FAMU/FSU College of Engineering
Department of Mechanical Engineering

Midterm I Report

Marine Keel Cooler Optimization Tool

EML 4551C Senior Design

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Abstract

This report defines the project plans, product specifications and team methodology 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.

1. Introduction

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.

There are two main types of cooling systems for marine engines; the first is known as a raw water system and the second is known as the freshwater (closed) cooling system. In a raw water system, surrounding water is drawn from the outside of the ship and is circulated through the engine block and then expelled from the exhaust. This is hazardous to the system in both salt- and fresh-water application due to the corrosiveness of salt on the water pump impellers and the risk of foreign contaminants which could lead the system to foul. The engine components risk early failure and may lead to an engine overhaul before the vessel operator's expected to.

The second type of cooling system is known as a closed cooling system. These systems do not employ water as a direct cycling fluid rather, rather piping is used to separate the coolant and the surrounding medium. Some systems function similar to the radiator in automobiles where coolant is pumped through one side of a heat exchanger and raw water is pumped through another in order to dissipate heat. Another type of closed cooling system removes the need for a heat exchanger by employing an external set of pipes which protrude from the bottom of the vessel to exchange heat directly with the surrounding water. Keel coolers operate by taking advantage of the surrounding water as an endless heat sink for a vessel's heat transfer fluid. Due to the risk of

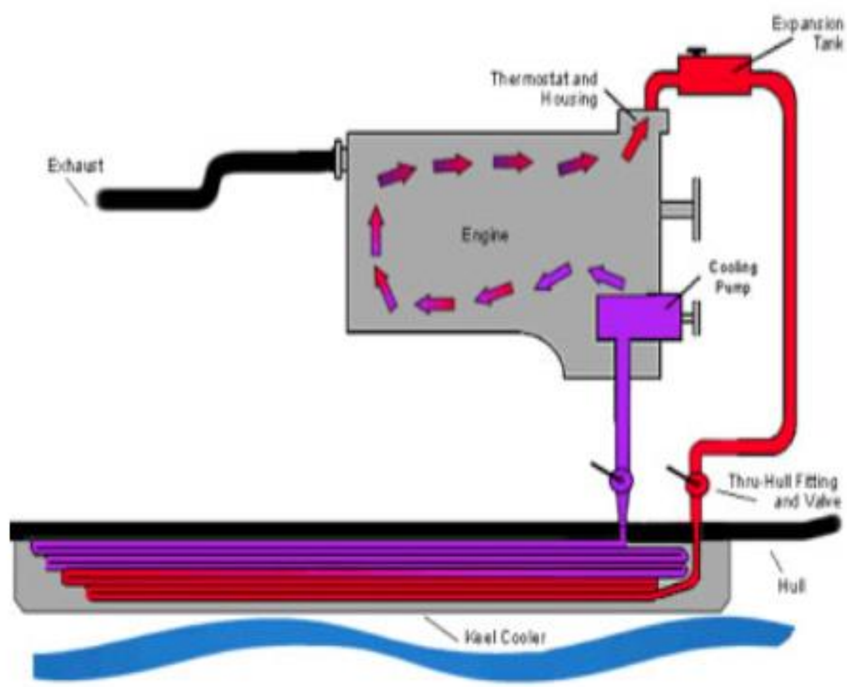

Figure 1: Simple diagram of a typical keel cooler system

fouling from various contaminants contained in the water medium, these coolers typically do not run ocean water directly through the power cycle, but rather exchange heat via convection through external tubing between the engine coolant and the surrounding medium. This process is illustrated in *Figure 1*, explaining just how this process takes place. A pump draws coolant from the thermostat and sends it through and expansion valve, which sends coolant into the keel cooler at the bottom of the vessel. The heated fluid moves through a series of highly conductive pipes which remove the heat via convection with the heat sink. The cod coolant is finally pumped back into the engine via a cooling pump. This process eliminates the need for a heat exchanger, and other components vital for closed cooling systems.

Cummins Marine is one of the different specialized markets of Cummins Inc. which specializes in the “Marinization” of engines and the design of new components to allow the current Cummins engine line survive in marine applications. Customers often times ask the Application Engineers to ensure the engine selected will work properly with the vessel it is going to be installed in. This includes the sanity check of ensuring that the keel cooler will provide the correct cooling for the engine. These factors are important to consider since the vessel must pass an Installation Quality Assurance Review in order to meet warranty. In order to meet customer’s requirements, Cummins Marine makes use of a web-based optimization tool which allows the Application Engineers to predict whether or not a particular keel cooler design will successfully meet the vessels’ requirements. The program operates on user-inputted parameters such as keel size, engine power, and temperature range. These values then predict whether the cooler will pass or fail based on extreme operating conditions. Although the tool has been in service for a long time, it has several limitations. The tool only predicts keel cooler systems which are made from steel and does not offer an option to optimize the design. The program lacks feedback and is outdated as a user interface. The goal of the Keel Cooler Optimization Tool Senior Design Project is to create a tool that adds feedback alongside the pass-fail conditions. The program will suggest improvements in the design of the keel cooler based on a thermodynamic analysis. Such improvements can range from material selection, pipe configuration as well as an optimal temperature range of operating conditions. The successful implementation of this tool will result in an increase in company profit and customer satisfaction. With a program which successfully predicts improvements in keel cooler design, boat builders will be able to build the keel coolers with confidence knowing it will be more efficient and optimize the performance of their engine and work in different nautical waters.

To achieve this goal, extensive background research must be conducted on the variables important to the design of a keel cooler. Once the group has a full understanding of the analysis process, the method for creating this tool must be decided upon; this includes the programming language, program structure, user interface and a means for testing the accuracy of the program. The group must show sufficient understanding of the thermal design process and develop a product that is user-friendly, intuitive and provides meaningful feedback to the end user.

2. Project Definition

2.1 Background Research

A current model of this program exists and is used by Cummins. The program is used to evaluate the current and future keel coolers which will be installed in the vessels[3]. The current system of evaluating the keel coolers is done by looking at the engine which will be installed on the ship, the total hear generated by the engine, design speed of the vessel, maximum water temperature the vessel will face and currently only evaluates keel coolers made out of steel. This current program does not provide the user with suggestions on how to design a more efficient keel cooler and has been in commission since the early 1980's and is in dire need for an update.

Cummins Keel Cooler program was only developed to test keel coolers after production and would only determine as pass or fail given worst case scenarios. The new program will not only determine a pass of fail, it will suggest an optimal keel cooler size, design and material. The program underdevelopment is meant to be easily transferable and shared between users and eventually be converted to a web based program. The new program will most likely ask for the same input parameters as the previous program, but will be more accurate to ensure the keel coolers are properly sized and fitted for the vessels. The ease of evaluation needs to stay constant as well since the easier the program is to use, the more likely it will be utilized. The current design is web based, therefore the new design will need to be converted to a web based system once it is completed.

A keel cooler works as a radiator or heat exchanger attached to hull of the ship. One such textbook which will be referred to for future equations, charts, and tables on heat flow from a high temperature to a low temperature would be "Fundamentals of Thermal fluid Science's". For possibly making suggestions for better keel cooler designs the group would possibly need to suggest the addition of aluminum to the material selection. To do so, material properties would need to be known to allow proper suggestions. The group will possibly be referencing the materials book "Materials Science and Engineering an Introduction".

There is no opposition for this product due to it being geared towards Cummins engines to ensure that installed engines will work properly on the vessels without overheating. This program will be licensed by Cummins for its own use. The only program that would compete with this end product would be the current program the Marine Application group has been utilizing.

Keel cooling utilizes a group of tubes, pipes or channels attached to the outside of the hull below the waterline. Engine coolant is circulated through the keel cooler to remove excess heat. Fabricated keel coolers are manufactured by the boat builder as a part of the hull construction. Structural steel or aluminum shapes are usually used with 0.187 inch [4.8 mm] to 0.500 inch [12.7 mm] wall thickness. These materials must be compatible with materials used in the vessel's hull in order to prevent galvanic corrosion. Fabricated keel coolers must be designed oversized to allow for the decrease in effectiveness which occurs with the formation of rust, scale, pitting and marine growth on the keel cooler. Keel coolers can be sized given the following data from the Engine Data Sheet: Engine Model and Rating, heat rejection, engine coolant flow to keel coolers, coolant type, as well as the design speed of the vessel (in knots). Typical sizing speeds are 1-2 knots for tugboats/push boats and 0.1-1 knots for generator sets.

Fabricated keel coolers can be made from many different materials and type of construction. Most commonly used are steel channel and pipe, although this tool will also allow calculations for aluminum channel and pips. The shape of the keel cooler is determined by the hull shape and size of the vessel. A fabricated keel cooler is not an efficient heat exchanger and therefore it is much larger in surface area than commercial keel coolers. Keel cooler length formulas for round pipe, half round pipe, and square channel can be found in *Table 1.* The “A” used in the formula is the keel cooler area coefficient. Utilizing these formulas the team will be able to calculate the cross sectional are required in order to size the keel cooler, as shown in *Table 2.* This is dependent on the design speed of the vessel as well as the maximum raw water temperatures as shown in *Figure 2.* Flow path is also a critical part of the design, since the keel cooler can be sized smaller the more flow paths available. It is also important to note, the program will ask for the length of the vessel in order not to conduct unnecessary size recommendations.

Table 1. Keel Cooler Length Formula

Round Pipe
$Length\ (ft) = \frac{Heat\ Rejection\ (\frac{BTU}{\min}) \times "A" \times 3.82}{Pipe\ I.D.Diameter\ (in)}$
$Length\ (m) = \frac{Heat\ Rejection\ (kW) \times "A" \times 1682}{Pipe\ I.D.Diameter\ (mm)}$
Note: For half round piping, multiply the calculated length by two.
Square Channel
$Length\ (ft) = \frac{Heat\ Rejection\ (\frac{BTU}{\min}) \times "A" \times 12}{Width\ (in) + [2 \times Height\ (in)]}$
$Length\ (m) = \frac{Heat\ Rejection\ (kW) \times "A" \times 5288}{Width\ (mm) + [2 \times Height\ (mm)]}$

Table 2. Keel Cooler Cross Section Area Formula

Round Pipe
$Round\ Pipe\ Cross\ Section\ Area = \frac{[Inside\ Diameter]^2}{1.27}$
Half Round Pipe
$Half\ Round\ Pipe\ Cross\ Section\ Area = \frac{[Inside\ Diameter]^2}{2.54}$
Square Channel
$Square\ Channel\ Cross\ Section\ Area = Inside\ Dimensions\ \times Width \times Height$
Note: Using **inch** dimensions gives **square inch** areas. Using **mm** dimensions gives **square mm** areas.

It is important to keep in mind the coolant velocity inside of the cooler. If the coolant flows through the keel cooler faster than 8 ft/sec [2.5 m/sec] the internal components will deteriorate, causing failure near manifold entrances and exits, elbows and other discontinuities in the coolant flow. Likewise, if the coolant flows through the keel coolers’ passages too slowly rust particles or other particulate matter will settle out, choke off the flow and degrade the transfer of heat. In order to determine the proper flow pattern through the keel cooler, one needs to determine the minimum and maximum expected coolant flow through the keel cooler. This can be obtained from the performance data of the engine water pump. Calculating the difference between the maximum and minimum expected coolant flow and multiply the resultant by 2/3 and adding 2/3 will help determine the coolant flow and how to distribute the flow through the keel cooler passages. Then one would divide the coolant flow by the cross-sectional area of one keel-cooler passage to obtain the average velocity. If the average velocity through the keel cooler flow passages is greater than 8 ft/sec [2.5 m/sec], one would arrange the coolant flow in parallel so it would pass through two or more of the keel cooler passages per pass through the keel cooler. If the average velocity though the keel cooler flow passages is less than 2 ft/sec [0.6 m/sec], a keel cooler passage with a smaller cross section would be most adequate.

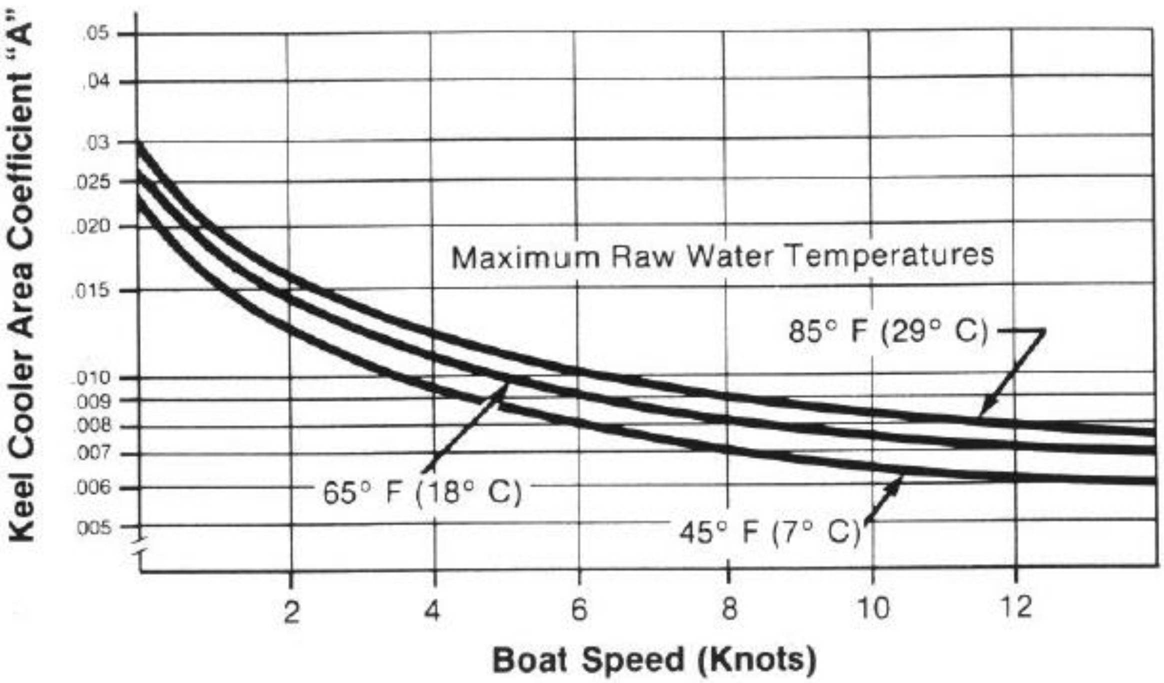

Figure 2. Minimum Keel Cooler Surface Area for Steel Channel or Pipe

The tool will focus on the three major data inputs for the engine in order to size/validate the keel cooler for the vessel, heat rejection, flow and change in temperature across the pressure ports. There are two 1-1/2 NPT threaded connection provided for the installer to connect to the keel cooler circuit. *Figure 3* shows the inlet and outlet connection points to which the engine connects to the keel cooler via hoses. The pressure service ports is where Marine Application Engineers collect the data readings for pressure testing as well as collect the change in temperature. There are different types of keel cooling layouts, for example the Jacket Water After Cooler (JWAC) and Low Temperature After Cooler (LTA) *Figure 4*. The program will ask the user which type is being utilized in the vessel, such detail is important since the flow of the coolant is affected by the position of the thermostat in each system. For example, in an LTA system the thermostat is before the keel cooler. When the engine coolant is cold, the thermostat is closed and all coolant flows directly to the after cooler and is by-passing the keel cooler. When the thermostat begins to open (depending on the engine the opening temperature will vary) coolant is directed through the keel cooler and is returned back to the thermostat housing where it is mixed with the main flow going through the after cooler. In an installation which is JWAC, the coolant passes through the keel cooler but is waiting for the thermostat to open in order for the coolant to pass through and enter the engine. This is important to take into account when designing the tool, especially if the team were to expand and include calculations for the expansion tank for the after cooler. In such case coolant capacity for the installation would then have to be considered as well.

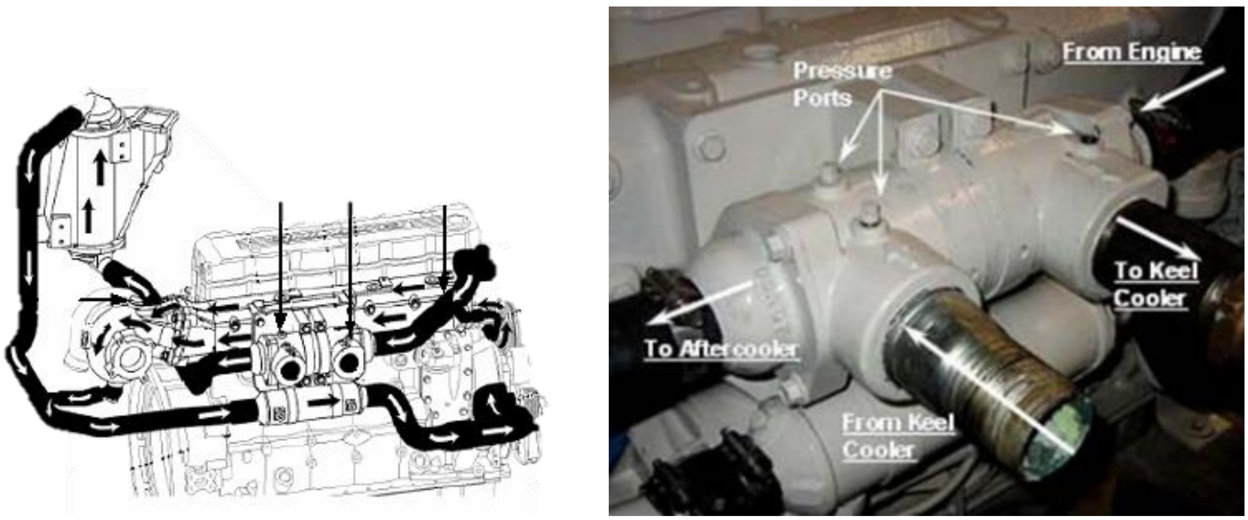

Figure 2. LTA Inlet and outlet connections and pressure service ports on engine

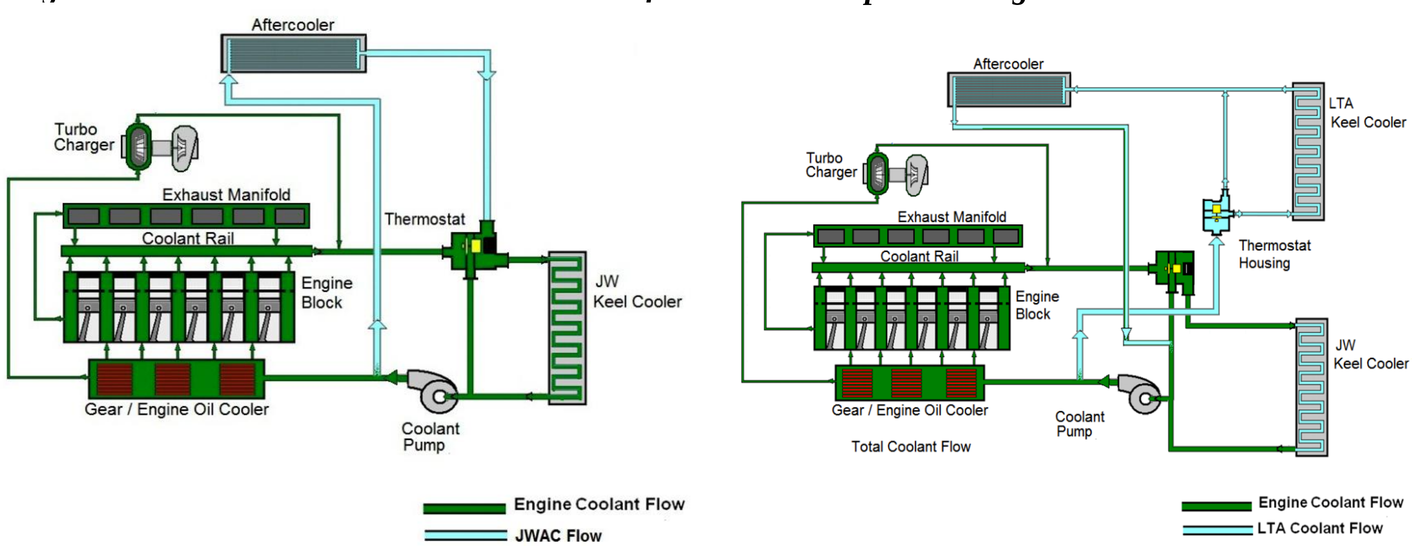

Figure 4. Jacket Water After Cooler system (left) and Low Temperature After Cooler (right)

2.2 Needs Statement

The Senior Design Project for Group 3 for the Marine Keel Cooler Optimization Tool is sponsored by Cummins Marine. The tool currently utilized by the Marine Application Engineers is severely outdated and only returns whether or not the user inputted parameters will result in a passing or failing keel cooler design. The program does not provide any feedback to the designer or operator. This limits the overall design process and does not validate the keel cooler design on the vessel for other nautical water climates.

Needs Statement for Team 3:

"The current Cummins keel cooler design tool provides no feedback on a particular design and is limited in its capability"

2.3 Problem Statement

The Senior Design Project for Group 3 for the Marine Keel Cooler Optimization Tool is sponsored by Cummins Marine. The tool currently utilized by the Marine Application Engineers is severely outdated and only returns whether or not the user inputted parameters will result in a passing or failing keel cooler design. The program does not provide any feedback to the designer or operator. This limits the overall design process and does not validate the keel cooler design on the vessel for other nautical water climates and does not evaluate multiple materials which is a necessity for the clients.

Problem Statement for Team 3:

"The current Cummins keel cooler design tool provides no feedback on a particular design and is limited in its capability"

2.4 Project Goal & Objectives

The project should cover all marine engines offered by Cummins, both current production and out of production which will/are installed in keel cooled vessels. The tool is to be used not only to validate the keel cooler system but also suggest the optimal keel cooler design to the boat builder. The tool must be able to calculate and predict how the cooling system will behave under different engine loads and water ambient temperatures. This tool will then be validated through testing on a sea channel constructed by the team and depending on boat builder availability, it will be tested on a current installation.

Project Goal for Team 3:

"Design a more versatile design tool which generates feedback and provides a more user friendly interface"

The team decided that the program delivered to the client will provide customer feedback and will offer ways to increase efficiency in the system. The new layout will allow for more customer focused interface, through a quick and versatile programming language which will allow the tool to be converted into other languages easily.

Project Scope:

- The current design has no customer feedback
- Only provides user an output of "Pass/Fail" on design of keel cooler
- Needs to provide recommendations for design improvement
- The device needs to be able to evaluate the design of the keel cooler through the use of different materials (Currently only evaluates steel)
- Current tool is outdated and not user friendly

Objectives:

- Successfully predicts the heat dissipation, efficiency, as well as the optimal operation temperatures for a particular design
- Suggests useful design alterations that would increase the efficiency of the design
- Validate the keel cooler system in scenarios where the vessel is at low idle or relocated to a different body of water (different ambient water temperature)
- Must be user friendly and intuitive
- Needs to provide results that as accurate as possible
- Be able to evaluate keel cooler designs for more materials than just steel

In the house of quality as seen below in *Figure 5*, the two important inputs are customer characteristics and engineering characteristics. The customer characteristics come from talking to our sponsor and asking what exactly the sponsor would like to see in the new program. These characteristics go in the column on the far left side of the house of quality. The engineering characteristics come from our team brainstorming how to best incorporate the customer characteristics into the new program. These characteristics go across the top of the house of quality.

In the customer priority list is how important the customer thought each customer characteristics is. Inside of the matrix is how well each engineering characteristic correlates with each customer characteristic. A weak correlation is a 1, a medium correlation is a 2 and a strong correlation is a 4. After each box has a correlation number in it, each box is multiplied by the customer priority. Finally each column in the matrix is summed and the largest number is the most important in the design and lowest number is the least important in the design.

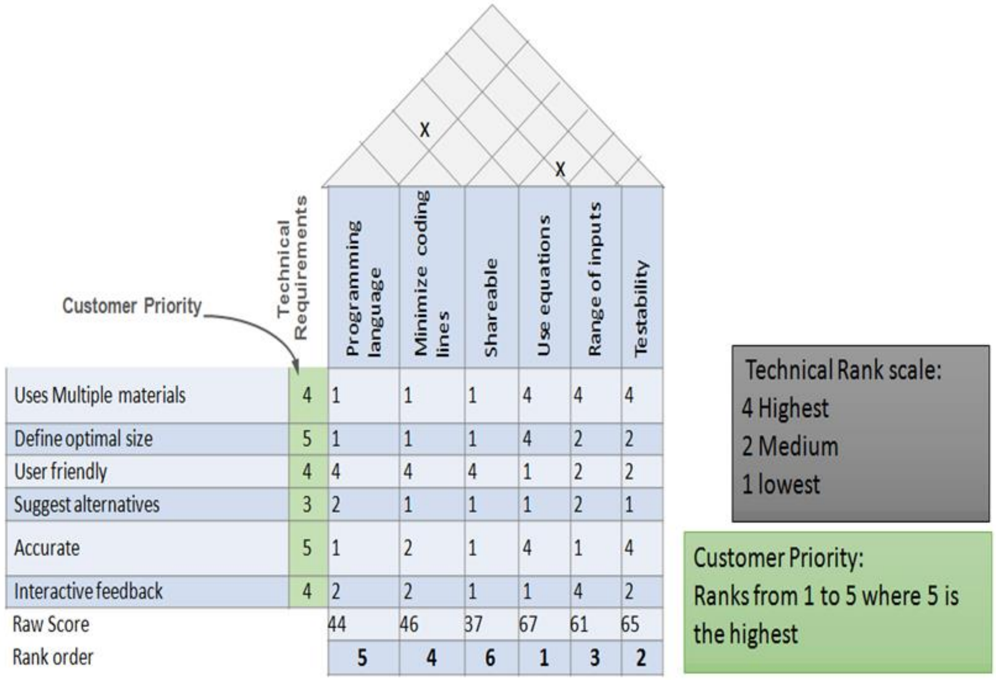

Figure 5. Team 3 House of Quality which helped determine which were the most important factors for the new keel cooler tool

So according to the house of quality, the most important characteristic for our program is the use of equations. For our design this means that the team will need to use more equations that take into account rust, paint, and marine life build up. It also needs to use more equations to account for multiple materials and to provide more customer feedback. The least important factor for our team to take into account is the share ability, the program, since it is electronic, will most likely be easily shared no matter how the program is made.

2.5 Constraints

This project will need to be able to take parameters from the different marine engine models both current production and out of production and be able to calculate the adequate size and cooling needed dependent on the vessel application. With over 15 engines models and each different performance rating available, it is going to be important to find the common variables which can serve as inputs for the tool. The tool must be able to conduct the test for low and high temperature and pressure ranges to ensure the engine receives adequate cooling under different conditions. Since the tool is to be used by Cummins Distributers and Marine Application Engineers around the world, the tool needs to be accessible through the Cummins Marine website as well as available for download (for when the tool needs to be accessed in areas where there is no connection to the web.

The team is also faced with designing a sea channel for testing/validation of the tool to possibly creating a keel cooler based on the tools recommendation for one of the engines. The constraint would be adequately sizing a keel cooler for a vessel and not have the tool suggest a keel cooler length longer than the vessel itself. Due to the inherent inefficiencies of keel coolers, the tool needs to be able to process when to suggest different numbers of flows to improve cooling and ensure coolant velocity is below critical speeds.

Constraints:

- Budget of $2,000
- Time
- Material Acquisition

3. Design and 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 Java. 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. C programming ultimately prevailed to its superiority in knowledge, structure, and relevance. The decision matrix can be seen in *Table 3*.

Table 3. Decision Matrix

Program:	Knowledge	Structure	Aesthetics	Relevance	Total:
C	9	10	1	10	8.5
Java	2	7	8	8	4.2
Matlab	8	1	8	6	6.4

The second step of the design process was to identify the user in order to satisfy their needs in a program. After a coordinated sponsor meeting, the team was able to identify the primary users as application engineers as well as shipyard workers. After further inspection into the uses of the program, the design team concluded that the two primary uses of the optimization tool are for the validation and design of keel coolers. This led to the implementation of two main program modes, a verify mode and a design mode. The 'verify' user is one that has a premade keel cooler or keel cool design and wishes to simply evaluate whether their model will pass or fail. If the users design passes, the program would indicate so. If the users design fails, the program would allow the option of providing feedback in order to produce a passing design. An emphasis was placed on useful feedback of the program, providing the user with only the information that they seek, optimizing the user interface. The design mode of the program offers an alternative approach for a user who is seeking the optimal size for their particular parameters. The user would provide constraints such as available material, hull size, amongst others and the program would evaluate the correct size (if possible) for a passing keel cooler design.

The program would use the same input parameters as the current validation tool, while adding the variability of adding design parameters for additional analysis. *Figure 6* shows the specification sheet for the current tool.

Engine Data			
Engine Model			from General Data Sheet
Engine Brake Horsepower	[BHP]		from Performance Data Sheet
Engine Speed	[rpm]		from Performance Data Sheet
Select a Cooling Circuit Type			from Performance Data Sheet
Total Circuit Heat Rejection	[BTU/min]		from Performance Data Sheet
Coolant Flow to Keel Cooler	[gpm]		from Performance Data Sheet
Engine Coolant Capacity	[gallons]		from General Data Sheet
Coolant Type (50/50 glycol or Water/DCA)		Make a Selection	50/50 Glycol solution preferred
Maximum Sea Water Temperature	[deg F]	85	Typical sea water temperature is between 75-85 deg. F
Design Speed	[knots]		Typical sizing speeds are: 1) Tugs/Pushboats: 1-2 knots 2) Generator set: 0.1-1 knots
Keel Cooler Data			
Standard Channel Size		Make a Selection	C depth (inches) × Weight Per Unit Length (pound force per foot)
Channel Width	[inches]		from standard steel channel tables
Channel Height	[inches]		from standard steel channel tables
Web Thickness	[inches]		from standard steel channel tables
Cross Sectional (Web) Area	[sq. inches]		from standard steel channel tables
Coolant Velocity	[ft/sec]		Best if kept between 2-8 ft/sec
Channel Material		Steel	
Total Installed Keel Cooler Length	[feet]		Increase cooler length or number of flow paths until **Pass/Fail** criteria is met
Thermal conductivity "k"	[BTU/hr-F-ft]	26.5	
Number of Flow Paths			
Results			
Actual KC Exterior Area	[sq. feet]		
Calculated Exterior Area	[sq. feet]		
Minimum Keel Cooler Length	[feet]		
Minimum Expansion Tank Capacity	[gallons]		from Installation Directions bulletin No. 3884744
Passing Criteria	**[Pass / Fail]**		Increase cooler length or number of flow paths until Pass/Fail criteria is met

Figure 6. Current Specification Sheet

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. *Figure 7* shows a simplified flow chart for the Keel Cooler Optimization Tool.

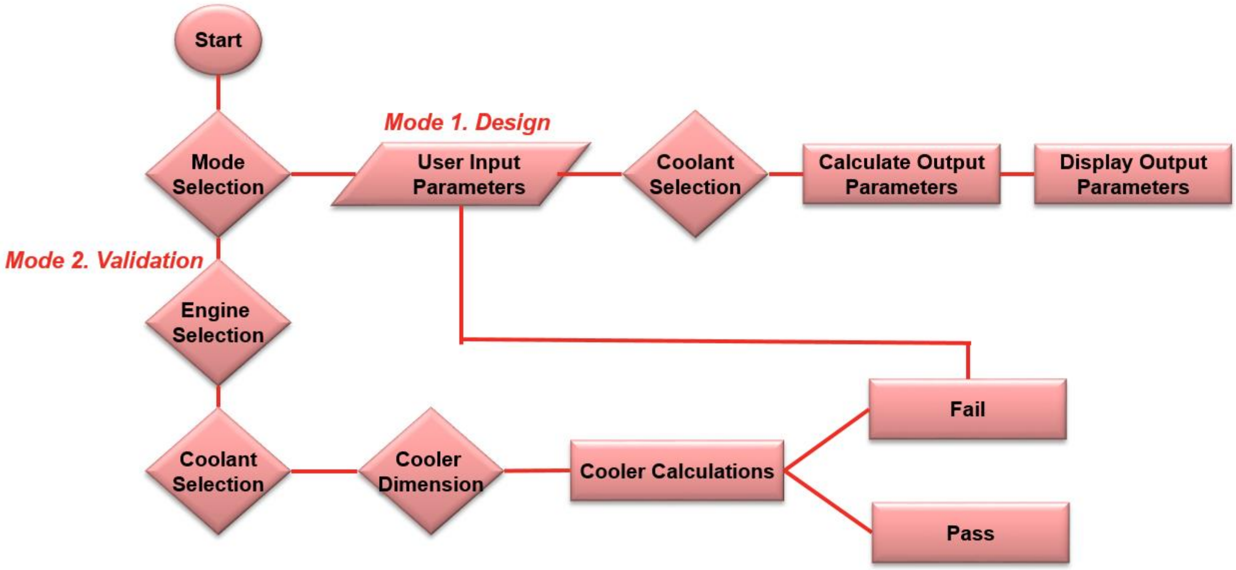

Figure 7. Flow Chart for Keel Cooler Optimization Tool

4. *Methodology*

4.1 Marine Keel Cooler Optimization Development

To ensure accuracy and Cummins industry standards are met, extensive research is being conducted in the design and science behind marine keel coolers. It is important to properly define the input design parameters since they will need to be able to be utilized cross engine models and performance ratings and provide the user accurate results.

Once the proper parameters have been defined, the program will be written to utilize the proper equations, constants and provide proper feedback to the user. Ultimately, not only provide a pass/fail result, but allow the option of the material used as well as a recommendation for the adequate sizing of the keel cooler per engine/vessel installation.

4.2 Analysis

As the optimization tool is being written, part of the team will utilize the resources available to construct a rudimentary sea channel. This sea channel will allow the team to conduct flow analysis testing in order to fine tune the program. The program will be tested for validation against the sea channel. Once accuracy from the tool has been obtained, the team plans to enter the parameters for a QSK 19 MCRS engine and construct an adequately sized keel cooler based on the programs suggestion or depending on the availability of the boat builder, test the program against a current engine installation.

4.3 Schedule

In order to efficiently make use of the time the team has until the end of the semester, a Gantt chart *Figure 8*, created through the use of Microsoft Project has been prepared which lays out a breakdown of the work that needs to be completed. According to the chart, the team has accomplished the required tasks up to the present date and is moving forward on schedule. The team has just mapped out the framework for the code to our program which can now receive user inputs for the basic parameters involved in keel coolers, such as engine model type, c-channel specification, coolant type, etc. To make additional progress with the coding, the thermodynamic properties and relations associated with keel coolers must be organized and then evaluated for accuracy. The team is in the process of arranging a meeting with our technical advisor Dr. Van Sciver for guidance in this step. During this meeting the team will also discuss plans for our testing apparatus. Once the program is “fleshed out” it can be debugged and to be tested by the sea channel the team will make. With the creation of the sea channel the team will be able to simulate the cooling system and test/validate the tool. The creation of the sea channel would allow the team to collect data from the simulation, such as flow rates, in order to ensure proper calibration of the tool. Once the team has created a tool which can test a cooling system and recommend an optimized keel cooler for the engine/vessel installation, the sponsor has agreed to remain in contact with the boat builder near Tallahassee, Florida to test the tool on a current keel cooled installation.

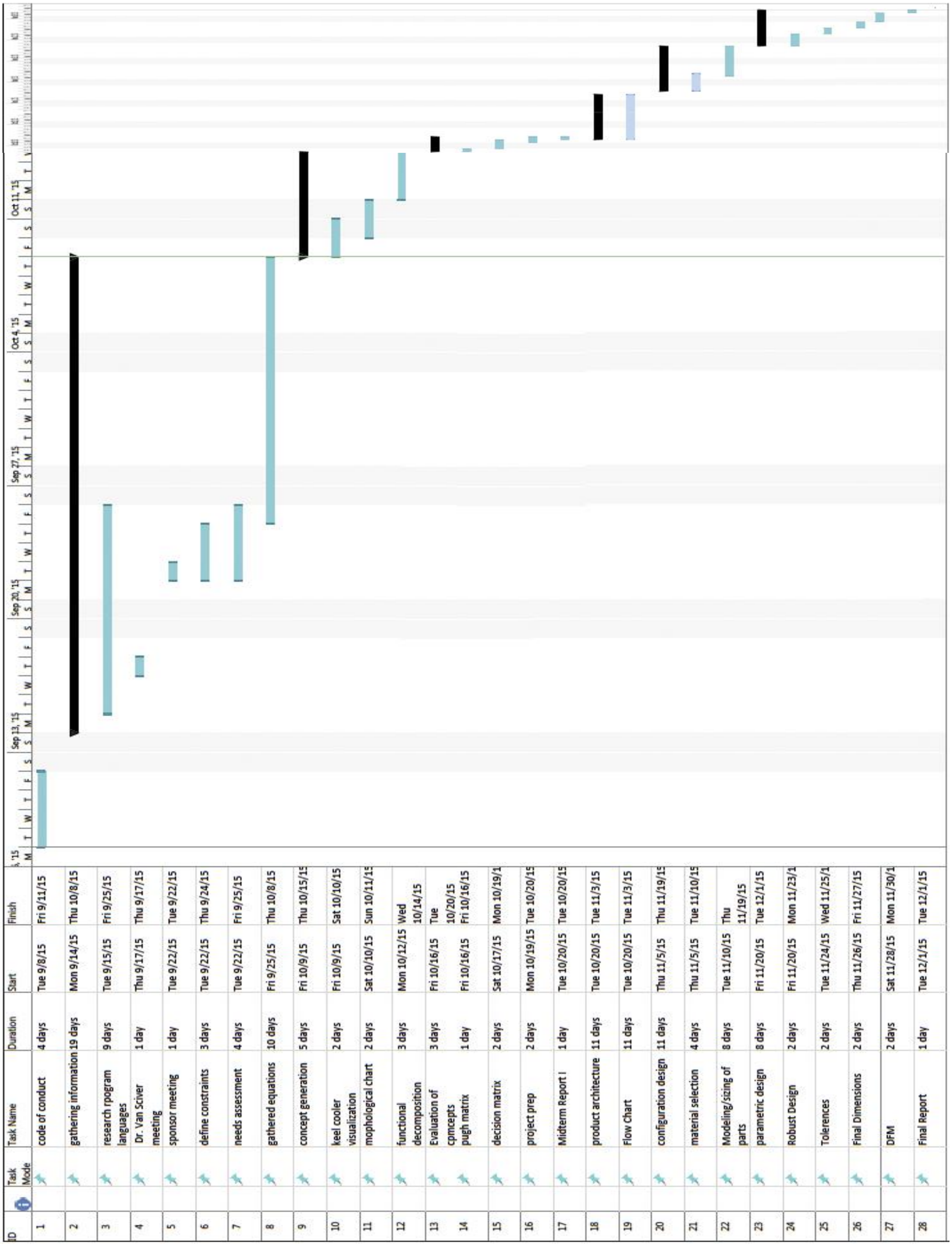

Figure 8. Team 3 Gantt Chart

4.4 Resource Allocation

4.4.1 Work Breakdown

Each team member is going to be contributing to the overall progress of our project through individual tasks. This will help make the work as a whole less daunting, and also aid in staying on schedule. Team members' strengths and weaknesses are taken into account when allocating tasks. Stanko is the most comfortable with programming so he has volunteered to take on the major brunt of the coding. Since Melissa works with our sponsor at Cummins, and can mostly only correspond electronically, she has been providing the relative equations, principles, and all other data associated with the design and assessment of keel coolers, aiding in our deliverables, and keeping us in close alignment with our sponsor and his guidelines. Jacob, James, and Grady are best suited for working out the thermodynamics and fluid mechanics associated with the operation of keel coolers and the design of our testing apparatus. This arrangement is optimized for efficiency according to the team dynamic. Sometimes it can be counter-productive for more than one person to be contributing blocks of code for a single program, which is why only Stanko is coding. The other group members will proof and debug the program to help catch any errors and give insight to possible alternative or more efficient scripts. Unlike programming, however, the thermodynamics, fluid mechanics, and also the design for our testing apparatus can be broken down into segments which are more manageable. A better representation of the current team resource allocation can be seen in *Table 4.*

Table 4. Resource Allocation

Team Member	Task	Time Allotted
Melissa Allende	Research design specification for keel cooled systems	2 weeks
	Create flow chart for optimization tool	1 week
	Assist with creation/development of tool	4 weeks
	Secure test vessel for tool validation	Continuous
Grady Beasley	Research thermal fluids/relevant equations	2 weeks
	Material acquisition for development of sea channel fabrication	2 weeks
	Assist with fabrication of sea channel	3 weeks
Stanko Gutalj	Research thermal fluids/relevant equations	2 weeks
	Create flow chart for optimization tool	1 week
	Assist with creation/development of tool	4 weeks
James Haga	Research thermal fluids/relevant equations	2 weeks
	Developing webpage	Continuous
	Assist with fabrication of sea channel	3 weeks
Jacob Ross	Research thermal fluids/relevant equations	2 weeks
	Assist with creation/development of tool	4 weeks

4.4.2 Cost Breakdown

In general, most keel coolers are made out of steel or aluminum and have rectangular or round cross-sections. These materials are readily available from any metal supplier for relatively low cost. For instance, square tubing is around $13 per foot for steel and for aluminum it is around $10 per foot. Round tubing is cheaper since it is easier to manufacture where steel is about $5 per foot and aluminum is $6.50 per foot. Depending on the dimensions required for the specified cooling rate and the scale that we choose to model this system at, these materials may end up contributing to the bulk of the cost. The pump required to circulate the coolant, the flanges to connect the flow channel to the pump, and the fasteners and other hardware will also be chosen depending on the scale and dimensions. Because the team has not designed the testing apparatus, estimates for these costs are beyond the scope of this report. At some point the team would like to (and have been encouraged by our sponsor) visit facilities where these keel coolers are manufactured and tested. These visits will contribute to the overall cost as travel expenses and can be estimated to be around $400. The team is hoping to schedule a trip to the Cummins Marine Integration Center Facility in Charleston, South Carolina in the spring of 2016. This would enable the team a firsthand look at production engine and keel cooler system. As well as provide insight of the typical keel cooler dimensions/specifications installed in vessels. Lastly, the programming languages and applications we have chosen are available to us through open source and licenses provided by the college so there is no direct cost associated with them.

5. Results

5.1 Risk Analysis

When planning a project it is important to first look into and asses' risk factors that may affect you and your project. When considering risk we break up the project into 4 different sections. First we start with concept generation which is a no risk section of the project that involves the gathering of information and the formation of ideas on how to tackle the project. Next is product assembly, for our project of the keel cooler optimization tool this involves programming and calculations. This creates a very low risk situation due to the very little physical labor and no use of heavy machinery. Risks during this process are limited to exhaustion. After product assembly comes product testing, In this stage of the project risk starts to become a serious factor and is considered a high risk stage. The Risk is due to the mechanical machining that is required in order to create the keel cooler needed for testing. Possible risks include cuts burns abrasions and possible loss of limb. In order to insure safety while completing this process it is important to wear proper safety gear, be properly trained on each machine used, work in groups, be properly supervised and to file a safety plan that outlines other possible hazardous situations and how to deal with them. Lastly there is risk in product implementation, the risk in product implementation is a different type of risk that occurs if our keel cooler optimization tool is not successful. This risk includes ruining motors and stranding boats in the middle of the ocean this also includes the ruining of reputations of both our team members and Cummins marine division. With so much risk involved throughout this project it is important to be careful and precise in every step of our project

6. Conclusion

The Marine Keel Cooler Optimization tool hopes to meet the needs of Cummins Marine in providing an up to date tool that is user friendly and reliable. In order to meet these requirements the group is faced with familiarization of keel cooled engines and how systems operate. The current tool Cummins Marine utilizes was commissioned in the early 1980's and only outputs a pass/fail response for the user. Cummins Marine is in need for an updated tool which would allow recommendations on improving the design of the keel cooler, validating the keel cooler not only in extreme conditions but as well as in normal operating conditions and in conditions where the vessel would be at wide open throttle at 0 knots (in cases such as a tug boat pushing a boat). The group will achieve such program by researching more information about keel cooled systems to serve as a foundation for designing the tool. The group is implementing the knowledge from thermodynamics and thermal fluids classes to ensure the tool is not only efficient but accurate. Since the main script which will serve as the backbone to the program has been written, it is only a matter of ensuring the proper science is applied. This step is crucial since a tool that does not provide the end user the correct data, could lead to catastrophic engine failure. As the program is written, the group will start taking steps towards designing a sea channel. The sea channel will serve as a validation tool for the team to test the accuracy of the tool. This will then prompt the team to make the proper changes to ensure the tool is calibrated to predict real life scenarios. Once the team has become confident over the capacities of the tool it is the goal for the team to test the tool on a current keel cooled vessel installation. Following the customer requirements defined by the Sponsor the team expects the keel cooler optimization tool will surpass current expectations while meeting customer needs.

References

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