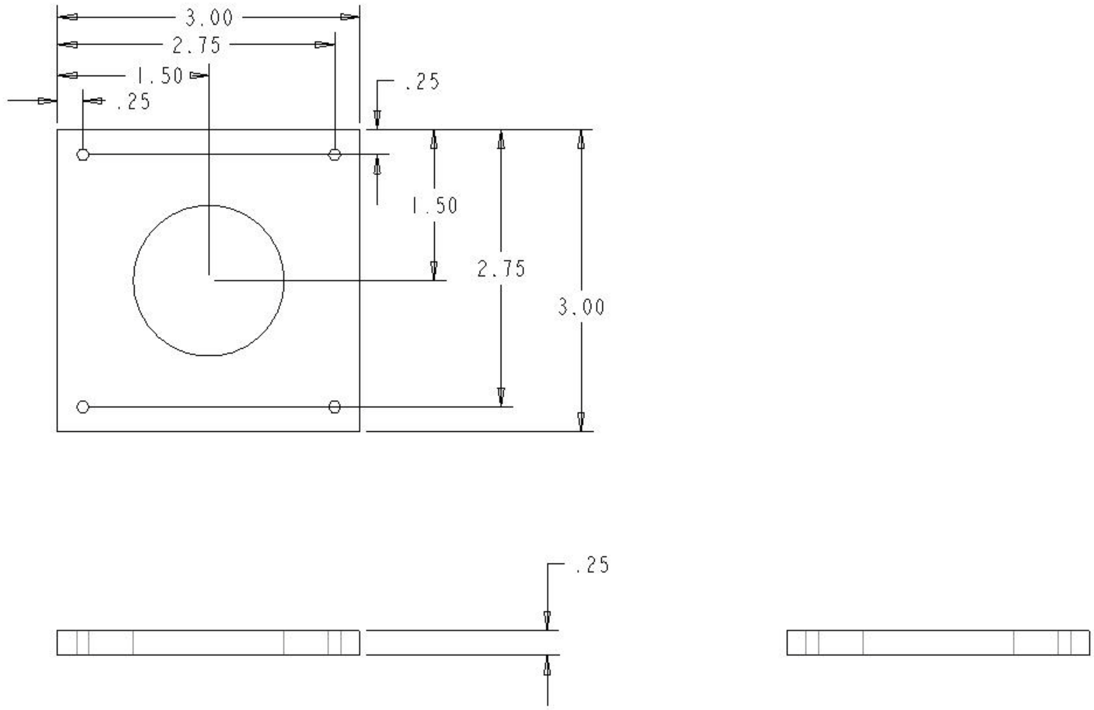
APPENDIX Y.4: PITCHING MACHINE TANK DIMENSIONS – WHEEL



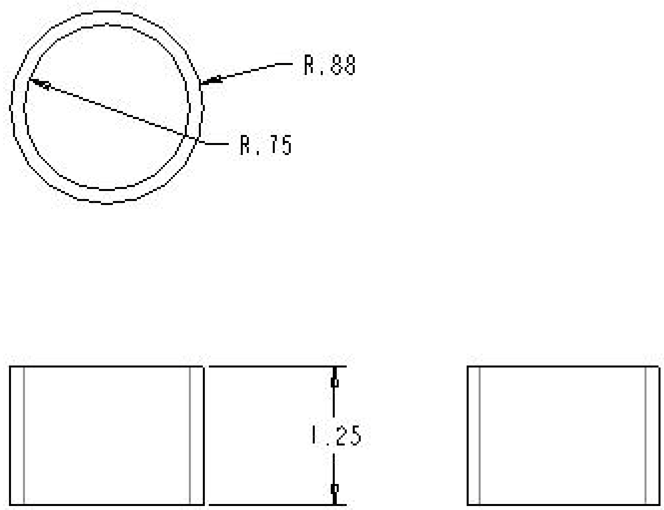
APPENDIX Y.5: PITCHING MACHINE TANK DIMENSIONS – BEARING



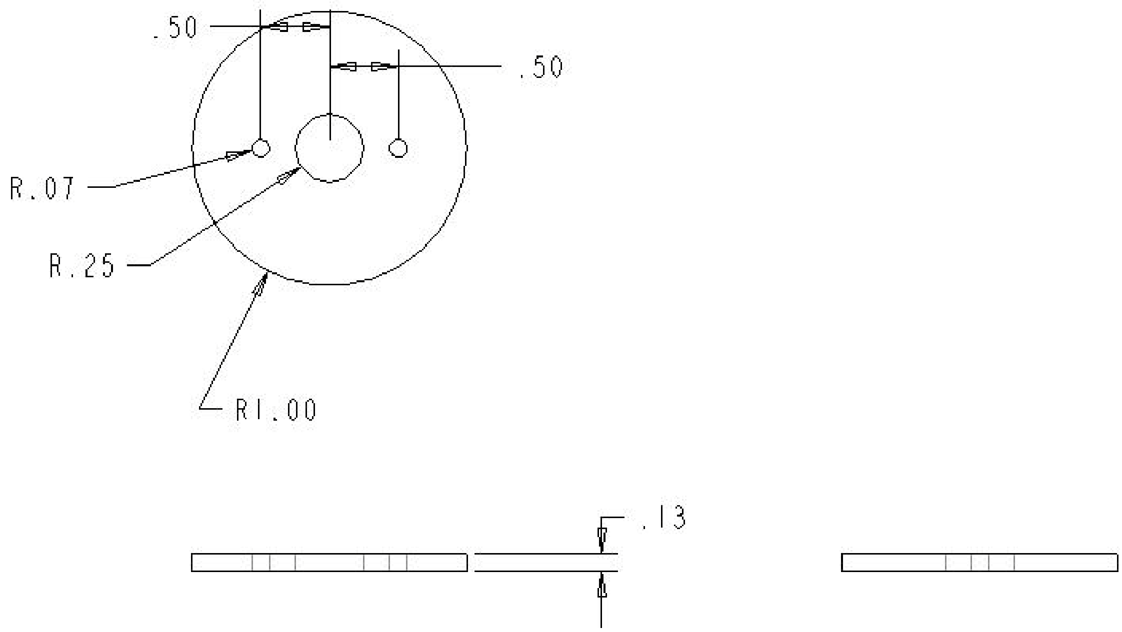
APPENDIX Y.6: PITCHING MACHINE TANK DIMENSIONS – MOTOR BRACKET TOP



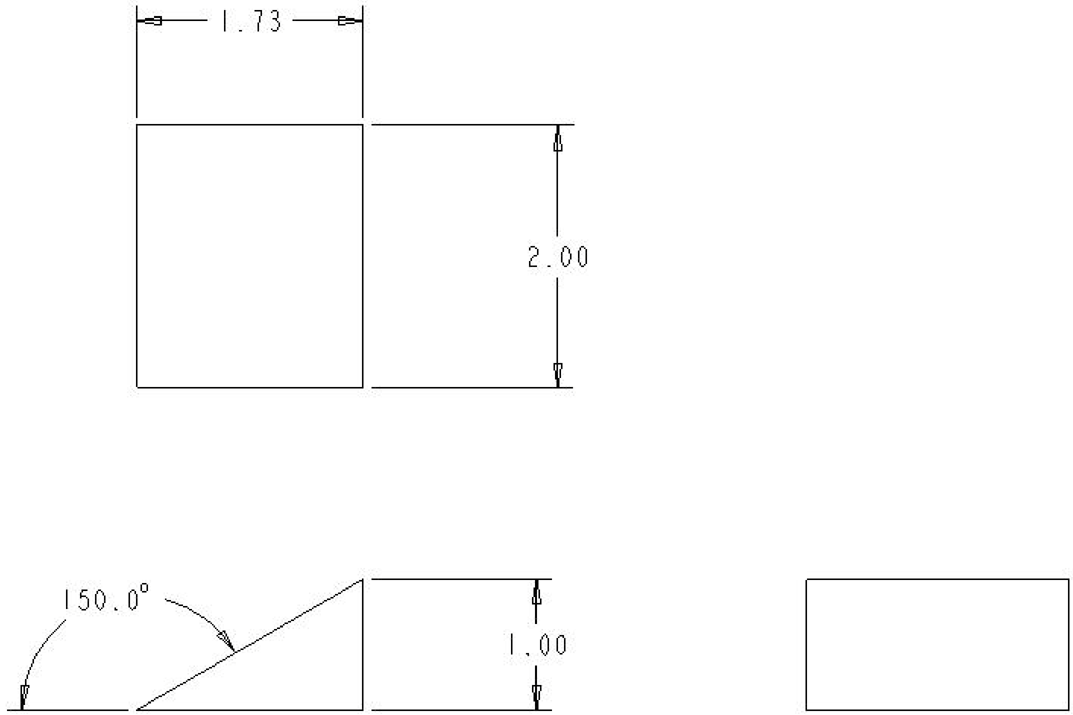
APPENDIX Y.7: PITCHING MACHINE TANK DIMENSIONS – MOTOR BRACKET MIDDLE



APPENDIX Y.8: PITCHING MACHINE TANK DIMENSIONS – MOTOR BRACKET BOTTOM



APPENDIX Y.9: PITCHING MACHINE TANK DIMENSIONS – RAMP



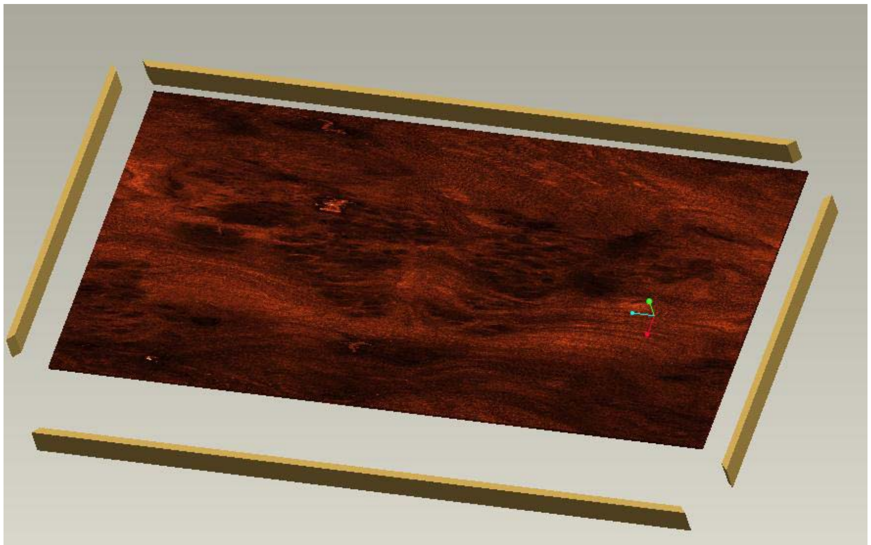
APPENDIX Z: ARDUINO CODE FOR THE PITCHING MACHINE TANK

```
#include <AFMotor.h>
#include <ServoTimer1.h>
AF_DCMotor motor3(3, MOTOR12_1KHZ);
AF_DCMotor motor4(4, MOTOR12_1KHZ);
ServoTimer1 servo1;
int i;
int servoStart = 14;
int downswitch = 15;
int upswitch = 16;
void setup() {
  Serial.begin(9600);           // set up Serial library at 9600 bps
  servo1.attach(9);
  motor3.setSpeed(200);
  motor3.run(RELEASE);
  motor4.setSpeed(200);
  motor4.run(RELEASE);
  pinMode(servoStart, INPUT);
  pinMode(upswitch, INPUT);
  pinMode(downswitch, INPUT);
}
void loop() {
  if (digitalRead(upswitch) == LOW)
  {
    motor3.setSpeed(200);
    motor3.run(FORWARD);
    motor4.setSpeed(200);
    motor4.run(BACKWARD);
  }
  else if (digitalRead(downswitch) == LOW)
  {
    motor3.setSpeed(200);
    motor3.run(BACKWARD);
    motor4.setSpeed(200);
    motor4.run(FORWARD);
  }
  else
  {
    motor3.run(RELEASE);
    motor4.run(RELEASE);
  }
if (digitalRead(servoStart) == LOW)
 {
   servo1.write(30);
   delay(1000);
   servo1.write(0);
 }
}
```

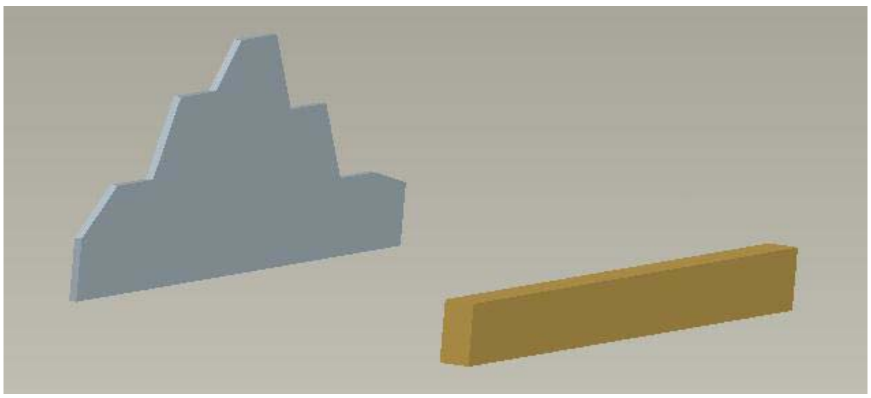
APPENDIX AA: BILL OF MATERIALS

Item	Quantity	Purchase Location	Price Per	Catalog Number	Contact
Arduino w/Atmega328	2	Adafuit Industries	$30.00		adafruit.com
Adafruit Motor/Stepper/Servo Shield for Arduino kit (v1.0)	2	Adafuit Industries	$19.50		adafruit.com
Half-size breadboard	2	Adafuit Industries	$5.00		adafruit.com
9V regulated DC wall-power adapter	2	Adafuit Industries	$7.00		adafruit.com
RS-555 Motor	2	Banebots	$6.50	M5-RS555-12	banebots.com
Spring	1	Carpenter Bros. Hardware	$1.19		Carpenter Bros. Hardware
1/2" plywood 8'x4'	2	Home Depot	$6.77		Home Depot
1"x4" x 8'	4	Home Depot	$1.87		Home Depot
2"x4" x 8'	2	Home Depot	$1.77		Home Depot
1"x2" 8'	2	Home Depot	$1.15		Home Depot
2 in. dia PVC elbow	1	Home Depot	$2.01		Home Depot
1 in length flathead screws	1	Home Depot	$5.94		Home Depot
1/8" Rod	1	Home Depot	$1.98		Home Depot
3/4 in length flathead screws	1	Home Depot	$3.97		Home Depot
Spray Paint	3	Home Depot	$2.97		Home Depot
Bearings	2	Mcmaster-Carr	$7.50		mcmaster.com
Balsa Wood 2"x2"x36"	6	National Balsa	$4.98		Nationalbalsa.com
120:1 Plastic Gearmotor 90-Degree Output	4	Pololu.com	$5.75	1121	pololu.com
Tower Pro MG995 Servo	2	Servos and Stuff	$14.98		Servosandstuff.com
Tower Pro SG90 Servo	1	Servos and Stuff	$6.76		Servosandstuff.com
22 Gauge Wire	150'	Shop Stock			Stock Material
PVC Cement	1	Shop Stock			Stock Material
1/4 in. 1 in. hex bolt	4	Shop Stock			Stock Material
1/4 in. 2.5 in. hex bolt	8	Shop Stock			Stock Material
1/4 in. 1 in. flat head screws	4	Shop Stock			Stock Material
Brass Spur Gear 32P 20 Degree Pressure Angle 18 Teeth x .188" Bore x .562" Pitch Dia	1	Small Parts	$4.17		smallparts.com
Brass Rack 32 Pitch 20 Degree Pressure Angle 24" Length	1	Small Parts	$12.35		smallparts.com
Mini Push Button Switch	20	Sparkfun Electronics	$0.32	COM-0009	sparkfun.com
1/4 in dia 1.25 in Dowel	5	Stadium Hardware	$0.50		Stadium Hardware
1/4 in. 20 thread brass nut	1	Stadium Hardware	$0.30		Stadium Hardware
JB Weld	1	Stadium Hardware	$6.99		Stadium Hardware
1/8 in PVC sheet	1	Stock Material			Stock Material
1/4 in PVC sheet	1	Stock Material			Stock Material
1/2 in PVC sheet	1	Stock Material			Stock Material
2 in PVC block	1	Stock Material			Stock Material
2 in PVC roundstock	1	Stock Material			Stock Material
Solder	1	Stock Material			Stock Material
12V battery	2	Zbattery.com	$7.50		zbattery.com
Battery Charger	1	Zbattery.com	$5.85		zbattery.com
Nerf Balls (package)	1	Toys R Us			

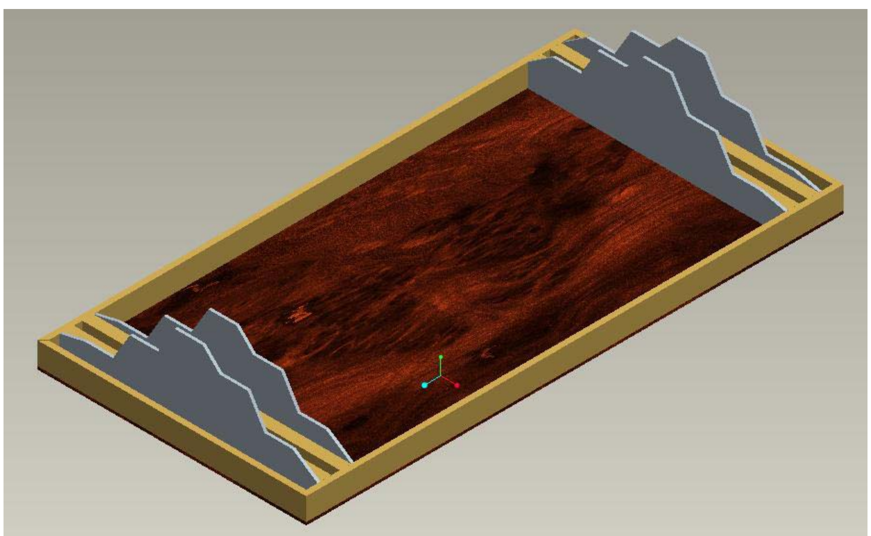
APPENDIX BB: BATTLEFIELD ASSEMBLY DRAWINGS



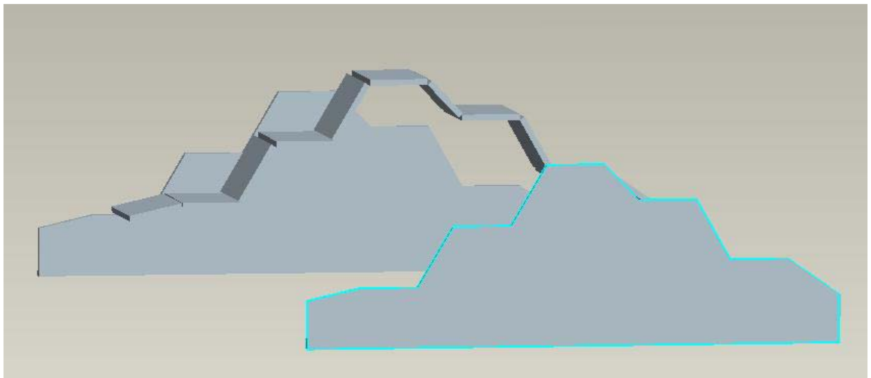
Step 1: Attach battlefield walls to base



Step 2: Attach 2 inch by 4 inch board to each hill



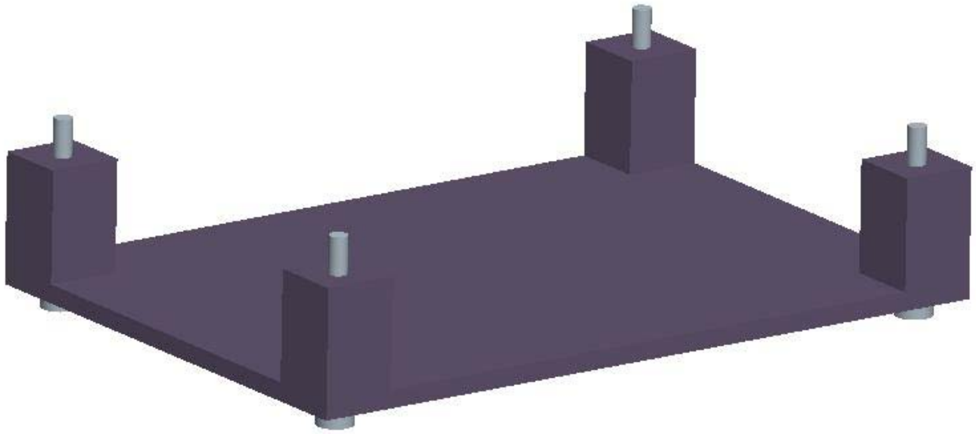
Step 3: Attach hills to platform using 2 inch by 4 inch board



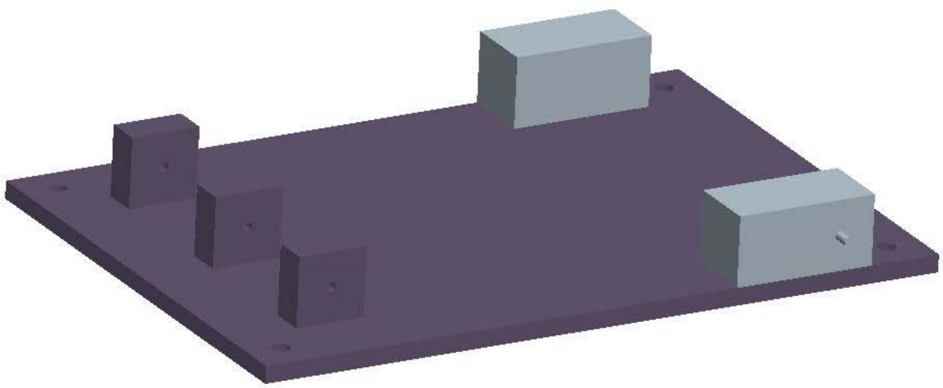
Step 4: Attach horizontal and angled hill platforms to hill

Step 5: Attach road barriers and road bumps to platform

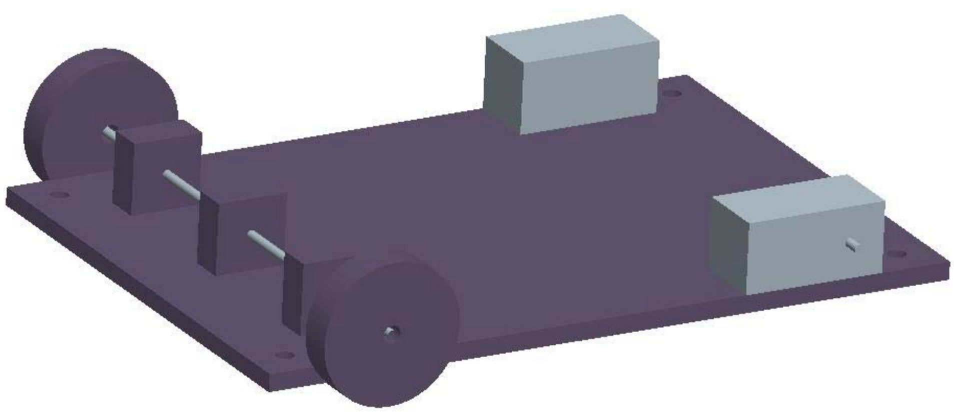
APPENDIX CC: TANK PLATFORM ASSEMBLY DRAWINGS



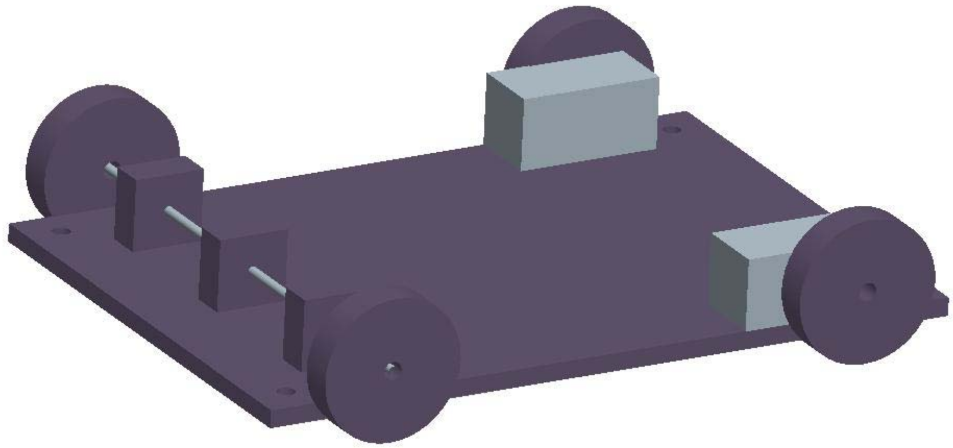
Step 1-3: Attach spacer blocks to base using bolts



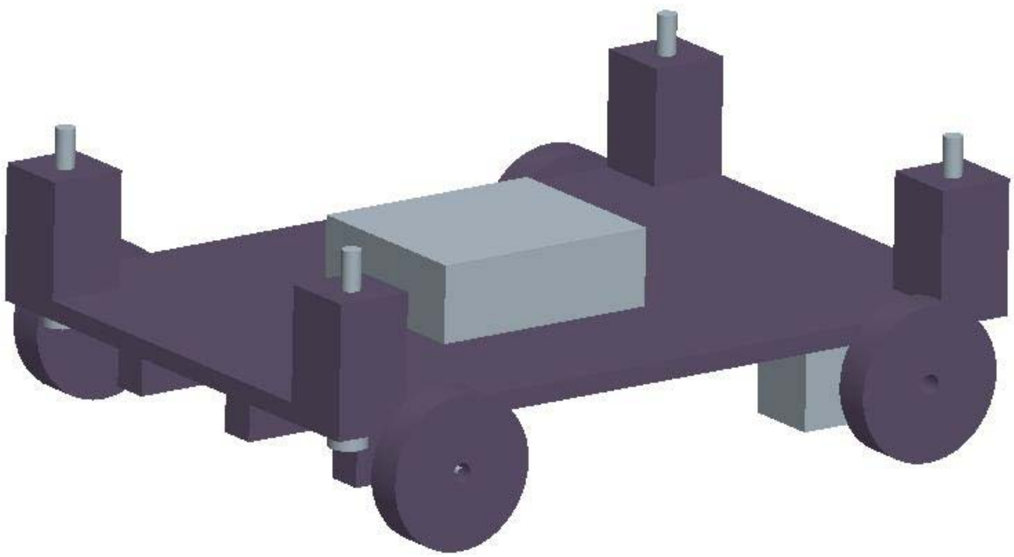
Step 4-5: Attach axle brackets and motors to base



Step 6-7: Press fit rear wheels onto metal axle

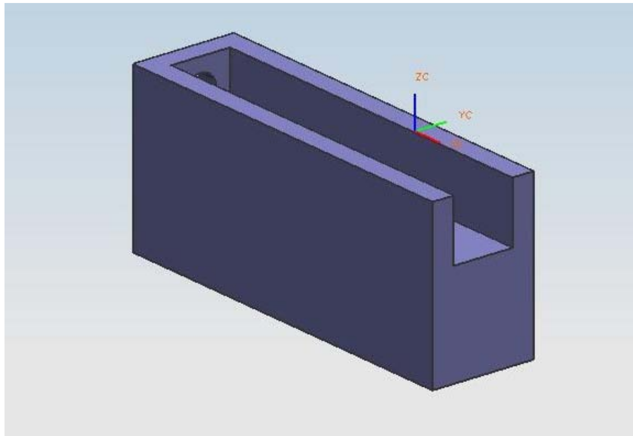


Step 8-9: Attach front wheels to gearmotors

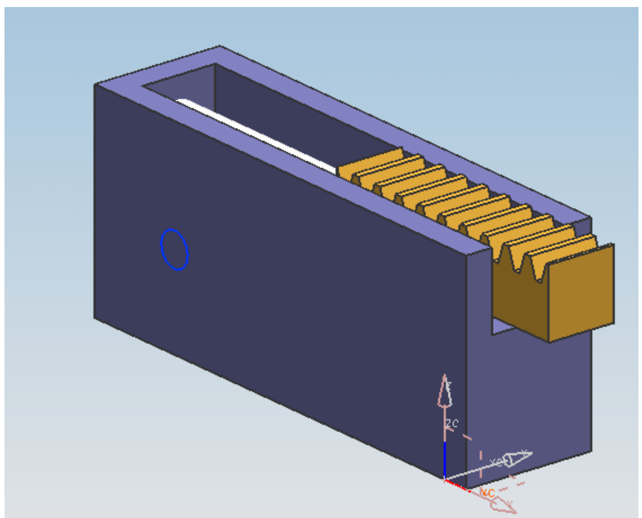


Step 10-11: Place Arduino and motor shield on base

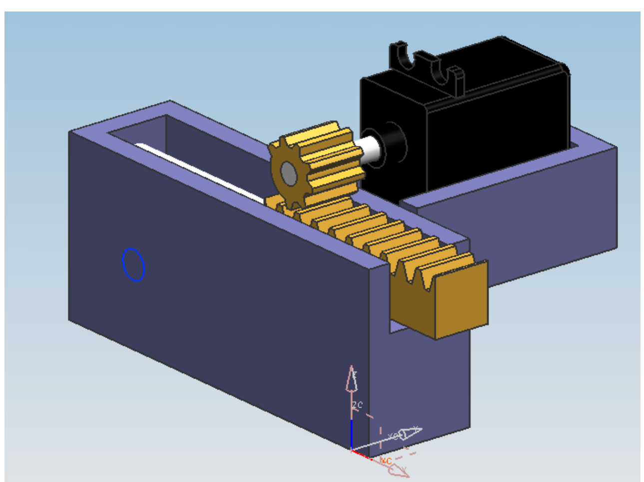
APPENDIX DD: COMPRESSION SPRING TANK ASSEMBLY DRAWINGS



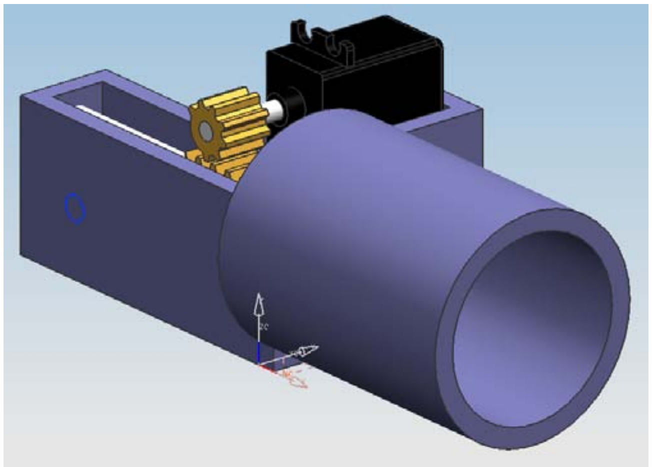
Step 1 – 2: Machine the groove in the body and drill a hole in the back



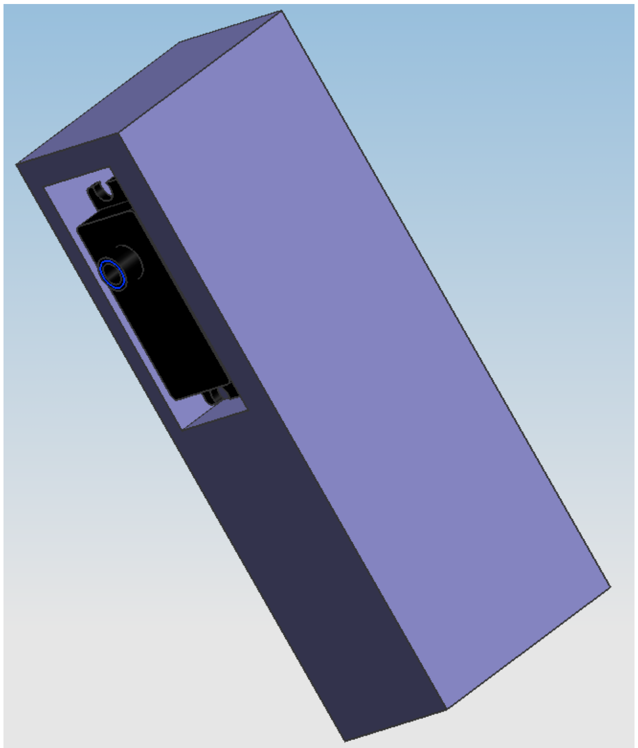
Step 3 – 6: Place a long bolt through the hole in the body and make contact with the rack



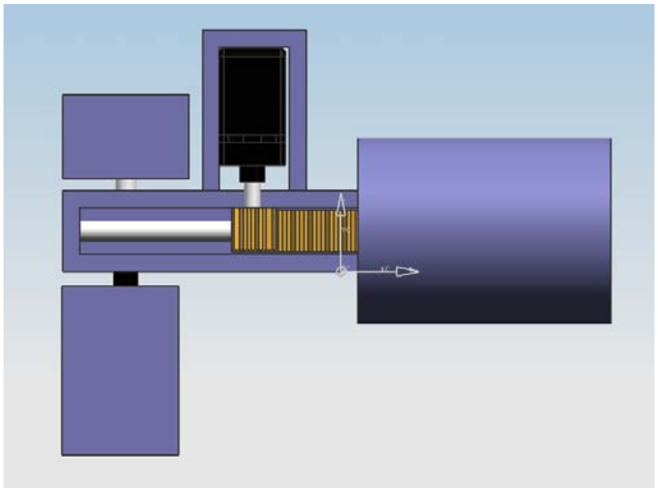
Step 7 – 11: Screw the sector gear into the firing motor and mount the firing motor onto the body along with the firing motor bracket



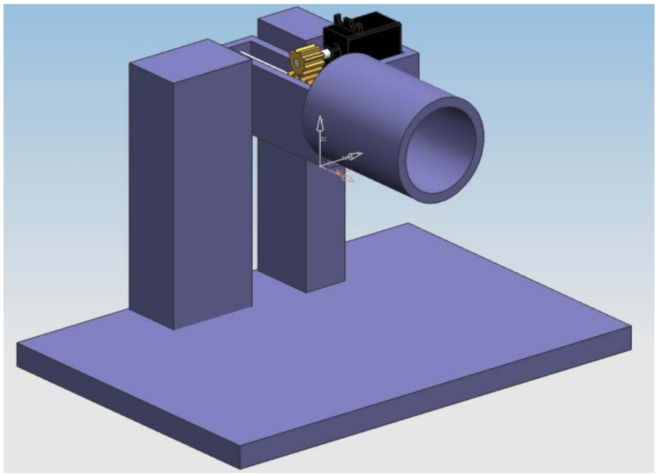
Step 12 – 15: Machine a hole in the barrel cap for the rack and attach the barrel, barrel cap, and body together so that the rack fits through the hole



Step 16 - 18: Assemble the servo motor to the large support column



Step 19 – 24: Connect the two support columns to the body

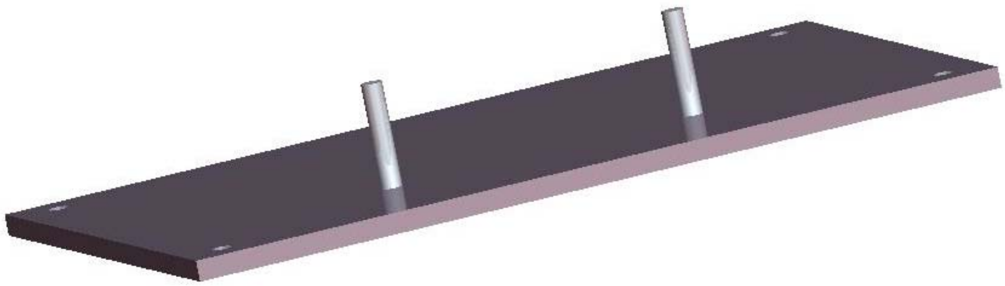


Completed Prototype

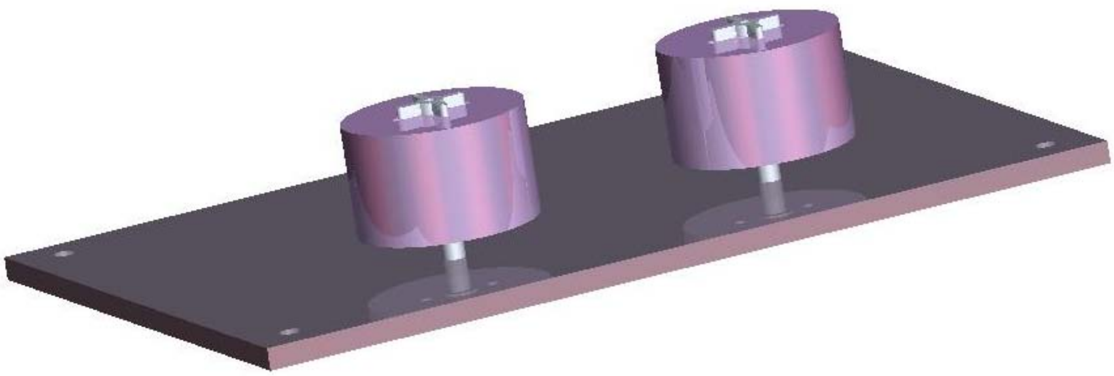
APPENDIX EE: PITCHING MACHINE TANK ASSEMBLY DRAWINGS

The steps in the following assembly procedure correspond to those listed in the fabrication section of this paper.

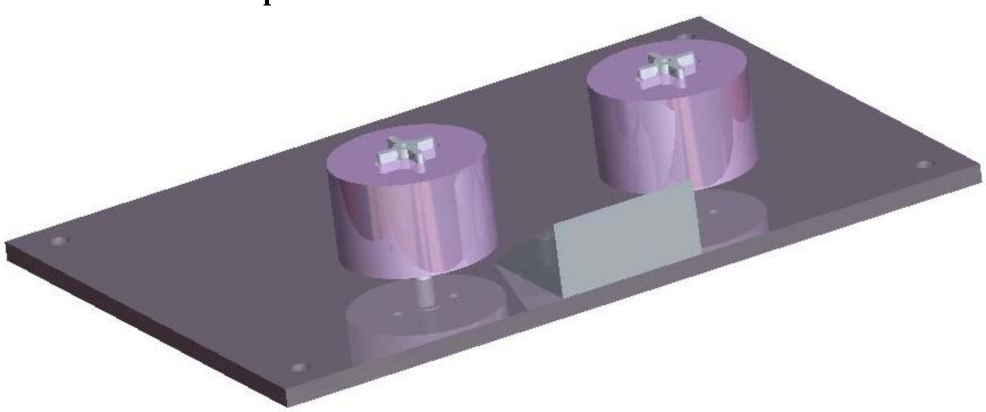
Step 9: Press fit both of the dowel pins into the machined holes in the base so they are flat with the bottom of the base



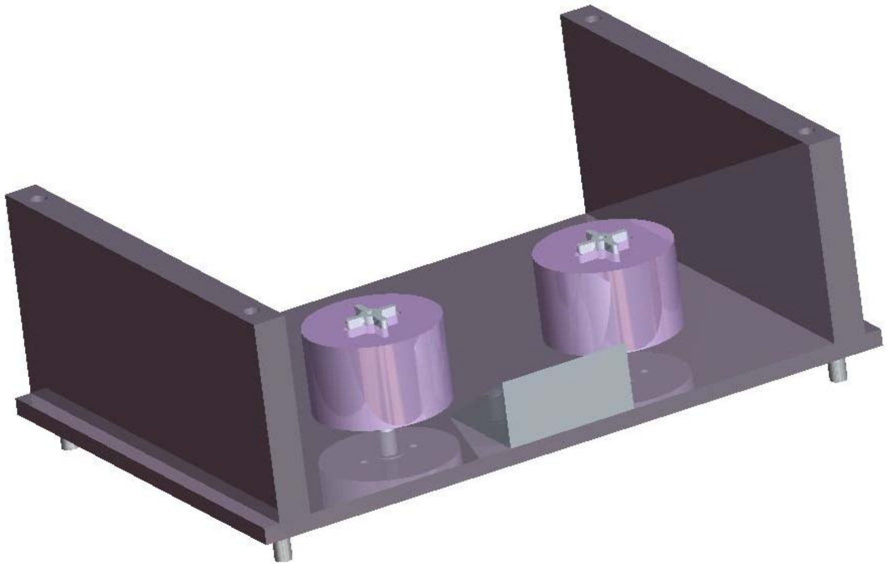
Steps 10-11: Creation of the wheel assemblies and mounting onto the tank base



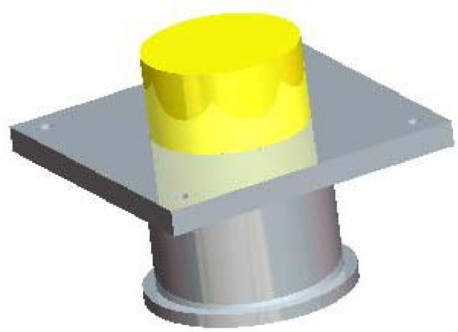
Step 12: Attachment of the ramp to the base



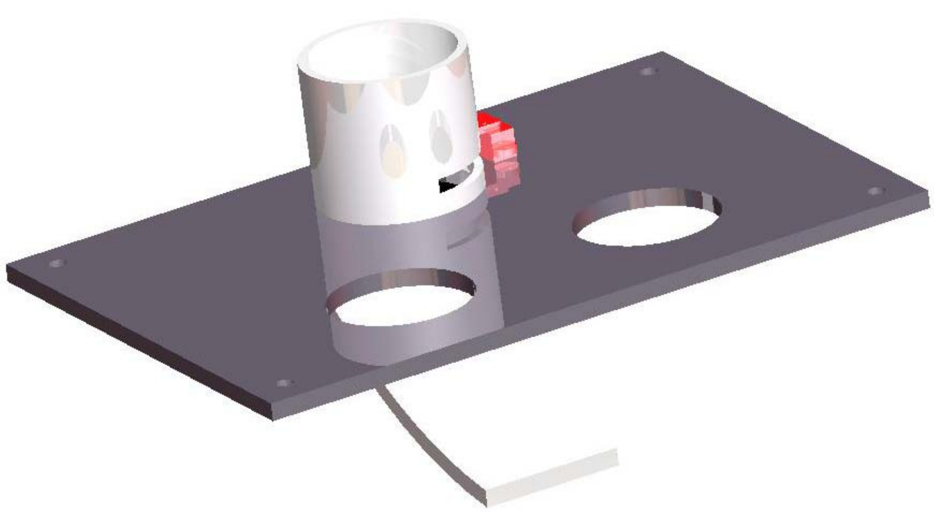
Step 13: Attachment of the supports to the base



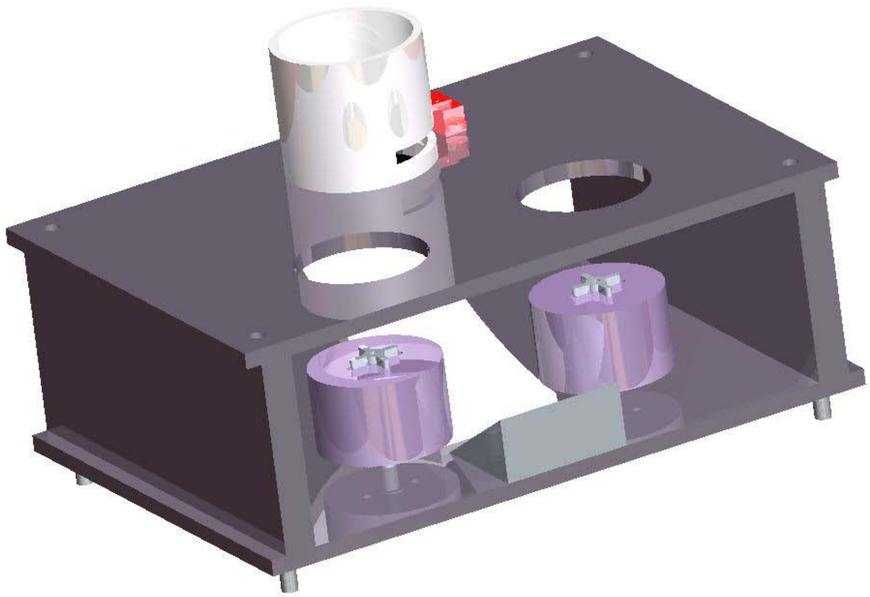
Step 14: Attaching the DC motor and motor bracket pieces to for the motor assembly



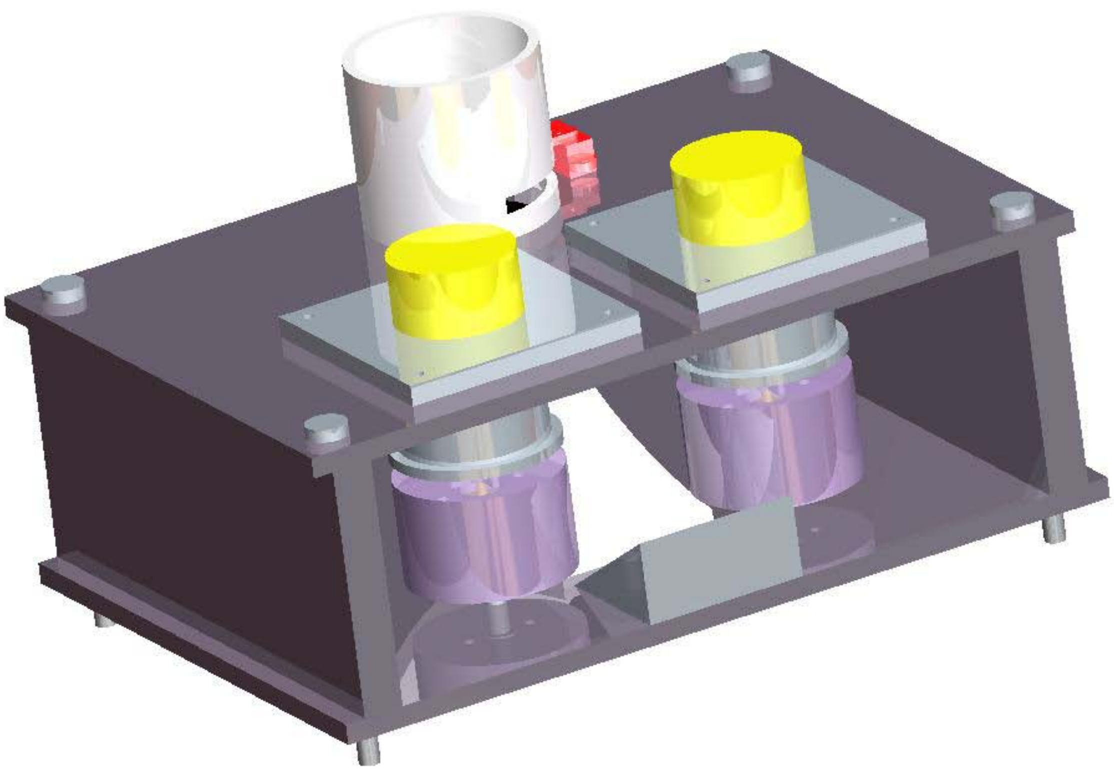
Steps 15-17: Attachment of the PVC elbow chute and servo motor to the top plate



Step 18: Attachment of the top plate



Step 19: Attachment of motor assemblies, giving a complete prototype



APPENDIX FF: CURRENT ME250 STUDENT SURVEY AND RESULTS

<u>Questions regarding the current ME 250 project</u>

1. How do you feel about your current ME 250 project?

   POSTIVE RESPONSE: 80%
   NEGATIVE RESPONSE: 20%

   COMMENTS: "Better than all the other years, more engineering is involved"
   "Don't really like it because it doesn't apply for students from other majors taking the course"
   "It's ok, kind of boring"
   "More interesting with the competition
   "Lacks iteration (design, change, repeat)

2. What is too difficult about the current ME 250 project?

   COMMENTS: "Designing all the parts"
   "Time consuming"
   "Don't like Unigraphics"
   "Need more time to machine"

3. What is too simple about the current ME 250 project?

   COMMENTS: none

4. Do you think you are given enough room for creativity with the current ME 250 project? If not, what could be changed to allow this?

   POSTIVE RESPONSE: 50%
   NEGATIVE RESPONSE: 50%

   COMMENTS: "Definitely"
   "Can do whatever we want"
   "No. All designs are similar because of the size restrictions."
   "Had trouble finding compatible parts for the gearbox"
   "More time would allow for more creativity"

<u>Questions regarding the proposed Tank Wars project</u>

1. Would the Tank Wars Project be interesting to you?

   POSITIVE RESPONSE: 80%
   NEGATIVE RESPONSE: 20%

   COMMENTS: "Yes"
   "Awesome!"
   "Seems kind of difficult"

2. Do you think the Tank Wars project would allow you enough room to be creative in your design? Why/Why not?

   POSITIVE RESPONSE: 60%
   NEGATIVE RESPONSE: 40%

   COMMENTS: "Yes"
   "Definitely more than this semester"
   "CNC-ing the housing may be difficult"
   "The housing may be too much to handle on top of creating a mechanism"

3. With necessary mechanical topics being taught during lectures, do you believe you would be capable of completing a tank prototype for this project? If not, what would prohibit you from doing so?

   POSITIVE RESPONSE: 100%
   NEGATIVE RESPONSE: 0%

   COMMENTS: "Yes"
   "As long as the professors and GSIs are helpful"

4. Do you think it would be useful to be taught about the design process?

   POSITIVE RESPONSE: 90%
   NEGATIVE RESPONSE: 10%

   COMMENTS: "We did that last year in ENG 100"
   "It could be helpful"
   "Yes"
   "As long as the professor doesn't make it drawn out and obvious"

5. Are there any different tools/materials you wish would be provided to you?

   TOOLS: Larger lathe/mill

   MATERIALS: Styrofoam
   Metals
   Wood
   Metal pins/dowels
   Fasteners

   OTHER: Easier access to a GSI to get tools/bits
   More shop time

List of Student Participants and contact information

Name	Uniquename
Adrian Stecula	astecula
Justin Isaacs	justini
Amanda Hanley	amandadh
Michael Rothenberg	mikesg
Robert Eastman III	eastmanr
Stephen Russano	srussano
Benjamin Frink	bfrink
Raymond Jonathan	rayjnth
Sarah Markey	markeys
Marshall Poland	mepoland
Phillip Bajor	pbajor