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Application of Engineering Design Principles to Design and Build Solid Propellant Analysis Machine

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Abstract

Engineering concepts from multiple disciplines can be utilized to create new and innovative solutions to solve problems. Applying these concepts requires the combined effort of several disciplines, each bringing their unique ideas and perspectives. The goal of this multidisciplinary project was to apply knowledge obtained throughout each of the group members' undergraduate studies to design and build a combustion chamber to observe combustion reactions and acquire combustion behavior data. The team working on this project was comprised of two Mechanical Engineering students, one Engineering Technology student, and one Electrical Engineering student. Project activities were evaluated based on seven ABET (Accreditation Board of Engineering and Technology) criteria[1]. Combustion data is essential to the study of solid fuel. A combustion chamber capable of obtaining this data safely and efficiently allows the researcher to investigate solid fuel characteristics that might have otherwise been unobtainable. Due to the complexity of characterizing combustion reactions, principles from solid mechanics, dynamics, thermodynamics, and electrical circuit design were employed to build the combustion chamber. Using these principles, the design group was able to design a chamber optimized for the observation of combustion using a high-speed camera. The design also features an automated ignition arm, five temperature sensors, a humidity sensor, a flame sensor, an oxygen sensor, an optional environment control gas inlet, an automatic locking door safety mechanism, and an exhaust system equipped with a filter for capturing emissions for future analysis. Over the semester, students employed the engineering design process to create a combustion chamber with features that make it unique and unlike any commercially available solutions to combustion characteristic observation tools. For example, the ignition arm allows users to ignite samples safely and the flame sensor removes the arm from the flame once the flame has been detected preventing the arm from being damaged by prolonged exposure to the fire. Based on the findings from the unit testing, students successfully built a design system that meets the group's design goals and provides a testament to students' learning at the West Texas A&M University Engineering program. Future senior design project will enhance the current system for a better arrangement and location of sensors used.

Introduction

A capstone project is a key component to assessing a student's comprehension of the knowledge obtained throughout their undergraduate studies as well as their readiness to enter the next stage in their careers. One of the primary benefits of a capstone project is that it helps students bridge the gap

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between the theories and skills they have learned with the real-world challenges and problem-solving techniques that they will experience in industry. Collaborative capstone projects in particular, allow students to experience working in a group setting[2]. This allows students to develop teamwork and communication skills and other soft skills that employers today often value over academic abilities[3,4]. These projects can help students stand out as desirable employees and potential leaders in their field or company as well as to improve their ability to grapple with arduous challenges[5,6]. Moreover, the incorporation of capstone projects has demonstrated an enhancement in team collaboration and the ability to cultivate leadership skills through self-directed projects[7].

The students involved in this project were gathered from different backgrounds to produce a multidisciplinary team. This design group consisted of two Mechanical Engineering students, one Electrical Engineering student, and one Engineering Technology Student. Students of these disciplines specifically were selected for this project based upon the expected requirements of the design. Assuring disciplines of the students were aligned with the needs of the design allowed for a more balanced project in which students contributed work and ideas more evenly[8].

Engineering is the application of mathematical and scientific concepts to solve problems. Therefore, identifying a clear and challenging problem is a necessary first step for any engineering design project. The need for this project stemmed from research involving the creation and assessment of solid rocket fuel samples made using recycled polystyrene as an eco-friendly alternative binding agent. The scope of this study, however, was limited by the fact that university lacked the facilities to study the ignition and subsequent combustion behavior of the samples. A laboratory combustion chamber would allow for the obtaining of combustion data for this study. Additionally, the chamber would open the door for the university to conduct more studies involving energetic materials providing professors and students alike more opportunities to become involved in the field of combustion and energetic materials.

The evaluation of the project activities completed by the group was based on the seven student outcome ABET (Accreditation Board of Engineering and Technology) criteria[1]. The seven student outcome ABET criteria serves the purpose of ensuring adequate comprehension of concepts fundamental to the engineering practice as well as confidence in being able to directly apply these concepts to solve problems in an ethical and effective manner. Based upon the groups self-evaluation of the project the group believes that it provides testament to the success of the West Texas University Engineering Program's in ensuring that students are provided with curriculum designed with the seven ABET criteria as a main focal point.

Project Overview

The time frame of this project from conception to completion was only one semester. Due to this fact, planning out the design process was a critical step for the student group to ensure they are able to stay on track. By using the engineering design process shown in Figure 1, the student group was able to establish an efficient method for tackling this project. After identifying the group's project requirements, the synthesis of potential solutions was initiated. The student group produced design alternatives for the chamber assembly which primarily differ from each other in overall geometry. Three alternatives, a cubical (Figure 2A), spherical (Figure 2B), and cylindrical

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design shown in Figure 2C were compared by utilizing a Pugh matrix. Pugh matrices allowed the design group to add more weight to certain parameters which are considered of higher importance to the customer's needs and project synthesis. Not only does this simplify the design alternative selection process, but it also compels the students working on that project to take the time and consider which concepts are most critical to the design. Using this method, the group determined that the cylindrical alternative would be the most optimal solution to fit this project's requirement. Once the cylindrical design was selected, the group began utilizing various optimization and analysis techniques in an iterative manner to further develop and refine the alternative.

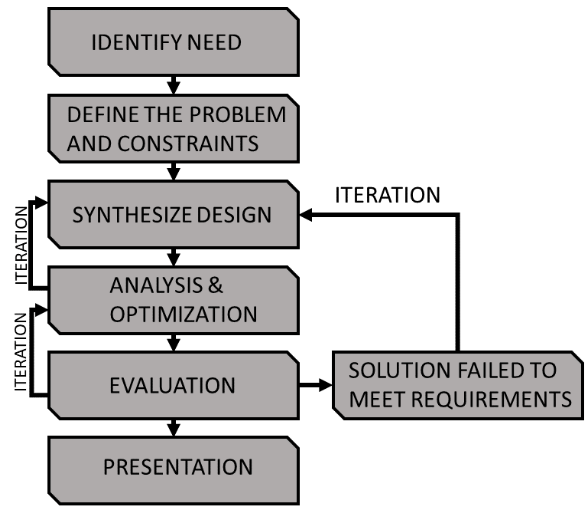

Figure 1. Engineering Design Flowchart

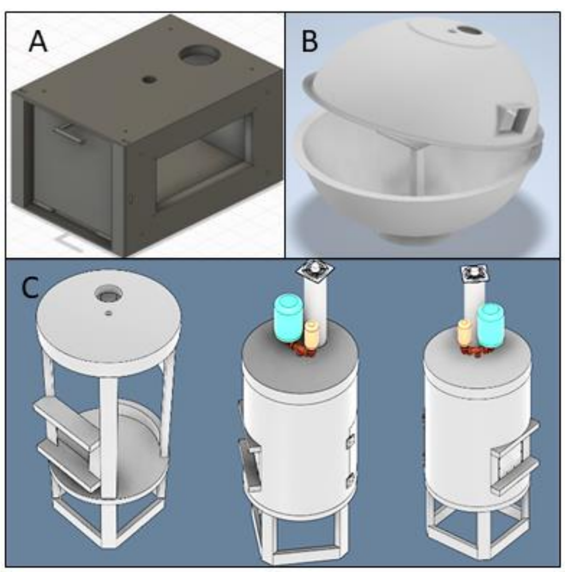

Figure 2. A) Cubic Geometry Design Alternative, B) Spherical Geometry Design Alternative, C) Cylindrical Geometry Design Alternative

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Initial optimization and refinement of the selected design alternative included the application of primarily conceptual ideas. Practicality was the motivation for many of the design choices during this phase of development. The design group visited a combustion laboratory located at another university to gather ideas as to what features are most beneficial to combustion chambers designed for a similar purpose, and more importantly what issues do other combustion chambers have, that in the design of this chamber, the group could strive toward finding unique and innovative solutions for. One of the most prominent issues the design group observed was the difficulty of igniting samples safely and consistently. To solve this, the student group implemented a robotic ignition arm that can be used to ignite the sample remotely. Other innovative features the design group set to incorporate in this design include a support frame, a fire suppression system, an exhaust system, multilayered insulation, a door with an automatic safety locking mechanism, an automated ignition system, an emissions capture filter, a gas inlet for environment control, and a variety of sensors for combustion characteristic determination. Other design elements were optimized using more technical knowledge gained from courses typically included in most engineering undergraduate programs as well as more discipline specific courses. These courses include, but are not limited to, material sciences, mechanics of materials, thermodynamics, heat transfer, circuit analysis, and fire protection engineering. This includes both analysis by hand and analysis aided by computer models and tools such as Fusion 360 and Inventor.

After finalizing the design sufficiently and presenting their progress to the course instructors for approval, the design group was allowed to proceed with the build and evaluation process. The actual manufacturing of engineering designs is an aspect of engineering that is often not covered in most courses despite its importance in any engineering role post-graduation. Understanding how designs translate from concept to prototype stage allows students to consider the assembly process and what complications might arise during said process as a factor during the design process. The building of this project required students to apply their knowledge of welding, metal fabrication, electronic wiring and installation, fastener installation, and application of insulating materials.

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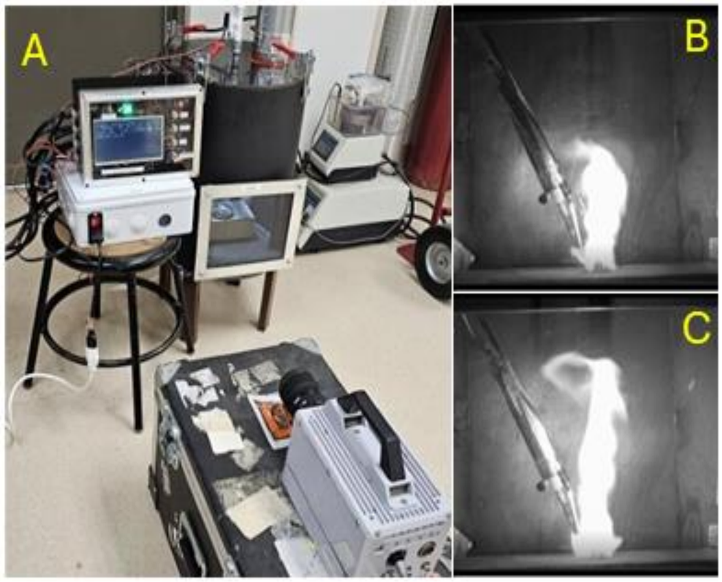

Figure 3. Dropout A) Final Design Instrument Set Up with High-Speed Camera, B) Still Frame Capturing Flame Ignition, C) Still Frame Capturing Flame Peak

The final design, titled the Solid Propellant Analysis Machine, shown in Figure 3A was evaluated to determine if the design successfully met the initially defined objectives. Because the design parameters were selected to be measurable the testing procedure was a relatively straightforward process. The design group ensured that the various components and features of the design worked as intended. Once the design was confirmed to be working properly, the group tested the chamber using smokeless powder samples as placeholder representation for the customer's samples. These tests are showcased in Figures 3B and 3C. The incorporation of these tests allowed for further optimization and finalization of the project until the combustion behavior of samples could be successfully studied as intended.

The student design group met all of the requirements established by the ABET program.[1] To meet the first criteria, the students implemented their culminated understanding from courses such as mechanical design, circuit design, material sciences, thermodynamics, and fire protection engineering. To satisfy the second requirement, the design group took into consideration the health and safety of the public and the environment by capitalizing on sustainability methods for material selection as well as employing several automated safety systems to prevent misuse and accidents. To fulfill the third criteria, students provided live presentations to multiple groups of individuals, including a local conference and at a university open house event. For the fourth criteria, students took into consideration the impact of the design pertaining to its use by users without the knowledge of the instrument's functionality. In order to meet the requirements of the fifth criteria, the student group continuously communicated throughout the duration of the project by establishing weekly meetings, maintained dialogue with the customer with regard to project updates, and consolidating project responsibilities to adhere to the provided timeframes. To ensure the sixth criteria was achieved, the design group implemented a series of experiments to establish that the data gathered

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was reliable and made certain that the instrument behaves in a safe manner during each operation. Lastly, for the seventh criteria, students accumulated contemporary methods on various topics ranging from, but not limited to, programming, application of codes and standards, and manufacturing practices. Likewise, the knowledge gained from these topics aided the student group in decision-making for design strategies and material procurement. These efforts to achieve each and every ABET program outcome demonstrate the group's commitment to excellence and professionalism in the field of engineering.

Summary and Conclusions

Capstone projects are an essential component of the engineering curriculum by providing students with a multitude of unique opportunities to apply their knowledge and skills to real-world problems. In addition to assessing a student's readiness to graduate from the program, capstone projects also offer a range of benefits that can only be obtained from projects of this nature. Based on experience and observations, an interdisciplinary capstone project similar to this one could provide students with a significant increase in their confidence within their respective disciplines. The collaborative nature of the project is one of the key aspects that contributed to its effectiveness. By working in teams, students learn how to communicate effectively, delegate tasks, work towards a common goal, and develop leadership skills. This experience is invaluable in the engineering field, where teamwork and project management are essential for success. Another critical aspect of the project was its focus on achieving the ABET student outcomes. By aligning the project with these outcomes, students were able to develop the skills and abilities necessary to succeed in their future careers. Future iterations of this system will consider to enhance the accuracy of measurement by optimizing the locations of sensors. In addition, collaborating national labs and local industry will be invited to evaluate the system and suggest future improvements.

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