AC 2009-576: DESIGN, BUILD, TEST, COMPETE: A BATTLEBOT

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Design–Build–Test-Compete A BattleBot

Abstract

Students working toward a baccalaureate degree in Mechanical Engineering Technology at the College of Applied Science, University of Cincinnati are required to complete a "Design, Build, and Test" senior capstone design project. In 2007/08, one of these capstone design projects was to design and build a robot to participate in the BotsIQ National Competition. This robot was built to meet the BotsIQ 120lb weight class specifications.

A BattleBot is a robot which possesses fighting capabilities and competes against other BattleBots with the intent to disable them. The weapon is the main component of these robots. BattleBots compete one on one and the winner is determined by the amount of damage inflicted to the other using the weapon.

In the 2007-2008 academic year, a team of four Mechanical Engineering Technology students at the University of Cincinnati built a Battlebot as their senior capstone design project. As with all capstone projects, the expertise and knowledge acquired from their coursework and co-op was utilized. This project gave them an opportunity to showcase their abilities as well as develop additional skills needed to be successful in a team oriented business world. This team also enjoyed the personal satisfaction of working on a technically complex project from concept-to-design, build, test, and compete against other university participants in the competition.

This paper will give the short description of the senior capstone design course sequence in the Mechanical Engineering Technology department, University of Cincinnati and the list of pre-requisites for this capstone design sequence. It also describes the 2007-2008 Battlebot project, the student team experiences from start to finish, and the results from the national competition.

Introduction

Completing a senior design project is a graduation requirement for all students in the Mechanical Engineering Technology (MET) department at the College of Applied Science (CAS), University of Cincinnati (UC). This is a four-course sequence that must result in a working product/process. These courses are designed to facilitate a student's abilities to synthesize and apply the knowledge and skills that have been acquired prior to their senior year. This sequence also enhances their abilities to solve open-ended problems and to prepare them for the transition from an academic environment to industry.

Most projects consist of designing, building, and testing a prototype of a product or process. At the completion of this capstone project, students will have acquired the following necessary skills, which will apply to their professional careers:

1. Synthesizing knowledge from earlier courses.
2. Starting from concept to a working prototype.
3. Project management.

4. Time management.
5. Dealing with vendors.
6. Oral communication with a technical and non-technical audience.
7. Writing a formal project report.

SENIOR CAPSTONE PROJECT

The four-course sequence for the MET senior project consists of Senior Seminar, Senior Design Project I, Senior Design Project II, and Senior Communications. This sequence lasts the full academic year, which allows students to work on complex projects, demands project planning, and the ability to perform in-depth research. The Senior Communications course is taken simultaneously with Senior Project II, providing students individual guidance in writing their final project report. Students are also required to present their project at the annual Technical Exposition (Tech Expo). The first three courses are offered by the MET department, and the fourth one is offered by Humanities, Media and Cultural Studies (HMCS) department. This sequence represents 6.75% of the baccalaureate degree requirements. The following is a short description of each course and the required pre-requisites.

Pre-requisites:

In addition to statics, kinematics, dynamics, strength of materials, device and system control, and design graphics courses, MET students take three design courses, one each year during their sophomore, junior, and senior years. This sequence consists of Design of Machine Elements, Mechanical Design, and Product Development. Topics in these courses include Quality Function Deployment (QFD), Concurrent Engineering, Design for Assembly (DFA), Design for Manufacturing (DFM), and Project Management. The main emphasis of the Product Development course is to teach systematic design methodology, and to expose students to the tools and techniques currently practiced in industry. This prepares students to apply some of the above tools and techniques to their senior project.

Senior Seminar:

Students are required to propose ideas for their senior project in Senior Seminar. These ideas may originate from industry, departmental faculty, national competitions, by themselves, or any other sources. By the end of this course, all students must have a written, detailed project proposal, which includes research, cost estimates, customer surveys, and tentative schedules, etc. Students are assigned a project advisor who works with them to finalize the proposal. The relationship between the advisor and students is like a project engineer and her/his supervisor/manager.

Senior Design I:

Admission to the Senior Design I course is contingent upon the successful completion and approval of the proposal submitted in Senior Seminar. Students use a systemic design methodology to create final technical specifications for their product/process. They generate conceptual designs, and select the best concept using weighted objectives or the Pugh method.

They do detailed design and analysis of all of the parts, generate working drawings and create a bill of materials. These analyses may consist of stress, kinematic, kinetic, heat transfer, DFM, etc. The above activities are documented in two different forms: weekly reports and a comprehensive, professionally written design report as well as a short oral report to all MET faculty.

Senior Design II:

During Senior Design II, students are expected to manufacture and/or purchase the necessary parts to build the prototype. Students are expected to machine and/or manufacture most parts, except those requiring sophisticated or precision machining using equipment not available in the department facility. This constraint does not apply to standard commercially approved components. The finished prototype is then tested and debugged to verify that it meets or exceeds the technical specifications proposed by the students in Senior Design I.

Senior Communication:

Senior Communication prepares students for oral and written communications with both a technical and a non-technical audience. During Tech Expo (described below), students make an informal technical presentation to project judges, as well as brief presentations to general public, including the media. Two formal oral technical presentations and a written professional technical report are required from each student.

Tech Expo:

Local industry, employers, parents, families, alumni, and the media are invited to the college sponsored Technology Exposition (Tech Expo) in May. Seniors from all the departments in the college display, demonstrate and present their projects to interested parties. Each department invites representatives from industry to judge these projects. All judges invited by the MET department are practicing engineers. Projects are judged on technical complexity, creativity, application of existing technologies in an innovative way, and the students' communication capabilities to explain their projects. The winning project from each department is then judged on a college-wide basis.

2007-2008 BATTLEBOT PROJECT

As mentioned in the Senior Seminar course description, the Battlebot project falls into the category of national/regional/local competitions. The Battle robot was designed and built to meet the BotsIQ National Competition specifications.

The BotsIQ program website emphasizes that it is "responding to the critical challenge impacting America's technical labor pool and the number of students without hands-on science, technology, engineering, and math (STEM) skills used in our manufacturing, industrial, and technical business areas." These skills are promoted through the design and creation of competitive robots. It also encourages competitive sportsmanship and creativity among teams of students.

The tournament rules and procedures document defines the rules and procedures for a safe, fair and efficient BattleBots competition. The technical regulations document defines the specific requirements needed in the design and construction of BattleBot robots. Technical requirements include safety, weight limits, control systems, batteries, pneumatic/hydraulic systems, weapons, etc.

Some of the basic requirements/rules include:

- Weight limited to 120 lb for middleweight collegiate competition
- BattleBot robots must be able to move at a speed of one foot-per-second
- Hazardous or toxic materials cannot be used anywhere on a BattleBot
- Safety covers are required on all sharp points, corners and edges on the exterior of a BattleBot
- All competition matches were 3 minutes in duration

Based on the detailed rules and requirements, the design for the CAS Battlebot was broken into four main areas:

- Weapon (offensive)
- Drive train and control system
- Defense and armor
- Body and frame

Each area was completed by a single team member. They worked individually on their research, Quality Function Deployment, design, manufacturing, and project management but also functioned as a cohesive team to ensure that the BattleBot was fully integrated and ready for combat.

This paper describes the design, analysis, manufacture, and assembly of the weapon system, complying with the BotsIQ requirements. The same process was used for all systems and components in each area.

Some of the major requirements related to the weapon design and operation were:

- Weapon safety–when the weapon is deactivated, it is non-hazardous to all personnel and objects
- When using modular weapons, all weapons comply with all applicable Battlebot regulations. The combined time for adding and removing each modular weapon must be less than 30 min.
- Projectile weapons are allowed–provided; they are restrained by a tether less than 8 feet in length. The tether must restrain the fired projectile even after being discharged multiple times.
- Flywheel weapons--at maximum spinning speed the fly wheel will not break or affect the control of Battlebot. Flywheels must comply with all safety and spin-down time requirements. Flywheels must use a separate power source and cannot be spun prior to the match.
- Large spring weapons are allowed provided they meet all safety standards. A large spring requires more than 20 lb of force at any point of its movement. In the deactivated

position, spring cannot exert a force of more than 5 lb. All arming must be done by remote control, and must have a backup mechanical release mechanism for releasing the spring force in less than 30 seconds by one person without placing any body part in the path of the weapon system or the Battlebot. Special tools can be used to release the spring force.
- Ineligible types of weapons–Tesla coils, stun guns, radio frequency jamming equipment, water, corrosive chemicals, large quantities of small dust, blinding bright light, explosives, heat and fire, etc

The objectives for the weapon design upon completion were:

- Cause extensive visual damage to opponent
- Weapon shouldn't stall
- To be fully accessible upon removal of armor for repair, and no special tooling required
- All repairs to be completed within 20 minutes including full replacement, if needed
- BattleBot robots should be able to move/maneuver when the weapon system is disabled

<u>Weapon Design:</u>

Several different weapon styles were considered (see Figure 1) before finalizing a style from the list below.

- Flipper Bot, uses a flipping mechanism to tip the opposing robot on its back, rendering it unable to move
- Full body spinner, uses the entire body and frame of the robot as a weapon by spinning it around itself
- Dead blow, uses a hammer-like mechanism to swing at an opponent with large mass or a puncturing weapon.
- Inertial spinner, uses the inertia of large rotating masses to inflict damage, picture to be found (Figure 2)

(a) Flipper Bot | **(b)** Full Body Spinner | **(c)** Dead Blow

Figure 1: Weapon Styles

Inertial Spinner Weapon:

The inertial spinner design was the final selection for the weapon style. Research indicated that the Flipper Bot and Dead Blow should be eliminated because, in most cases, they caused minimal damage to the opponents' Battlebots. The Full Body Spinner is capable of causing the most damage but usually is the hardest to control due to the reaction forces caused by the attacks. The Inertial Spinner was chosen due to the balance of controllability and the amount of damage it can inflict.

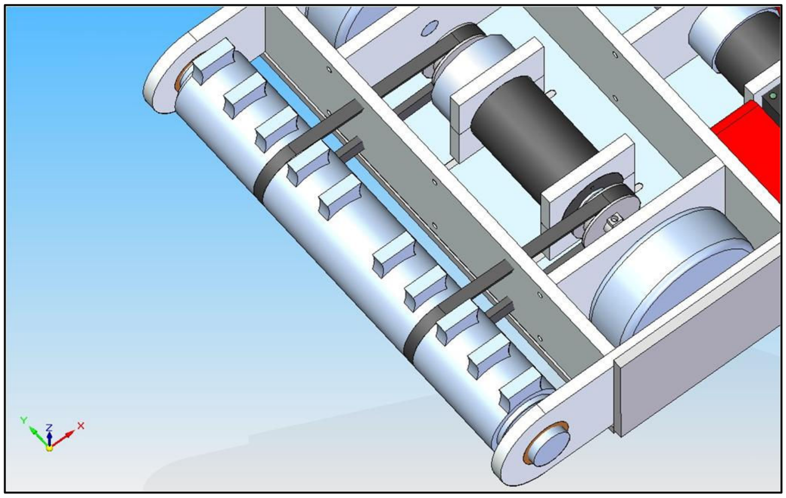


Figure 2- Inertial Spinner

Figure 2 shows the final weapon which was used in the CAS BattleBot. This style of inertial spinner is called a "drum" weapon for obvious reasons. The energy of the rotating mass of the drum is translated through the projections on the drum called teeth and into the opponent's Battlebot inflicting the damage.

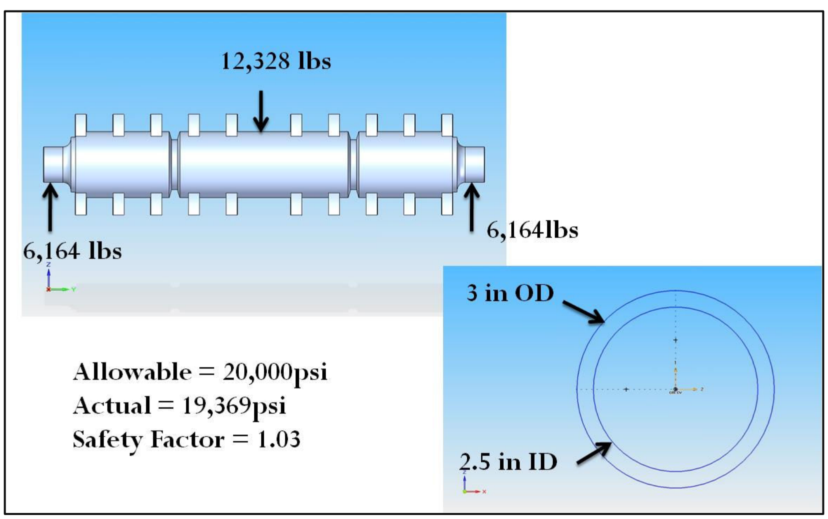


Figure 3 - Bending Stress Analysis

The weapon included the drum with teeth, bearings and rotors, the motor with drive train, and batteries for motor. To meet the 120 pound weight requirement, the drum was designed to be hollow. Since the majority of the mass of the drum is on the outermost radius, the drum was considered a flywheel for the stress analysis. Flywheel assumptions resulted in forces and stresses within 2% of rotating body analysis. It was assumed that 50% of the total energy could be delivered during a blow because the full amount of energy available by the drum cannot be released due to deflections and reactive motions. The drum was designed to withstand the bending stresses as shown in Figure 3. The teeth were welded to the drum, and were analyzed as a cantilever beam.

Bronze sleeve bearings were selected because they are inexpensive, easy to replace and light weight. The load ratings were not as high for the sleeve bearings as for the other bearings but it was sufficient for the three minute match. The highest power to weight ratio brushed 24V DC motor was chosen. A V-belt drive was selected as it was light weight and allowed for limited lateral motion which cannot occur during the combat. BotIQ approved batteries were selected to drive the weapon motor.

<u>Fabrication of Weapon:</u>

The weight restriction limited the thickness of the drum wall to ¼". To keep the ¼" thickness in the space between the belt grooves, a process called the bottle boring process was utilized. A greater thickness of material was needed in the areas of the body where the V-Belts are attached. The bottle boring process consists of boring out the center of a cavity whose diameter is larger than the area available to enter that cavity. A section of the drum body where the process was needed is seen in Figure 4.

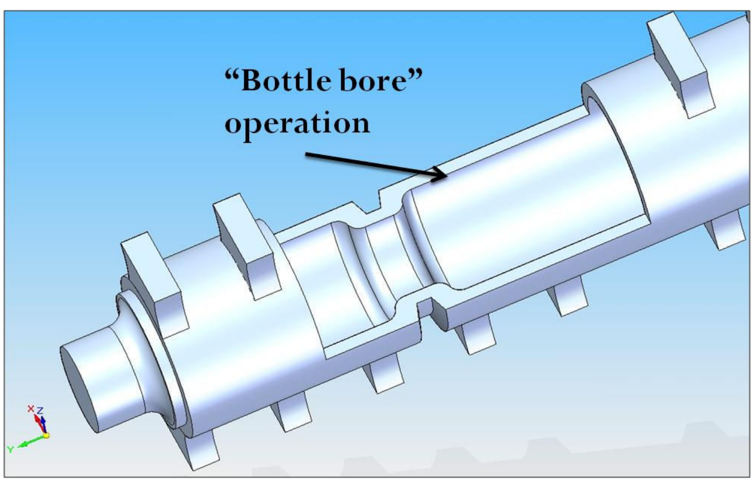


Figure 4 - Bottle Bore Manufacturing

The drum body, rotors and teeth were MIG welded to form one unit as shown in Figure 5. The MIG welding process provided adequate strength for the joining the three parts and to withstand the damage from opponents' attack. The completed BattleBot is shown in Figure 6.

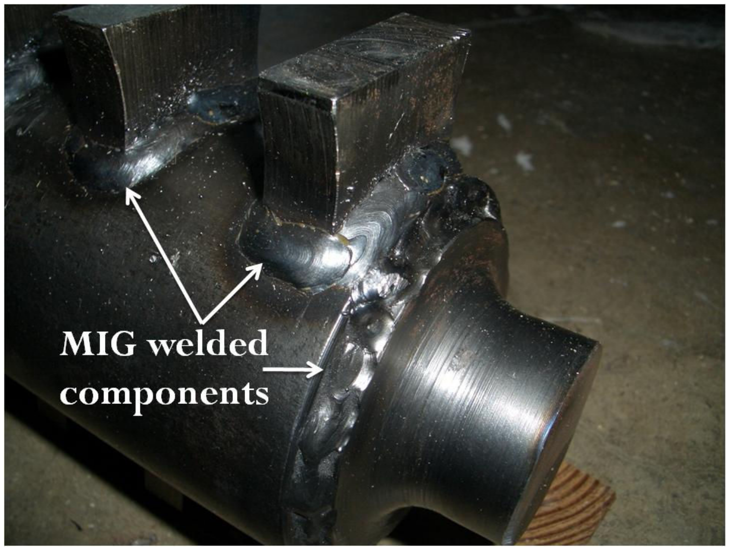


Figure 5 - MIG Welding Components

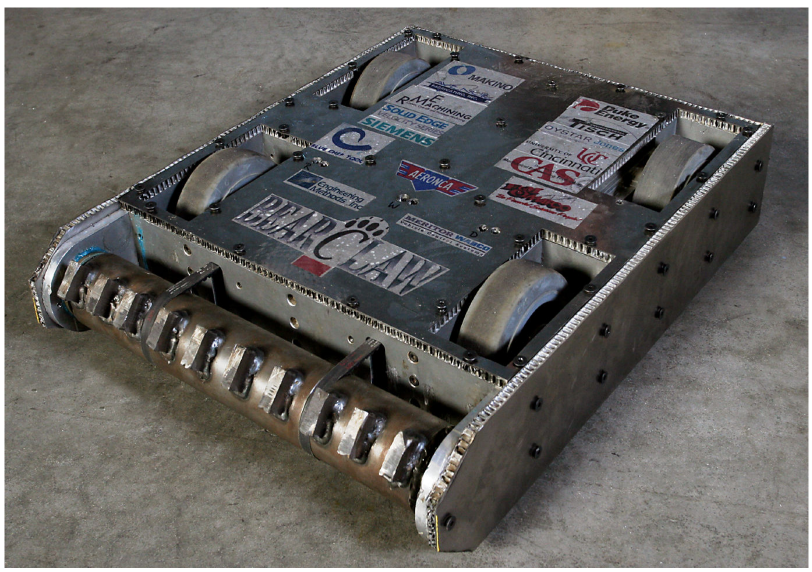
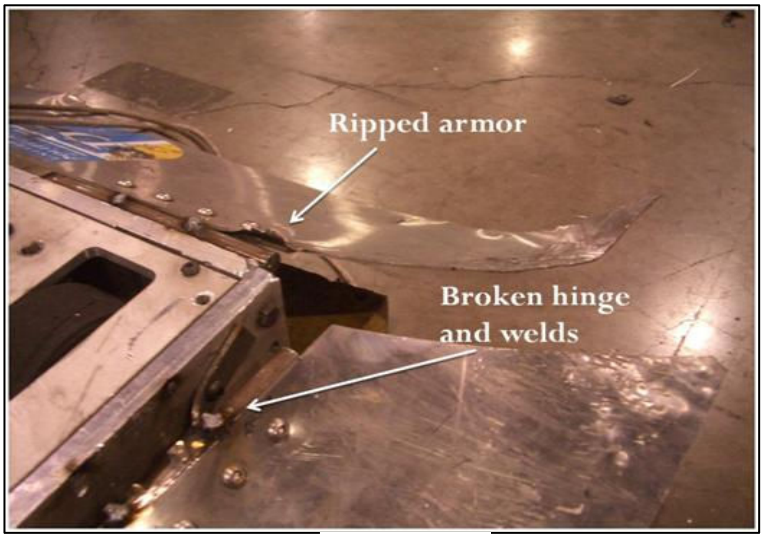


Figure 6 - Combat Ready BattleBot

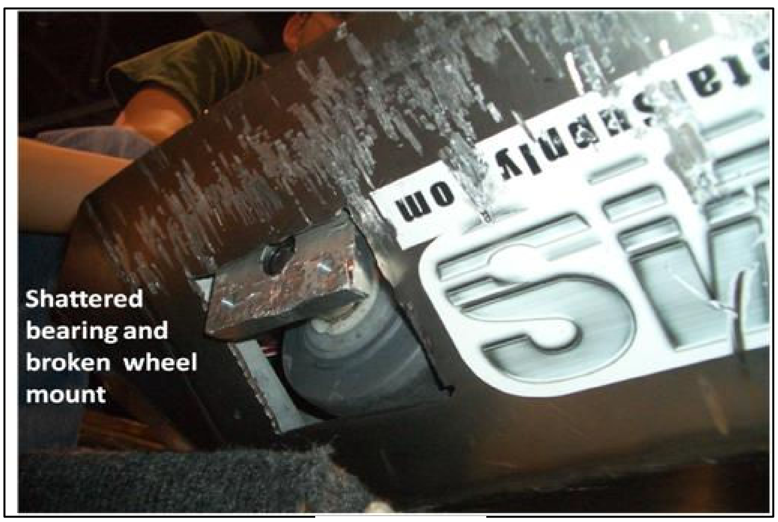
<u>Competition and Results:</u>

Preliminary testing of all components, including motion of the weapon, was done in the College of Applied Science laboratories. Batteries and controllers were also tested. The effectiveness of the weapon could not be tested before the competition. During the preliminary testing, the weapon reached its maximum speed in less than ½ second.
The BotsIQ National Competition was held in Miami, FL, from April 30 through May 4, 2008. The competition was a double elimination event, meaning that any team losing twice was out of the competition. During the competition, the 2008 CAS BattleBot placed first overall in the 120lb collegiate division, winning all but one of their matches. Participating collegiate teams included University of Miami-Florida, Georgia Institute of Technology, University of Puerto

Rico, etc. The CAS BattleBot also won the "Best Engineered" award and the team received the "Best Driver" award.



(a)



(b)

Figure 7 – Visual Damage of Two Opposing BattleBots

During the competition, a spacer for the weapon was placed in backwards, causing it to seize. In order to fix the problem, the weapon had to be completely taken out and reassembled. The time needed for this operation was only 15 minutes which satisfied the 20 minute requirement. The visual evidence of damage sustained to opponents during matches is shown in Figure 7 (a) and (b).

<u>Project Management and Team Experience:</u>

The CAS Battlebot robot was a team project. Students learned how to function as a team. They also gained skills in writing sponsorship letters, fund raising, establishing a budget, dealing with vendors, and time management. These skills enabled them to meet deadlines and work within organizational rules and regulations. In addition, they learned to communicate and deal with team members, thus improving the team's efficiency.

Students conducted their fund raising in two main ways: the first was sourcing free manufacturing by using idle machining centers at local industries; the second source of funding was through material or cash donations from organizations, companies, and individuals. The total cost of the project, including travel, was $17,000.

One of the issues was the clearance by the legal department at University of Cincinnati, which didn't agree with all of the terms and conditions required by BotsIQ. This was worked out between the parties with the mutual agreement. Also due to timing of the competition, the project advisor couldn't be present at the competition, and a replacement had to be found.

CONCLUSIONS

The CAS Battlebot project was one of the more complex senior design projects in the MET department. During the 2007-2008 academic year, this group of students learned to design, build, test, and function as a team. Beside the research needed for design, analysis, and building this robot, the team obtained valuable experience in fund raising, teamwork, vendor negotiations, organization compliance, time management, writing technical reports, and product testing. During the competition, they learned "on the spot" problem solving. They completed every step-from the concept to a competing/winning battle robot.

Two suggestions were made by the team if they had to redo the design. One would be a more sustainable tooth profile design. At the competition, some teeth lost their original profile and were dull. This could be done by either heat treating or using a different material for the teeth. The other suggestion was to have a more reliable belt tensioning device. The installed device functioned adequately but required constant tuning to keep the proper tension on the V-belts.

Without extreme dedication and proper planning, future teams could encounter frustration and failure. All team members in this particular group were battle robot enthusiasts and among the better MET students. The project advisor believes that future team members must be selected carefully for any project of this complexity to be successful.

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