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Learning Engineering Material Selection and Design Process Using an Engine Dissection

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Abstract
During the fall 2022 semester, the Mechanical Engineering department at the Virginia Military Institute (VMI) was interested in implementing a hands-on project in their Introduction to Mechanical Engineering course. The goal of the project was to provide new students an exposure to mechanical engineering through means of reverse engineering and experimental data collection. It was decided upon that the project would be based around a 5 hp Briggs and Stratton engine. In the projects students disassembled a set of engines and had discussions about the material selection and engineering design choices made. Then, using an identical engine, performance measures were collected using a small engine dyno. In this paper, the implementation of the project along with the learning outcomes from the project are presented. The results and conclusions drawn from a reflective assignment will be provided to express how students perceived their knowledge gained from the project specifically in the area of engineering design and analysis.

Introduction

It is common knowledge that hands-on project add in reinforcing material taught in the classroom and often times help students gain a deeper knowledge of the material. In fact, product dissection style projects have been around since the mid- to late-1990s [1]. Hands-on projects are often used in two applications: 1) to gain a deeper understanding of the course theory through application, 2) to motive learning of engineering topics. In this work the latter is the focus for using a hands-on project in a first year engineering course. One goal of the hands-on project development is to motivate the students make them excited to study mechanical engineering. A second goal, is that the students leave the course with an introductory level knowledge of the engineering design process. Specifically, material selection and manufacturing methods.

Through conducting this engine dissection project, the following learning outcomes are desired. First, students will be able to describe the design process and provide examples of how the process is applied to an engine. Second, students will be able to identify the role that materials play in the design process and describe the basic material properties of common materials used in mechanical engineering applications. Third, students will gain more confidence using hand tools to disassemble and assemble parts, which will provide a foundation for future machine shop education.

In this document background information about the benefits of hands-on projects and mechanical engineering dissection projects are provided. Next, the development of the engine dissection project is presented. Following, the learning outcomes achieved from the project are provided along with a discussion of the lessons learned and future improvements that will be made to the project. Lastly, concluding remarks are provided.

Background

In the mechanical engineering department at the Virginia Military Institute (VMI) a scaffold style project education is used, where each year students are required to design, analyze, and build a project in one of their engineering courses such as: Solid Mechanics, Mechanical Analysis, and Mechanical Design. To provide students with a more substantial foundation for these projects, a dissection project for the first-year engineering students is proposed. This project will provide the provide a visual, hands-on education that will provide students with exposure to complex parts and provide a foundation to improve their creativity in future project designs.

Mechanical dissection projects have been done several times and the product that has been dissected has ranged from simple children's toys to more complex items such as engines [2, 3, 4]. Commonly, the limiting factors to conducting a product dissection is the cost of the product, the laboratory/institute constrains on space and safety, and the handling of the waste once the dissection of the product has occurred [5,6]. Some of these issues can be addressed by obtaining small items that are meant to be assembled and disassembled multiple times. However, often times students misplace parts which results in missing or inoperable products from year to year.

While mechanical dissections can be challenging to implement, if the right project is selected the benefits will outweigh the drawbacks. A mechanical dissection can be categorized as a visual learning project. This is important because it has been documented since the late 1980s that engineering students are largely visual learners that will retain information better when educated using active, tactile, and visual methods [7]. In addition to catering to the dominate learning method, visual learning projects are useful because they can: improve reasoning skills, students learn important physical skills, and can improve creativity [8].

Project Development

The primary goal of this initiative is to provide the students with an educational hands-on project that piques their interest in mechanical engineering while providing the students with an opportunity to learn about engineering design practices and common manufacturing methods. A useful project that satisfies these objectives is a product dissection, where the students are tasked with dissembling an item and perform reverse engineering to see how it functions. A secondary goal of the project was to provide students with an early exposure to how data can be collected and analyzed in order to quantitively define the performance of an item. Ultimately, we decided to use a 5 hp Briggs & Stratton engine for our project. This choice was made due to the longevity and engine would provide, pending parts did not go missing. Engines are made to be serviced and torn down and rebuilt, which means less of a chance of parts breaking during the dissection. In addition, the small engine was selected due to the variety of manufacturing methods that are used to build all of the engine parts, which would provide great discussion surrounding the primary goal of the project. In addition, we already have two small engine dynos which meant that we had a way of applying external loads to the engine and collecting measurements to determine the engine performance. In the subsequent paragraphs, the specifics of the developed project including the engine dissection and the performance measurements are covered.

Engine Dissection

The first step the students completed was the dissection of the engine. The students started by removing the fuel tank, the air filter, and the exhaust. After completing this portion of the dissection, the class had a discussion regarding these initial parts. Some topics of discussion included: material choice (e.g., use of plastic for the airbox but metal for the fuel tank), the manufacturing process (stamping of metal for the fuel tank and injection modeling for the airbox). After removing these components, the students needed to remove the carburetor to gain more access to the engine head. After removing the carburetor, the students removed the engine head that houses the spark plug and intake and exhaust valves. By removing these parts, the students were able to see the inside of the engine, specifically the top of the piston and the cylinder walls. At this point, the students were able to use some measurement equipment to measure the volume of the engine to see how close their measurements came to the advertised engine displacement volume. In addition to the measurements more discussion of the engine components were had, however this discussion tended to be more engine focused (e.g., how does a carburetor work, why are there fins on the engine head and block).

One of the items we wanted the students to have exposure to was seeing the crankshaft of the engine, sometimes referred to as the bottom-end. To see this part, the students would need to remove the crank case plate. It was decided that this would not be performed in the lab because the engines contained some oil that would spill out when then crankcase were opened. To address this issue a pre disassembled engine was brought into the lab so that the students could see the crankshaft and the other components in the bottom-end of the engine including the governor system. This opportunity provided a good discussion because some of the students who have been around small engines have heard the term "engine governor" but were not aware that was used to regulate engine speed and how it worked. In addition, on the engines we used one of the interesting manufacturing features was that the gears that are connected to the governors were made of plastic. Students were surprised by this because they know engines get out and that plastic is not aways an ideal material in hot environments.

Engine Performance Measurements

After conducting the engine dissection, the next project task was to measure the engine performance. The measurement of the engine performance was broken into two tests. The first test involved measurement of the engine output torque across the engine operating range of engine RPMs (revolutions per minute). The second test involved estimating the fuel efficiency of the engine at various operating loads.

To measure the engine torque across the range of engine RPMs an engine dynamometer (dyno) was used. Each student was given the opportunity to run the engine dyno. After all students on the team ran the engine, the data (engine RPM and engine output torque) was stored in an Excel file. An example torque versus RPM plot is shown in Figure 1. In Figure 1 the raw collected data is shown by the blue points while a polynomial fit is provided by a red line. When analyzing the data with students in the classroom fitting a model to collected data, such as a polynomial function was discussed.

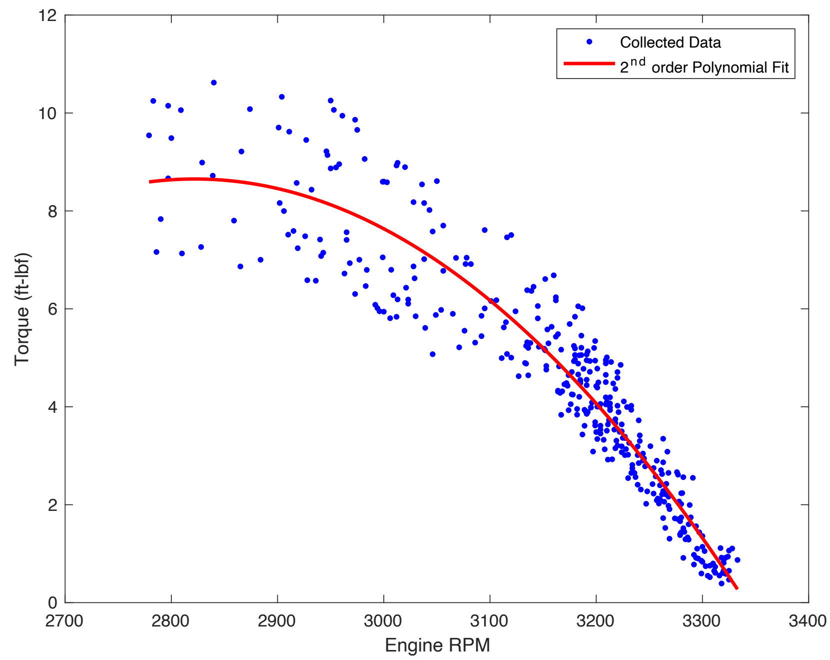

Figure 1. Example plot of collected torque and engine RPM data.

In typical engine convention torque and RPM only tell the user part of the story, the other part that is important is the engine power. That is present at the current torque load. Using Eqn. (1), below, the students were able to take the collected data and calculate a corresponding engine output power in units of horsepower (HP) for each torque-RPM data point.

$$\text{Power[HP]} = \frac{\text{Speed [RPM]} * \text{Torque [ft} \cdot \text{lbf]}}{5{,}252} \tag{1}$$

Through calculation of horsepower, the students were able to create a typical engine dyno plot of power and torque versus engine RPM, as shown in Fig. 2. One of the features of the plot is the large spread of data points at higher torque readings. This issue is due to the governor controlling the engine RPM based on the torque requirement at the time.

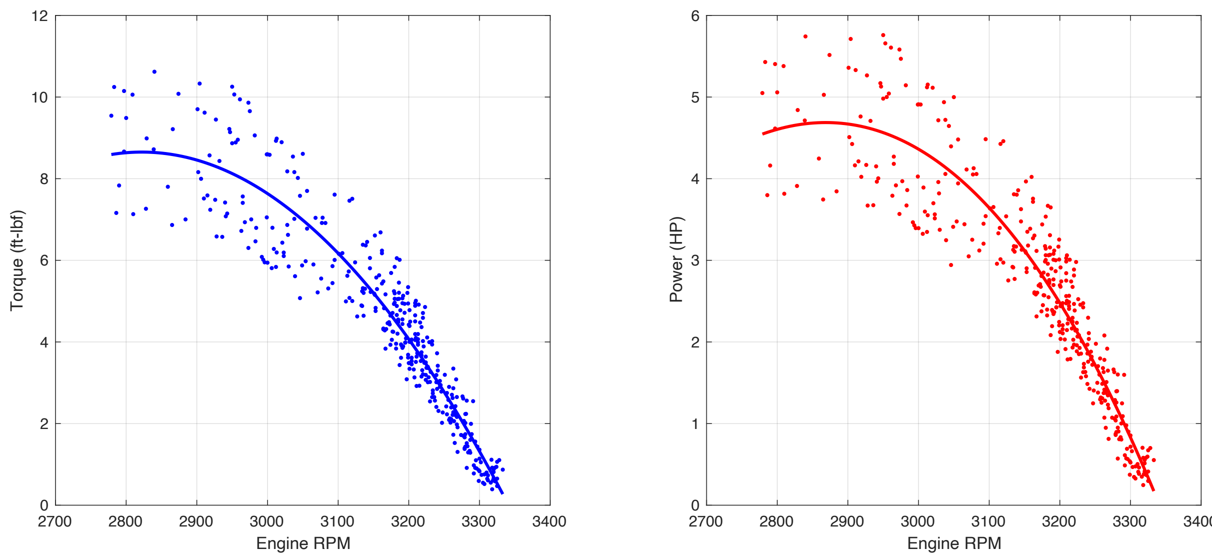

Figure 2. Example plot of engine output power and torque as a function of engine RPM.

The second performance measure was a fuel consumption measurement. To complete this measurement each group was tasked with running the engine on the dyno at a target RPM for 15 minutes. Prior to starting the engine, the fuel tank was removed from the engine and weighed. Then, upon completion of the 15 minute run, the fuel tank was removed and weighed again to determine the amount of fuel used during that time. Then, using an Excel file, a copy of which is provided in Appendix A, with a proposed go-kart drivetrain setup the students were able to use the RPM their engine was operating at during their test find the proposed forward speed of the go kart. This would then give them the information they need to determine the number of miles the go-kart would travel in the 15 minutes of run time. The students then found they could convert the weight of fuel to gallons using the density of gasoline to find the last missing piece to the fuel mileage calculation.

Discussion

It is believed that the first implementation of this engine dissection project was successful and the students gained knowledge regarding the engineering design process. It is believed that by slowing down during the dissection portion of the project and making the students engage in discussions it helped them think more about the engineering design process and how the engine fit into the process rather than just disassembling and re-assembling the engine for fun of taking something apart. This belief was validated by the student's evaluation responses that stated they felt that by going through the reverse engineering process they were able to gain a deeper understanding of the engineering design process.

In addition to the dissection portion of the project, a large portion of the students enjoyed the process of collecting experimental data. A large reason, this was a highlight portion of the project was because the data testing included running an engine on a dynamometer. Based on feedback at the end of the semester, less students found the analysis of the collected data interesting; however, they did find the process of performing analysis to make and support a claim useful.

During the development of this project there are three learning outcomes of focus. The first learning outcome related to the design process. Throughout this project the students had an exposure to the design process through a reverse engineering process. The second learning outcome was the role that materials play in the design process. As the engine was dissected a discussion regarding material choices occurred for several parts. As an example, when the students removed the fuel tank a discussion regarding the material was used occurred, which was stamped steel. Ultimately, the students came to the conclusion that due to the engine temperatures metal was used to avoid issues with the fuel tank melting/deforming. The third learning outcome was that students would gain more confidence using hand tools. At the end of the project, it was reported that all students reported an increase in confidence with using simple hand tools.

Future Work

Overall, it is believed that the engine dissection and testing project was successful and only small changes should be made in the future relating to clarity and timing throughout the class periods used to conduct this project. One area for future work is assessing the retention of the engineering design process. At VMI the students complete a design and build project during their sophomore year in Statics and Solid Mechanics, again in their junior year in Mechanical Analysis, and lastly in their senior year in Mechanical Design and Capstone Design classes. It would be good to see how much of the design process the students remember from this engine dissection lab when they perform their design project in Statics and Solid Mechanics. In the subsequent courses it is believed that they will have learning experiences from Statics and Solid Mechanics that will aid on those designs making it harder to assess how much of an effect the engine dissection has on designs in those classes.

Conclusion

The goal of this work was to develop a project that focused on learning material selection and the design process by dissecting an existing part. This goal was achieved using a dissection project involving a 5 hp engine. It was decided that this small engine would be used for the project due to the ability to purchase enough engines to conduct the project in two person groups and the availability of small engine dynos to perform the performance testing. While conducting the project the students found immediate interest in disassembling the engine and collecting data. It was observed that this interest helped the students stay engaged with the project and engage in good in-class discussions.

References

1. M. Regan and S. Sheppard, “Interactive Multimedia Courseware and the Hands-on Learning Experience: An Assessment Study,” J. Eng. Educ., vol. 85, no. 2, pp. 123–132, 1996, doi: 10.1002/j.2168-9830.1996.tb00221.x.

2. M. Brereton, S. Sheppard, and L. Leifer, "How Students Connect Engineering Fundamentals to Hardware Design: Observations and Implications for the Design of Curriculum and Assessment Methods," in the 10th International Conference on Engineering Design, Prague, WDK, 1995, vol. 23, pp. 336-342.
3. J. S. Lamancusa, T. M. Kumar, and J. Jorgensen, "Learning engineering by product dissection," presented at the ASEE Annnual Conference, 1996.
4. A. F. McKenna, W. Chen, and T. Simpson, "Exploring the impact of virtual and physical dissection activities on students's understanding of engineering design principles," in ASME IDETC/CIE, Brooklyn, NY, 2008, pp. 359-368: ASME.
5. M. Borrego, J. E. Froyd, and T. S. Hall, "Diffusion of Engineering Education Innovations: A Survey of Awareness and Adoption Rates in U.S. Engineering Departments," Journal of Engineering Education, vol. 99, no. 3, pp. 185-207, 2010.
6. M. Devendorf, K. Lewis, T. W. Simpson, T. W. Stone, R. B. Stone, and W. C. Regil, "Evaluating the use of digital product repositories to enhance product dissection activities in the classroom," Journal of Mechanical Design, vol. 9, 2010.
7. Learning and Teaching Styles in Engineering Education, R.M. Felder, L.K. Silverman, Engineering Education, 78(7), April 1988, pp 674-681.
8. T. Gamdi and M. Watson, “BYOE: Advancing Petroleum Engineering Undergraduate Education Using Visualization Labs,” ASEE 2022 Annual Conference, 2022.

Appendix A. Go-Kart Drivetrain for Fuel Consumption Calculation

Off-Road Go Cart Drivetrain				
You are building an off road go cart and the engine is connected to the wheels through a single chain drive setup. The engine sprocket size, the axle sprocket size, and the tire diameters are provided below to determine how fast the go cart is capable of going based on the RPM of the engine.				
Engine Sprocket Teeth:		10	teeth	
Rear Axle Sprocket Teeth:		70	teeth	
Tire Diameter		22	in	
Engine RPM	Wheel Speed (RPM)	Wheel Speed (rad/s)	Forward Speed (in/s)	Forward Speed (mph)
2000	285.7142857	29.91993003	329.1192304	18.69996226
2100	300	31.41592654	345.5751919	19.63496037
2200	314.2857143	32.91192304	362.0311534	20.56995848
2300	328.5714286	34.40791954	378.4871149	21.50495659
2400	342.8571429	35.90391604	394.9430765	22.43995471
2500	357.1428571	37.39991254	411.399038	23.37495282
2600	371.4285714	38.89590904	427.8549995	24.30995093
2700	385.7142857	40.39190555	444.310961	25.24494904
2800	400	41.88790205	460.7669225	26.17994716
2900	414.2857143	43.38389855	477.222884	27.11494527
3000	428.5714286	44.87989505	493.6788456	28.04994338
3100	442.8571429	46.37589155	510.1348071	28.9849415
3200	457.1428571	47.87188805	526.5907686	29.91993961
3300	471.4285714	49.36788456	543.0467301	30.85493772
3400	485.7142857	50.86388106	559.5026916	31.78993583
3500	500	52.35987756	575.9586532	32.72493395
3600	514.2857143	53.85587406	592.4146147	33.65993206