FAMU/FSU College of Engineering
Department of Mechanical Engineering

Design for Manufacturing

Marine Keel Cooler Optimization Tool

EML 4551C Senior Design

Team 3

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Table of Contents

Table of Figures

Table of Tables

Abstract

This report defines the design for manufacturing, design for reliability and design for economics for the Marine Keel Cooler Optimization Tool. Cummins Marine is in need of a better tool which would enable the Marine Application Engineers to ensure proper validation of the marine keel cooler. The current tool was developed in the early 1980's and is limited to only steel keel coolers and only provides a pass/fail output to the user. The team is then faced with the creation of a new tool which will not only test the pass/fail cooling capability of the keel cooler but the tool will also be able to calculate box channel, half round and full pipe sections in steel or aluminum. It will evaluate an existing keel cooler system and be able to recommend other sizes which would optimize the cooling per vessel/engine installation. Such tool will allow the Marine Application Engineer to validate the keel cooler not only in extreme conditions but in different climates as well since most commercial vessels will navigate across international waters.

To ensure tool accuracy, research has been conducted to obtain adequate knowledge with regards to keel cooled systems and the design parameters needed to keep in mind. The following report includes an overview of the schedule being followed in order to complete the project. The overall plan, methodology and project approach decided upon by the team will ensure deliverables are met on time and an accurate product is delivered to the sponsor.

Acknowledgements

The team would like to acknowledge our advisor, Dr. Van Sciver for his insight and direction. The team has been given the opportunity to meet with Dr. Van Sciver weekly in order to talk about the science involved as well as the methodology the team should follow when approaching this project. He has provided the insight needed in order to ensure success in the project ventures. The team would also like to acknowledge the Senior Design instructor, Dr. Gupta who also has met with the team weekly to discuss schedule and make sure the team covers the project scope appropriately. The team would also like to extend an acknowledgement to Frank Ruggiero for the opportunity to work on a project for the Marine Application Engineering group as well for the sponsorship and technical support of this project.

1. Introduction

The Marine Keel Cooler Optimization tool will be a great development and upgrade from the current tool available to Cummins Marine. It has a bold new look, feel and functionality allowing the Application Engineer, technician or boat builder to validate the sizing of a keel cooler given a broader range of input parameters. Modern ships and boats rely upon high-powered propulsion systems in order to successfully navigate through their respective environments. The delivered power of engines for typical commercial marine vessels ranges between 230-2700 hp (169-2013 kW)[1]. In order for these vessels to function properly, heat must be dissipated effectively in order to achieve the optimal efficiency for sailing conditions.

Throughout the design process there are three underlying motivations: manufacturability, reliability, and economy. When designing a product for manufacture there is an implicit obligation to make the manufacturing process as efficient as possible. Having this foresight during the design stage will make for an easy transition to production later. Once manufactured though, how consistent will the product be and for how long? This is typically determined by the intended application and is ultimately limited by cost. This leads to the final motivation: economy. It is important to consider cost when designing a product and how these costs may limit the overall design. If there are similar products on the market, it would be beneficial to design a product at a competitive price. These concepts will help streamline all processes from concept generation all the way to post-production. Our team made every effort to include these motivations into the design of our Keel Cooler Optimization Tool.

2. Design for Manufacturing

Since our project is code-based, the term "assembly" is used loosely. Although the team is technically putting the code together, the process consists of more than just designing/ordering parts and putting them together. In addition, the team's general lack of proficiency in various programming languages exacerbated this effect. With the framework and logic established using C-programming language, the team began by cataloging all of the relevant constants and parameters that are involved in keel coolers. This included engine data for various Cummins power plants, properties of various fluids, dimensions for standard steel c-channels, etc. and debugged. Next we incorporated all of the thermodynamic principles pertaining to keel coolers. We modeled our application to the most appropriate heat exchanger configuration and arranged all of the pertinent equations in a manner that the program could process. Once debugged, we then added functionality for multiple materials, namely aluminum, which included all of the relevant dimensions for aluminum c-channels. It was at this point we decided to transition to Python for a cleaner and graphical user interface, and also to allow for web-based interaction.

After the code was converted and web functionality established, everything was debugged one last time. The program is still being tweaked and modified and will continue to be optimized as necessary. The timeline for progress on the program is very sparse, with intermittent breakthroughs occurring here and there and not a lot in between. This is the nature of coding in a new language; there is much to learn along the way. Although the progress of the program came in bursts, the overall time required to put it together seems adequate, given the circumstances. The process could have been expedited had the team been more familiar with different coding languages, or for an added cost, outsourced to someone more skilled. The number of components involved in our optimization tool would most appropriately refer to the amount of complexity in the code itself. After the program was first completed, we evaluated it for efficiency and made efforts to simplify its structure. We cleaned it up and made it so that the code was more organized and efficient without removing any functionality. There can always be improvements, and we will continually make efforts to enhance our product.

3. Design for Reliability

The lifetime of the software designed in this project is meant for a long life. The previous program used by Cummins was designed in the 70's. This shows that the program needs to be designed with plenty of future use.

The program out team designed will ideally perform the same task as many times as necessary. There is no limit to how many times it can evaluate a keel cooler design. The program will deliver consistent results every time it evaluates since the formula in the program does not change. The only exception would be if the program was altered after the program was delivered and Cummins felt it necessary to do so.

The main reliability concern for the program is that it will not evaluate every keel cooler design perfectly. This is due to the fact that there is a small possibility that our team may have used some assumptions or formulas that might not evaluate perfectly. What this means is that a cross sectional area may have been assumed to rectangular when in fact it could be more of a trapezoid shape. Although the two shapes can be very similar, they can also be fairly different as well. The way to address this problem would to be test the program against data that already exists and see how close the program is to the actual numbers. If there is a discrepancy, our team could potentially go back through the program and try to figure out where we could tweak the formulas that would gave a possibly more accurate result.

As for the hardware side of the design, it was designed to evaluate our engineering intuition that went into developing the software side of the program. This testing hardware was designed so that it would be cheap, easy to construct and deconstruct and have little to no manufacturing time. So for the reliability of the hardware, we made assembled it taking into account possible leak points. This would be the worst case scenario for our hardware since we do not want any hot fluid to leave the system. This would give us inaccurate data and possibly skew our results.

This hardware setup should ideally perform the same each time it runs. The only changes that could possibly happen within the hardware would be pipe erosion or corrosion. This could just be due to age and use. The leak points (between pipes, at flanges, and at hoses) would need to be checked regularly to ensure that no leaks have occurred over time if the hardware is used often.

The main reliability concern for the hardware would be leaks as mentioned before. These leak points have been mitigated as much as possible so far by using pipe tape and by securely fastening flanges together. This would be addressed by checking the pipe connections every so often to ensure they have not loosened up or that the pipe tape does not need to be replaced.

3.1. FEA Analysis

In order to design and write a successful program there are three primary considerations that the program designer must consider: Choosing the right programming language, identifying the user, and structuring the program correctly and effectively. In the design on the keel cooler optimization tool, careful consideration was given to these steps in order to maximize the tools effectiveness in servicing the applications engineers at Cummins Marine.

The choices for the programming language were based on a comprehensive list of the suitable languages that the members of the project group had exposure to. In order to select a language for consideration, the project group agreed upon options that they felt familiar with, had the capability to do mild computing, and had useful functions for implementation. The three final choices were reduced to C programming, MATLAB, and Python. A decision matrix was implemented in order to make the proper selection for the task. The group chose four main attributes and weighed them in order of importance to evaluate their ranks. The judging criteria was knowledge (the groups familiarity with the language), structure (does the program contain useful functions to structure a logic based selection system), aesthetics (user friendly interface), and relevance (how universal is the language). The attributes were ranked from 1 to 10 and were given a weighted multiplier with knowledge and structure given 60% and 20% weights respectively. These values were added up to produce a score. Python ultimately prevailed to its superiority in knowledge, structure, and relevance. The decision matrix can be seen in *Table 1*.

Table 1. Decision Matrix

Program:	Knowledge	Structure	Aesthetics	Relevance	Total:
Python	2	10	8	10	8.5
Matlab	8	7	2	8	4.2
C	8	8	1	6	6.4

Several considerations were given to the program structure. In order to minimize run time and maximize coding efficiency, the program was structured with a main function with conditionally accessed sub functions. The program will open up from the start and prompt the user to choose whether they would enter design or verify mode. The selection decisions are prompted by the use of switch statements that access sub-functions depending on the number that the user enters. If the user enters the analyze mode, the engine selection tool will ask the user for their engine selection. Depending on their response, the program will access separate functions which will store the parameters corresponding to their selection. Following the engine selection, the user will enter their coolant selection followed by their channel size dimensions. The program takes the information stored from these inputs and calculates the minimal cooler length and heat dissipation and compares it to the users input. If the user's cooler parameters correspond to a passing design, the program will display a message indicating passing and the program will terminate. If the user enters parameters that prompt a failing condition, the user will be informed as well as given the option to enter the programs design mode. The design mode will invoke a similar structure to the verification mode, with the exception that the user will be able to select additional parameters such as boat hull size that constrain their design. The program will evaluate the user's criteria and generate design parameters that will provide a passing condition. Because of the vast number of sub-functions the program employs, most of the variables will be redefined by the use of pointers. This reduces the number of variables and the memory required by the program minimizing run time.

3.2 FMEA Analysis

Although the project is based on the creation of a software, the biggest possibility of system failure would occur if the program outputted the incorrect feedback. For example, if the tool told the user the keel cooler being validated passed the cooling requirements, when it actually did not. The engine in question could end up overheating in the worst case scenario, leading to engine failure. This would lead to an immense cost to the company to cover for warranty.

4. Design for Economics

The Keel Cooler Optimization Tool is an upgraded version of the current tool Cummins marine uses that is able to evaluate keel coolers with Steel C channels. Senior Design Team 3 has upgraded the tool to a web based application that will be able to evaluate multiple materials in C channel form. Because this is an upgrade from an original Cummins design there are no competitive products.

The project costs a total of $1,782.17 out of a $2,000 budget given to us by Cummins, Inc Marine division. *Figure 1*, shows 89% of the budget was spent to achieve our project goal.

Due to our product being a web based optimization tool we were able code our product on a free downloadable version of python coding program. Though we were able save money on the product we still required a validation tool, and this is where our budget was spent. The most expensive item for the mock keel cooler was the five 4 foot pieces of aluminum piping and the connecting fixtures costing a total of $856.94 - which was 43% of our budget. The second most expensive item was the water pump costing a total of $374.23 and 19% of the budget. Additionally, a heater ($239.00, 12%), Barrel ($143.00, 7%), Sensors ($90, 4%), and Reservoir ($79, 4%) were purchased in order to create our mock keel cooler.

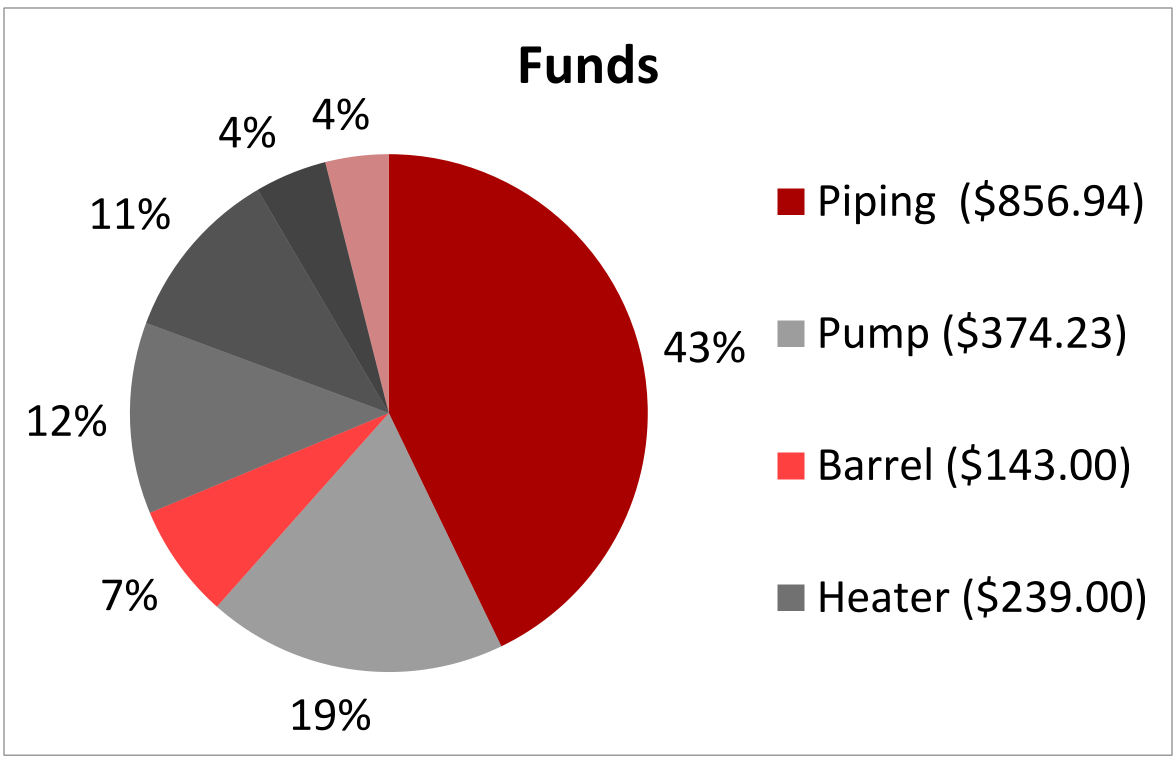

Figure 1. The graph shows the allocation of the funds for Senior Design Team 3.

5. Conclusion

The Marine Keel Cooler Optimization tool hopes to meet the needs of Cummins Marine in providing a tool that is up to date, user-friendly, and reliable. The current tool utilized by Cummins Marine was commissioned in the early 1980’s, is limited in its ease of use, and only provides a pass/fail output for the user. Cummins Marine is in need of an updated tool which not only validates a proposed design (pass/fail), but can also provide additional design requirements and specifications that will ensure proper cooling performance in the application environment. The team is tasked with writing a program that will utilize these features and provide accurate results. The group has been (and will continue throughout the duration of the project) researching general information and implementing the knowledge from thermodynamics, fluid mechanics, and heat transfer in order to successfully achieve the project goal. In addition to writing the program, the team will build a testing apparatus that will be used to model and evaluate the differences in performance for various design configurations, i.e. number of flow paths, types of materials, orientation, etc., and can also be used to verify the accuracy of the program. The parts for the hardware side that are hardest to obtain have been ordered, such as the pump, heating tank/element, and thermocouples and the keel cooler has been assembled. Since the main script (framework) of the program has already been written, it is only a matter of ensuring the proper engineering principles are employed when fleshing out the rest of the program. This is a crucial step because if the tool does not provide correct data to the end user, the design could cause catastrophic engine failure once it is implemented on a production vessel. Once the program has been coded, it can be verified for accuracy by using both data obtained from our testing rig and with data provided by Cummins regarding successful systems that are currently in use. Following the customer requirements defined by the Sponsor the team expects the keel cooler optimization tool will surpass current expectations while meeting all of the customer needs.

References

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