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Lessons learned in engine temperature control through radiator configurations: A formula SAE design

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Abstract

Racing cars rely on many systems to be successful in their competitions. One of the most vital systems to any race vehicle is the engine system that provides power to the vehicle. When racing an internal combustion engine, the regulation of temperature is critical to its performance. The radiator system plays a critical role in regulating the engine temperature and optimizing its operating temperature is the key to quality performance. This paper presents student efforts to configure a radiator system to be used in a Formula SAE vehicle. Heat transfer formulae are utilized to optimize the size of the radiator system. The system is then tested on an actual vehicle to compare real performance to theoretical. Part of the experience gained includes the determination that airflow adjustments across the radiator are a key factor in performance.

The process of radiator selection and size optimization and the configurations made to improve air flow is presented. The perspectives for students and faculty from the University of Georgia are presented. The student main engineer took the lead to formulate this paper. Five other students that worked on the project were unable to engage in writing the paper.

Introduction

The Formula SAE activities at the University of Georgia are recognized as a platform that provides experiential learning to its undergraduate students. Most of the students in the Formula SAE program come from engineering disciplines. Students range from Freshmen to Seniors. Freshmen, Sophomores, and Juniors participate as non-capstone members. Senior students mostly participate as cap-stone members. Regardless of one’s category, the students design, fabricate, and test various systems of the Formula SAE race car. Formula SAE is a platform that calls for a strong engineering knowledge and skill set. Seniors and those participating as capstone students are expected to transfer learned content and skills from different engineering classes and use it to design required parts or systems that fulfill the efforts to create a race vehicle [1]. Mostly mechanical and electrical engineering content is needed for vehicle creation.

In the Fall semester, students in Formula SAE study the scope of upcoming competitions. Students then choose or are assigned to one of the following vehicle systems: powertrain, suspension, chassis, or electrical. Once assigned to specific systems, students study what is required for that particular system and develop a plan for creating the system through design. The design must meet the specifications of the SAE Rules. Several approval stages and mechanisms are put in place to ensure design robustness and safety. The Spring semester is typically used for procurement of fabricating materials and purchase of off the shelf parts. The fabrication ensues and system assemblies are made. The goal is to have the systems seamlessly integrate to create the race car. Therefore, not only are technical skills required, but interpersonal skills and teamwork aspects are promoted for successful results. This paper presents lessons learned in the determination and creation of an optimal cooling system for the race car engine.

The powertrain system of the Formula SAE Internal Combustion includes the engine, and transmission on power. Engine performance is dependent on several subsystems such as, the intake, the exhaust, timing in mechanical and electrical parts, and the cooling system. This paper discusses the cooling system that enables an engine to run on optimal temperature at all times. This case, however, was not experienced in this project, and hence prompted the review and seeking solution for the cooling system. The discussion herein presents the work that was done to improve the cooling system by examining and rectifying problem of an overheating radiator.

Design Stages

In order to begin setting requirements for the cooling system, it is important to understand the design parameters and system requirements. The engine selected to power the vehicle was the Honda CBR 600RR from 2006. The relevant background from the engine to determine cooling needs are the temperature thresholds and max engine power. The engine' s thermostat allows for max coolant to flow at a temperature of 180 Fahrenheit, and the fan begins cooling at 160 Fahrenheit. The power of the engine is approximately 67HP (50kW). These results provided us with the preliminary information in considering design requirements and assumptions.

Assumptions

- Vehicle speed is not taken into account for airflow rate
- Constant fan flow rate
- Constant fluid flow rate
- Analysis is independent of time (non-transient)

Design constraints

- Coolant in the system is distilled water
- The dimensions of the radiator cannot exceed 11.75in x 11in x 2in
- Coolant of the system cannot exceed 212 Fahrenheit due to boiling point of water

Radiator choice

Students had to determine a radiator that would optimize heat transfer that allows the engine to operate effectively. The first approach was to determine the horsepower output of the engine. Using equation 1, Students derive horsepower from torque of the motor and RPM.

$$\text{Horsepower}=\text{Torque}*\text{RPM}*(1/5252) \quad \ldots\ldots\ldots\ldots \quad (1)$$

Students determined that at 32lb-ft of torque at 8,000RPM equates to approximately 50.5 HP (38kW). About ⅓ of the power generated by the engine is transferred as heat into the coolant system. This meant that 12.6 kW of heat needed to be removed from the system given by our design.

The next step required the use of heat transfer equations [2] to determine the radiator size needed to dissipate the heat from the system. This was done using the Effectiveness NTU method for cross flow heat exchangers. Equations 2 to 4 were used to determine and compare the cross sectional area to heat transfer effectiveness, engine heat output, and Volume flow rate through the radiator, respectively. A MAT-Lab® script was created to compare multiple sizes of radiators simultaneously.

$$NTU=U*A*(1/C_{min}) \quad \ldots\ldots (2)$$

where NTU is unitless , U is heat transfer coefficient, A is heat transfer area, and C is the smallest thermal capacity of the two fluids.

$$\varepsilon = 1 - exp\left\{\frac{NTU^{0.22}}{c}\ [\exp(-c\ NTU^{0.78}) - 1]\right\} \quad \ldots\ldots (3)$$

where ε is effectiveness, and c is ratio of smallest thermal capacity to largest thermal capacity.

$$q=\varepsilon*C_{min}*(T_{h,i} - T_{c,i}) \ldots\ldots (4)$$

where q is heat transfer rate, ε is effectiveness, $T_{h,i}$ is temperature of hot fluid in, and $T_{c,i}$ is temperature of cold fluid in.

Seeking Solution

In order to discover an optimized radiator, students compiled the above equations into a MAT-Lab® script. Using inputs provided by the design contraints, engine power, and standard values for specific heat of water and air. Those inputs are used to solve for heat effectiveness at a range of temperatures in equation 4. Equation 3 is then used to solve for a range of NTU values that give area solutions. Air volumetric flow rates of fans can be considered in order to increase or decrease the necessary radiator size to achieve the necessary heat transfer.

The optimized solution generated by MAT-Lab® is determined by two graphs. The first determines the most efficient radiator area for a given heat output. The solution occurs where the minimum area for heat transfer needed to provide adequate heat transfer out of the system 12.6kW is achieved. Figure 1 indicates that this point occurs at approximately 0.0465m^2 (72in^2). Using this area, students determined the minimum volumetric flow required to provide adequate cooling is 0.69 m^3/s, as shown in figure 2.

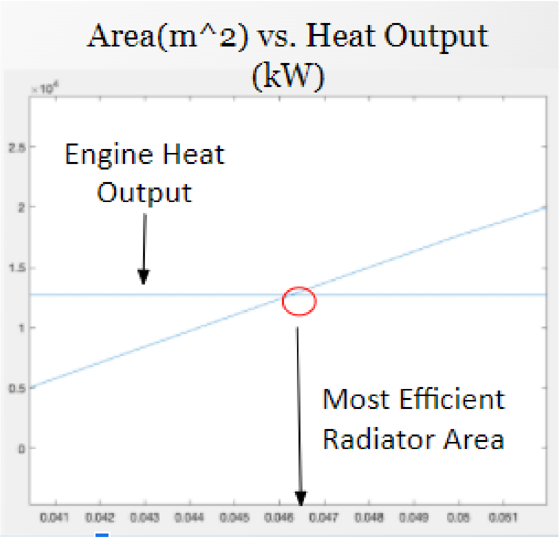

Figure 1: Solution for most efficient radiator output

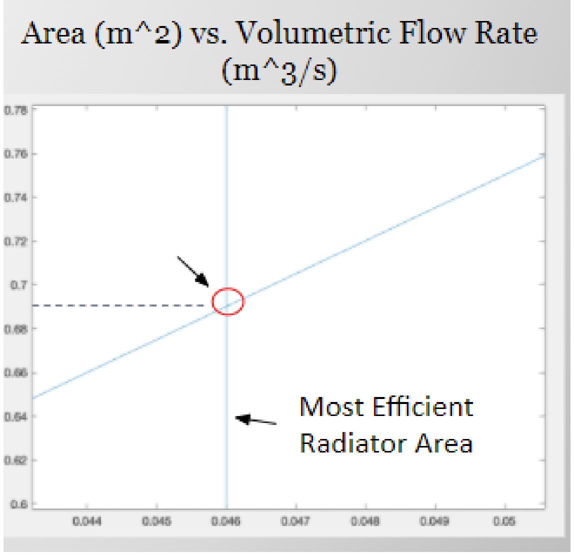

Figure 2: Required Volumetric flow rate for given Radiator area

Taking these solutions into account the team decided to add a factor of safety and increase the total radiator area 20%. Resulting in the selection of a radiator with a 0.058 m^2 (90 in^2) cross section for the final design and a fan that has a volumetric flow rate greater than 1 m^3/s. The final system had a radiator with a core area of 10 x 9 inches with an 8 inch fan. This gave the team confidence that the system would be kept at a reasonable temperature. After testing the design and making the decision to add the fan shroud, the system was determined to be effectively cooled.

Overheating problems

Upon finalizing the initial design parameters of the radiator students proceeded to place it onto the vehicle. Students then used the radiator with a 10 x 9 inch core as specified by our solution as well as a circular fan that provides the optimized volume flow rate. In order to achieve the calculated volume flow rate, an 8 inch diameter fan was selected to mount to the radiator. As a result, the fan only covered a portion of the actual radiator's rear surface area. The lack of coverage in parts of the radiator resulted in an adequate cooling section in the center and hot spots at the corners which can be viewed in figures 3 to 5 showing images captured using the Seek Thermal iphone equipment.

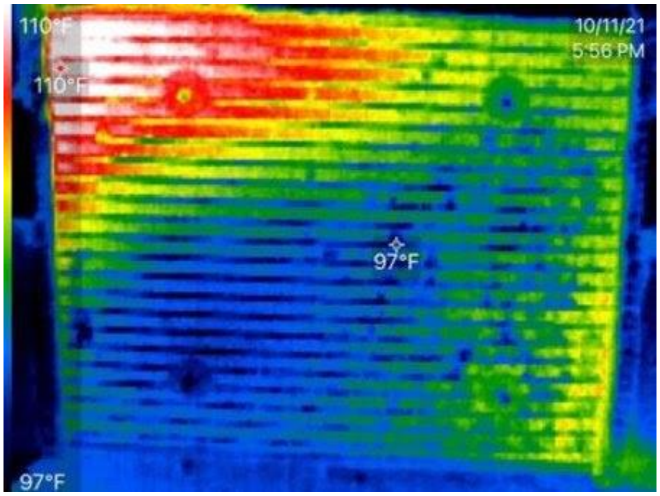

Figure 3: Temperature before fan is activated

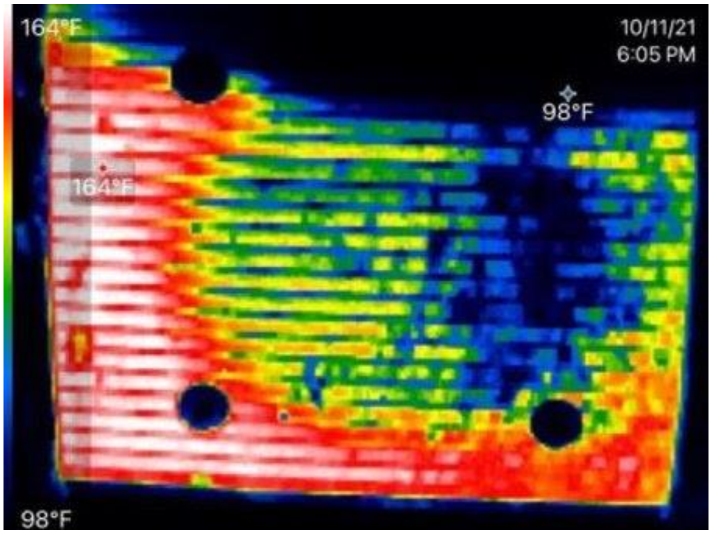

Figure 4: Few minutes after fan is activated

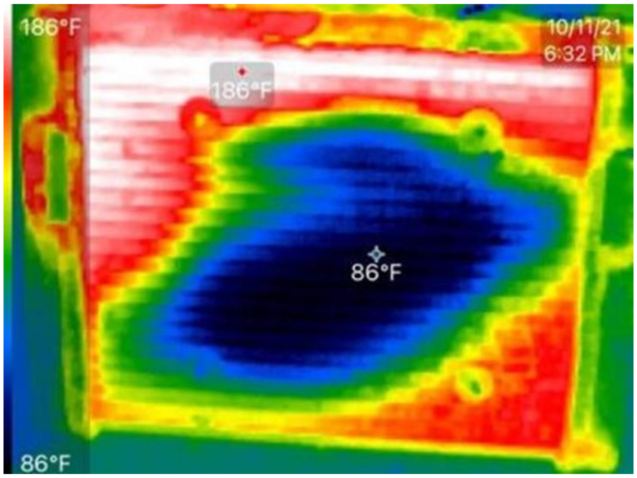

Figure 5: Parts of radiator reaching critical temperatures

Figures 3 to 5 show the temperature building up throughout a typical vehicle test. It is important to note that the ambient temperature was within the expected range designed for. Figure 3 shows temperatures just before the fan was activated, figure 4 shows a few moments following activation, and figure 5 shows the system after exceeding critical temperatures of 212 degrees causing the water to boil in the overflow tank. Figure 5 shows the cooling takes place exclusively inside the fan area.

The overheating condition arose as a result of our calculations making the assumption that the airflow over the radiator would pull across the entire radiator's core area. However, in our design, the airflow occurs only in the center of the radiator. The coolest sections appear to be approximately 86 Fahrenheit while the hottest temperatures at the edges exceed 180 Fahrenheit. To solve this issue, students chose to design and manufacture a fan shroud to channel flow over the entire cross section. Students tested the performance of the system with the new shroud. Figure 6 shows the overall cooling area has increased dramatically to the edges of the radiator, and the max temperature is less than 140 Fahrenheit.

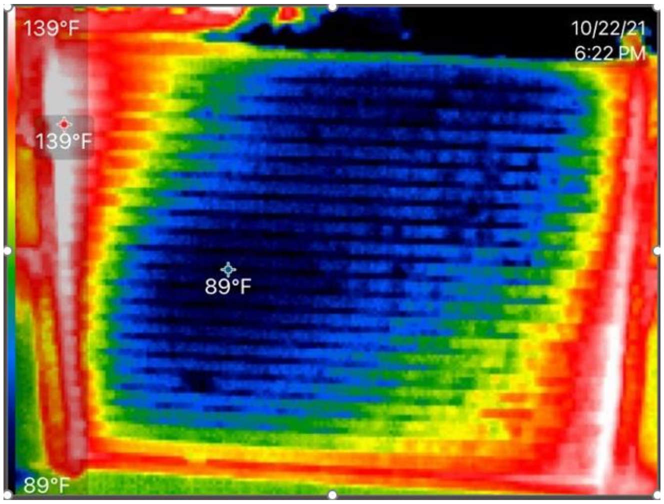

Figure 6: Effects of shroud mounted on radiator

Student reflection

On this project I served as the main engineer and designer of this system. Fellow student of mine assisted in compiling the code and acquiring equipment to image the radiator after testing. My priority throughout the course of the design process was to optimize the system as much as possible. This research led me to develop a method of optimizing any system I desired with the given input parameters I selected. After correcting the issues regarding the fan shroud, I began to imagine ways to further optimize this process and provide a more accurate model. I believe the most effective way of doing this would be to perform transient analysis and calculations on the system. Comparing transient calculations to real world data over time would allow students to develop a model to further optimize any future cooling system.

This process allowed me to engage into many different facets of engineering that I had been interested in such as: coding, thermal fluid systems, and heat transfer. As a student interested in working in mechanical design, this project provided me the technical experience to carry forward into the professional world. Beyond technical experience, this project also provided me with the opportunity to strengthen my skills as a system design lead providing me with many opportunities to grow as a student and an engineer.

Faculty reflection

My involvement in the Formula SAE has reinforced the belief that experiential learning is key to deep understanding of concepts through applying knowledge in real life projects. Students push themselves to reach optimal solutions for their team. One observes selflessness in interaction within the teams and all effort placed towards a common goal. Students learn from one another and are receptive to peer suggestions and guidance. They develop their own way to refine what they have done and that is the joy of learning, i.e., not settling for less but striving for the best!

Conclusion

A capstone course is used to solidify students' knowledge, skills, and attitudes before they move on to the world of work and/or additional learning. At times, solutions to problems are not completed. We learned that students will rise to expectations. When faced with overheating problems, students did not give up. They were determined to provide solutions to the ongoing over heating problem. Through the use resources on campus, students were able to solve the overheating problem. The lessons learned include:

1. students were able to connect to courses they had taken such as heat transfer, thermodynamics, and fluid mechanics to seek solutions to the overheating problem.

2. students were able to use technology to detect areas of overheating.

3. creativity – students were creative to develop a shroud system that provided solution to the overheating problems.

This activity not only helped students solve a significant problem, but also were able to meet ABET's EC-2019 Criterion 3 program outcomes for 1,2 3, and 5. In that, they were able to identify, formulate, and solve complex engineering problems by applying principles of engineering, science and mathematics. They were able to design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. They were able to communicate effectively with a range of audience – including, faculty and the public. Lastly, they functioned as a team to whose members together provided leadership, created a collaborative and inclusive environment, established tasks, planned, and met objectives. Hence, capstone is a great way to realize the aforementioned objectives.

References

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