Bryson T. Peters;Trevor J. Lay;Dane C. Seal;Zafer Jesri;Catherine Potts

FAMU-FSU College of Engineering  2525 Pottsdamer St. Tallahassee, FL. 32310

Team 516: NASA-MSFC Cryogenic

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# Abstract

Team 516 is tasked with measuring cryogenic fuel levels in space. The project is funded by NASA and is a continuation of work doneby last year’s Team 514.

Determining the fuel level of a storage tank in space presents a variety of distinct problems. Since there is no gravity, and liquid fuel transitions to gas very easily, this is a difficult situation with few viable solutions. Measurement systems on Earth are vital to the success of travel from small vehicles to rocket flight. Therefore, devising a reliable method to measure the fuel levels in space will allow us to expand our horizons to interstellar proportions.

NASA has provided a Fiber Optic Sensing System (FOSS) which is the current best method for gauging cryogenic fluid. The system includes a laser and a fiber optic cable with evenly spaced sensors. The sensors use the strain of the cable at various points to determine the physical state of the propellant, as the strain will vary directly with the temperature of the fluid. For our experiments, liquid nitrogen will be used.

The project scope is to design a support structure that holds the FOSS cable inside of a storage tank. The current design has support rods and rings that guide the FOSS cable in a helical shape. Covering more volume with the cable directly correlates to more accurate results; exposing the sensors to more fluid allows for more data to be collected regarding the temperature of the fluid at various points in the tank.

The system will monitor the fuel levels before and after launch. The amount of fuel necessary for space travel can be determined from these readings, lowering excess fuel storage and the overall weight of the shuttle.

# Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

# Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

* Paragraph 1 thank sponsor!
* Paragraph 2 thank advisors.
* Paragraph 3 thank those that provided you materials and resources.
* Paragraph 4 thank anyone else who helped you.

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# Notation

|  |  |
| --- | --- |
| A17 | Steering Column Angle |
| A27 | Pan Angle |
| A40 | Back Angle |
| A42 | Hip Angle |
| AAA | American Automobile Association |
| AARP | American Association of Retired Persons |
| AHP | Accelerator Heel Point |
| ANOVA | Analysis of Variance |
| AOTA | American Occupational Therapy Association |
| ASA | American Society on Aging |
| BA | Back Angle |
| BOF | Ball of Foot |
| BOFRP | Ball of Foot Reference Point |
| CAD | Computer Aided Design |
| CDC | Centers for Disease Control and Prevention |
| CU-ICAR | Clemson University - International Center for Automotive Research |
| DDI | Driver Death per Involvement Ratio |
| DIT | Driver Involvement per Vehicle Mile Traveled |
| Difference | Difference between the calculated and measured BOFRP to H-point |
| DRR | Death Rate Ratio |
| DRS | Driving Rehabilitation Specialist |
| EMM | Estimated Marginal Means |
| FARS | Fatality Analysis Reporting System |
| FMVSS | Federal Motor Vehicle Safety Standard |
| GES | General Estimates System |
| GHS | Greenville Health System |
| H13 | Steering Wheel Thigh Clearance |
| H17 | Wheel Center to Heel Pont |
| H30 | H-point to accelerator heel point |
| HPD | H-point Design Tool |
| HPM | H-point Machine |
| HPM-II | H-point Machine II |
| HT | H-point Travel |
| HX | H-point to Accelerator Heel Point |
| HZ | H-point to Accelerator Heel Point |
| IIHS | Insurance Institute for Highway Safety |
| L6 | BFRP to Steering Wheel Center |
|  |  |
|  |  |
|  |  |

# Chapter One: EML 4551C

## 1.1 Project Scope

**1.1.1 Project Description**

The main objective of this project is to develop a solution to measure the amount of propellant in zero gravity conditions using a fiberoptic cable. Previous designs do not account for the shrinkage or embrittlement of metal under cryogenic conditions and thus cause the cable to experience tensile failure. We will be building upon work done in 2021 by Senior Design Team 514.

**1.1.2 Key Goals**

The main goals of this project are to:

* Complete a design analysis cycle on last year’s project.
* Produce our own design.
* Either improve upon last year’s project by means of bettering the existing design, taking aspects from both designs by combining them, or completely redesigning the entire system.

**1.1.3 Markets**

The primary market is the National Aeronautics and Space Administration (NASA). They utilize cryogenic propellant and need proper mass gauging techniques under zero gravity conditions to determine the optimum fuel capacity.

The secondary markets include other companies that are building vessels that could benefit from more efficient ways of mass gauging liquid propellant under little to no gravitational force. For instance, private space travel companies that are preparing for commercial flights are potential clients. These companies include but are not limited to: Virgin Galactic, SpaceX, Blue Origin, Orion Span, and Boeing. This project could also be applied to vessels beyond commercial spacecraft, such as rovers or shuttles meant for exploring planets and other celestial entities. The United States Air Force could also benefit greatly from a new and innovative way to measure propellant.

The last secondary market is automotive companies such as Ford, GM, and BMW. Although these companies would not be worried about cryogenics in microgravity conditions, they could consider new mass gauging techniques if they are more efficient and cost-effective.

**1.1.4 Assumptions**

Our first main assumption is that the fiberoptic cable will be provided to us by NASA.  In other words, we will not be responsible for 3D printing or otherwise procuring a cable. Additionally, we will assume that the cryogenic fluid will be operating under a set range of temperatures and pressures, and extreme or unpredictable changes will not be encountered. This set range will be determined as the customer needs and targets are identified. To ensure safety, it is assumed that all testing with cryogenic fluids will be completed at the National High Magnetic Field Laboratory (MagLab) at Florida State University.

**1.1.5 Stakeholders**

Throughout this project, there will be various stakeholders that play crucial roles in the development and sponsorship of our project. NASA is one of our most critical stakeholders, as they directly supplied us with this project and will hold final authority over most design aspects. Other stakeholders that will give us advice and guidance include Dr. Juan Valenzuela, Dr. Mark Vanderlaan, and Dr. Shayne McConomy. Additionally, key Research and Development and legal teams at NASA and various other companies, such as SpaceX, Boeing, Virgin Galactic, and Lockheed Martin, that are interested in private and commercial space flight further exist as potential influential stakeholders in our project.

## 1.2 Customer Needs

|  |  |  |
| --- | --- | --- |
| **Customer Questions** | **Customer Statements** | **Interpreted Needs** |
| Are there weight constraints for the support structure of the cable? | For your sake, no. The biggest constraints are going to be cryogenic temperatures and weight reduction. | There are no constraints on the weight of the support structure. |
| Are there geometry/dimension constraints? | In theory, no. The scale of your project will likely be determined by the dimensions of the dewar used for testing. | Our design fits adequately in the dewar we plan to use for testing. |
| Is there a preferred material? | G-10 is the main material that is used in cryo-tanks. Focus on aluminum and steel, PTFE Teflon and fiberglass, or materials that have low conductivity and do not embrittle at cryogenic conditions. | The material is of low conductivity and will not become brittle under cryogenic temperatures. |
| Are there various storage tanks that this structure will be used for? | Eventually, yes. Design small, but let it be of a scalable geometry. | The design is scalable to accommodate tanks of various sizes. |
| What is the most efficient way to mimic the fiberoptic cable for preliminary testing? | A simple test where the cable is dumped straight into the fluid in the dewar may suffice. You can reach out to the scientists that designed it for more advice. | The cable can be tested under cryogenic temperatures. |
| What are the ranges of temperatures and pressures the design needs to operate under? | LN2 (77 K) is typical for cryogenics. You may be limited to the dewar used for testing. | The structure operates under cryogenic temperatures. |
| Is our project scope constrained to creating a support structure for the cable, or should we also look at other ways of measuring the stored propellant? | Both. The geometry in which the cable is held will become important for analyzing the information from the sensors. | The project involves a design to support the fiberoptic cable, as well as a technique to interpret the information from the sensors. |
| Are there other known ways of measuring that do not require a fiberoptic cable? If so, should we look into these options? | Yes, consider other ways. | We will consider other mass gauging techniques that do not require a fiberoptic cable. |
| Are there constraints on the power supply? | No. Work with what is available to you. | There are no constraints on the power supply. |
| Is there a program that would be preferable when it comes to analyzing the information from the sensors on the cable? | The program you use is up to you. | Any program can be used to analyze the information from the sensors. |
| Once the tomography is calculated, what is the best way to display that information? | There are many ways. You could use a gas gauge like a car or show a graph as the tank is filling up. | The display indicates the mass of the liquid fuel and is easy to read. |
| We will be testing our project with liquid nitrogen, but are there other cryogenic fluids we need to consider? | The budget, and what is available at the MagLab, will likely limit you to only using liquid nitrogen. | Liquid nitrogen will be used predominantly for testing. |

***Table 1 Questions posed to sponsor, along with the responses and interpreted needs***

**1.2.1 Explanation of Results**

NASA (National Aeronautics and Space Administration) would like a design analysis comparison (DAC) to be performed on last year’s project to see if it is a viable option. The data from this can give guidance as to whether we redo the design, or just make changes to the existing prototype. Because our budget is not known, we will proceed by treating both as viable options, despite the total redesign being more expensive.

For this project, contacting outside resources is crucial. Creating a working relationship with last year’s project members, scientists who worked on the fiberoptic cable, and those involved with the MagLab who can offer expertise are all valuable to our success.

In summary, the main need of the customer is a method to measure the amount of cryogenic fluid in tank under zero gravity conditions. The suggested approach is to use a fiberoptic cable but testing of other methods is encouraged. For instance, after running the DAC on last year’s project, we may find that a cheaper or more accurate method is needed.

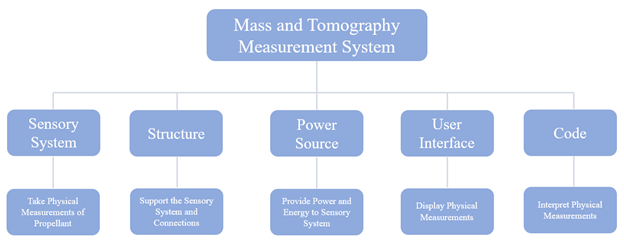
The customer questions were formulated by Team 516 as a team and are in the “Customer Questions” section of this document. An email was sent to the sponsor, Juan Valenzuela, who suggested that the questions be answered via a Microsoft Teams meeting. The meeting took place on September 26, where Juan answered the questions. The team typed summaries of Juan’s answers to the questions, and these are in the “Customer Needs” section of this document. As a disclaimer, the customer statements are summaries that Team 516 interpreted from the meeting and are therefore not word-for-word responses.

## 1.3 Functional Decomposition

**1.3.1 Explanation of Results**

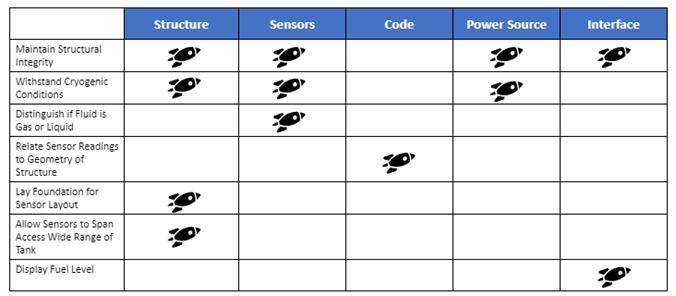
Functional decomposition is a method of analysis that dissects a complex process in order to examine its individual elements. When the functions are broken up, targets and metrics can be identified to allow for future alterations. Functional decomposition creates a framework of functions and their subtasks while simultaneously allowing for creativity and not setting constraints. To determine what needs to be a function, the customer needs were interpreted to determine what tasks our project had to be able to do.

The functional decomposition was gathered by a team meeting to interpret everything that we know so far and determine what our device needs to do. In our case, the mass and tomography measurement system is broken down into five smaller functions illustrated in Figure 1. The flow chart is used to visualize the functions and their separate tasks. For our system, we need a sensory system, structure, power source, user interface, and code. These are the five main functions for our project, and each has a task that they must perform.



**Figure 1: Functional Decomposition Flow Chart**

The functions all relate to one another and work in unison. The sensory system, interface, and corresponding code must be powered by the power source to operate. The code must work with the sensory system to analyze the data and display proper information to the user interface. The structure must support the sensory system to allow for proper data collection.



**Figure 2: Cross Reference Table**

Figure 2 shows a cross reference table where the main functions are compared against subfunctions from our customer needs to determine hierarchy. The main function of structure is deemed the most important as it checks four of the seven subfunction. Similarly, the sensors are second priority as it checks three of the subfunctions. Power source, interface, and code fall behind as the least priority, checking the least amount of customer needs. This hierarcy is explained in more detail in the following section.

**1.3.2 Connection to Systems**

The Mass and Tomography Measurement System is broken down into five subsections shown above in Figure 1. There exists a system priority when analyzing the functional decomposition with the highest precedence emphasizing the structure of our project. Functionally, this aspect of our project will undergo two or three iterations of testing as we determine the most compatible and logical solution to lay the sensors and support them. Analyzing the physical measurements of the propellant is essential to accurately gauging the mass, but without a structure, we will not have anywhere to put the sensors. Accordingly, the sensory system follows the structure in its hierarchical preference.

The functions of third hierarchical preference are the power source and the interface. For our project to function, the sensors and interface will both require a source of energy. It is best to make this separate from any aircraft power sources for ease of maintenance and removal for filling. The interface refers to the physical display mechanisms that will be used to show the fluid levels in the tank.

Last in the hierarchical preference of our functional decomposition, is the code. While still important to the functionality of our project, this function is least involved with other subfunctions. Since it is software, there are no concerns of it retaining its structure or embrittling under cryogenic conditions.

**1.3.3 Smart Integration**

The main functions of the Mass and Tomography Measurement include the structure, sensory system, power source, code, and user interface. All will interact with one another as indicated by the cross-reference chart shown above.

We will assume that the tank, where the propellant is stored and structure and sensory system are housed, can withstand the varying pressures and forces it will be exposed to. However, all components we place inside the tank must also maintain their structural integrity through launch and microgravity conditions. This makes the subfunction of maintaining structural integrity the most integrated of all the subsystems. The structure in particular needs to properly support the sensors, providing stability and ability to record data accurately. As indicated in the cross-reference chart, having a stable structure is the function of highest priority since four of seven subfunctions are included in its success.

Additionally, all components inside the tank must be capable of performing in cryogenic conditions. This does not include the code as software is not susceptible to embrittlement. Although the power source may be located outside the tank, we will design for the harshest possible conditions in case it needs to be housed inside.

The data read from the sensors, after analysis in the code, will be displayed on the user interface in a user-friendly fashion (e.g. contour plots, graphs, and distinguishable colors). The geometry of the structure, which ultimately determines the layout of the sensors, will determine how this code is analyzed. In order to have a more accurate range of data points, the structure will need to be oriented in a way that allows the sensors to interact with most if not all of the tank’s volume.

Finally, the power source is required to properly energize the system, allowing the sensors to work and the interface to turn on. The code and the interface were separated to allow for the different material requirements to be focused on. Meaning that the physical gauge or display interface is separate from the software behind it.

**1.3.4 Action and Outcome**

The purpose of this project is to accurately measure the amount of propellant in a storage tank while under cryogenic conditions. To accomplish this, a structure will be designed and built that measures the amount of cryogenic propellant. This structure will be composed of other sub-systems that serve their own purpose. The sensory device and structure will both be subject to cryogenic conditions and will need to fit in the specified testing apparatus. The sensory device will measure the amount of propellant and quantify the physical measurement into a desired unit or property.

**1.3.5 Function Resolution**

This project has a variety of subsystems that serve their own purpose, all work together in unison to solve the problem at hand. The smallest element of the design will be the sensory device sub-system, as it will need many sensors to accurately measure the amount of cryogenic propellant. Overall, each sub-system will work to perform functions that lead to the accurate execution of the objective.

**1.4 Targets and Metrics**

As we further analyzed our functions and customer needs, we began to associate certain values with the various required actions of the product. These values of evaluation, either numerical or subjective in nature, became our targets, and their units our metrics.

Tabulated below are what were identified as critical targets and metrics, which are values that correspond most directly to the overall success of our project. For these targets, it is imperative that they have a method of validation so that our overall success can be judged at the end of the project. A full catalog of all our targets and metrics for the project is included in the Appendix.

|  |  |  |  |
| --- | --- | --- | --- |
| Needs | Target | Method(s) of Validation | Metric(s) |
| Structure | **Stress incurred by structure at 77K does not exceed material bounds** | **Place structure in dewar containing LN2 at 77 K and leave for a few minutes. Watch for cracking or other signs of wear.** | **K, Pa** |
| **Strain incurred by structure at 77K does not exceed material bounds** | **Place structure in dewar containing LN2 at 77 K and leave for a few minutes. Watch for cracking or other signs of wear.** | **K, mm/mm** |
| Sensor | **Stress incurred by cable at 77K does not exceed 1KN per unit area** | **Measure the cross-sectional area of the cable and compute the force on the cable. Watch for signs of breakage.** | **K, Pa** |
| **Strain incurred by cable at 77K does not exceed 3.5%, or experimental value** | **Use a strain gauge to measure the strain on the cable. Watch for signs of breakage.** | **K, mm/mm** |
| Display Interface + Code | **Code runs and interface displays liquid fuel level** | **Running code and verifying that display gives accurate fluid level** | **%** |
| Power Source | **Supplies at least 12V, and up to 24V** | **Use a voltmeter at the positive terminal of the source** | **V** |

*Table 1 - Critical Targets and Metrics*

**1.4.1 Targets and Metrics Beyond Functions**

While many of our targets have to do with our functions, there are many other aspects of the project that will require evaluation.

One of the aspects our sponsor placed emphasis on was scalability. Since we are focusing on a proof of concept, our model will be scaled for use in a cryogenic dewar instead of a rocket fuel tank. Therefore, the geometry we pick will have a direct impact on how easy it is to upscale our model for future use. For instance, a more involved design may not only need more material, but it may also be too complicated for large-scale manufacturing and assembly. Therefore, the scalability of our design will be evaluated by cost and material amount.

Testing will play a crucial role in determining the success of our design, however one of the main challenges will be to mimic the behavior of cryogenic fluid in microgravity conditions. As there is no method at the time to simulate microgravity, we will need to manually change orientation of the fluid, and then measure how well our design can measure the fluid. Our current plan is to choose several distinct orientations of the dewar, and then measure the fluid in those positions for both last year’s design and our own. Many different tests will be carried out, particularly measuring the volume of the fluid propellant.

As spacecraft themselves become more and more reusable, so do the components that they rely on. Therefore, our design needs to keep its accuracy and structural integrity after repeated exposure to cryogenic temperatures. This applies most directly to the structural material itself, but also to the orientation of the cable. If the stress and strain on the cable is not kept to a minimum, this may induce imperfections that worsen with time. Talking with our sponsor, we have gathered a list of low-conductivity materials that do not fail or otherwise embrittle under cryogenic temperatures. Additionally, we are aiming to create a design that does not place too much tension on the cable or create large stress concentrations with sharp angles.

**1.4.2 Derivation of Targets and Metrics**

After generating the functions for the project, we further analyzed their impact on the design structure to derive the targets and metrics. Critical targets, in particular, were found by analyzing our customer needs and subfunctions. For instance, we understood that the overall main problem was that the cable would shrink when exposed to the code, and its structure did not allow it enough slack, so it snapped under the tension.

This meant that everything relating to the structure and sensors needed to be able to operate under cryogenic conditions, and that the structure would not place too much stress or strain on the cable. Lastly, it was brought to our attention the importance of launch conditions for our design. Heat from launch ultimately leads to a portion of the boil-off, and the vibrations can cause a cable or structure that is too loose to haphazardly move around inside the tank.

This led us to the first four targets listed in the table. The numerical values of the stress and strain for the structure have not been determined yet, since we have not determined the material that we will use. Additionally, the values for the cable are based off information gathered from an internet source that compares the stress and strain constraints of different fiberoptic cables. These targets in particular are geared toward ensuring that the cable does not snap at 77K.

The remaining targets are important but not paramount to success. They were derived by considering future plans of assembly, testing, and comparison. For instance, there are dimensions of our structure based on the size of our testing dewar, and a few main goals of our final comparison between our model and last year’s model. While the specific values of these comparisons are not yet able to be targeted, we need to begin considering which aspects will be the important to continue studying.

The target catalog contains each function or need and the corresponding targets, metrics, and methods of validation. While some of our numbers and target values may change as we change our testing procedures or dewar size, it is important that we begin considering all potential constraints.

**1.4.3 Discussion of Measurements**

To determine if we met our targets, methods of validation will be performed as necessary. The structure and sensors must withstand cryogenic conditions, so the method of validation will be using a dewar in the Mag Lab. To test that the code runs properly, test runs will be performed in the Mag Lab where the system is submerged in the dewar and LN2 is added. The dewar is placed on a scale and mass measurements are taken as LN2 is added. These mass measurements can be cross referenced with the sensor and code readings to check the accuracy of the code. To test that the power source supplies 24 V to the system, a voltmeter can be connected to the positive terminal of the power source to read the output voltage. This will validate the source’s power.

**1.4.4 Critical Targets and Metrics**

**1.4.4.1 Structure**

The critical targets for the structure are to ensure that the stress and strain incurred by the material at 77K is not more than the material bounds. As previously mentioned, the values of stress and strain have not been decided yet, as we haven’t decided which material we will use. The stress and strain were determined to be critical targets because it is imperative for the collection of data that the structure hold the sensors in constant, stable geometry.

**1.4.4.2 Sensors**

The critical target for the sensory system is prevention of snapping at LN2. Since this was the main issue with the original design from NASA, this quickly became one of our critical targets. The values are centered on the stress and strain of the cable, due to both thermal contraction and tension from the structure. The preliminary value of stress is based on data gathered on the tensile stress of glass, and the strain is from data based on fiber strain.

**1.4.4.3 Display Interface and Code**

The critical target for the code and user interface is a subjective opinion regarding its ease of interpretation. The goal of displaying the fuel level was emphasized by our sponsor, making it one of our critical targets, but its overall success will be based on subjective measures.

**1.4.4 Power Source**

The critical target for the power source is providing a stable supply of 12-24V for the FOSS DAQ system. While we do not know exactly what the power requirements of the DAQ system are, no constraints were placed on the power supply and 12-24V is a common range of applications.

**1.4.5 Summary of Targets and Metrics**

All of our functions (structure, sensors, display interface and code, and power source) have target values that are critical to the success of our project. For the structure and sensors, we have material stress and strain values to prevent failure at 77K. For the display interface and code, we will focus on the ease of interpretation. Lastly, for the power source, we have the required power supply.

However, we also have many targets for testing, specs, and comparison with last year’s design. For example, we have begun to constrain sizes to our model in that it cannot be taller or wider than our testing dewar. For our final data analysis comparison, we will compare several key points such as cost, scalability, and maintenance. The full catalog of our targets and their methods of validation are located in the appendix.

## 1.5 Concept Generation

**1.5.1 Concept Generation Tools**

Concept generation is an essential tool to solve problems effectively. Generating concepts allows for ideas that are not biased and approach the problem from various exercises. The first generated concept tends to be the one that groups want to pursue, as it seems the most feasible and applicable. The first solution is not always the best solution, so generating many concepts allows for more applicable designs and solutions. There are tools used for concept generation, such as morphological chart, biomimicry, and crap shoot. These approaches allow for generating concepts and forcing innovative ideas that can lead to a better solution.

**1.5.1.1 Morphological Chart**

A morphological chart is a tool that assists in generating conceptual solutions. This chart lists the functions identified for the design problem, as well as the solutions that perform each function. Combining one means for each function produces a potential integrated conceptual design. Depending on the number of functions and solutions listed, a majority of concept generation can be found using this method.

For our morphological chart, it was suggested that we take last year’s project and iterate on the design. Following this advice, we used the SCAMPER (substitute, combine, adapt, modify, put to another use, eliminate, reverse) method to branch off the work done by last year’s team. While no physical chart was made, our progress was tracked in our notebooks and in this manual.

**1.5.1.2 Biomimicry**

Biomimicry design is the practice of creating concepts or solutions based on structures or sequences from nature. These solutions can be found by analyzing the behavior of plants, animals, and other living organisms. By analyzing the functions and how these organisms operate and have evolved, these can lead to engineering innovations and new ideas. For instance, several of our ideas focused on decreasing the strain or stress in the structure, leading us to investigate branching patterns and plant fiber organization.

**1.5.1.3 Crap Shoot**

Crap shoot is another form of concept generation. The team lists six items under each category, and dice rolls are used to randomly select combinations. Three dice are used to roll and select the items. With these ideas, concepts are proposed by combining the three items to solve the problem or improve some part of the problem. While this method led to some questionable outcomes, the base ideas were able to be elaborated on and then turned into usable concepts.

**1.5.2 Concept Analysis**

**1.5.2.1 Medium Fidelity Concepts**

Medium fidelity concepts are ideas that address needs for the design, but do not deserve a large amount of effort or attention. These concepts propose feasible concepts but are not as accredited as the high-fidelity concepts. These concepts are still used during concept selection and are designs that may be pursued if high fidelity concepts are deemed unworthy.

|  |  |
| --- | --- |
| Concept Number | Medium Fidelity Concept |
| 21 | Light dispersed in a prism that is then refracted through the liquid and gas, the refracted angle is then measured to determine the state of the propellant. |
| 27 | Lasers on either side of the tank that are aligned at each other, and the angle of misalignment corresponds to the index of refraction, this can then back out the state of the liquid and the amount of remaining propellant |
| 31 | Radio frequency waves are sent through the propellant to determine the state of the propellant by determining their deflection at the base of the collector on the opposite side. |
| 93 | Use magnets on the outside of the tank to control a membrane that “combs” through the fluid and gas mixture and using thermal sensors and is able to determine which part of the fuel is gas or liquid. |
| 103 | Thermistors that are aligned in a circuit to determine the temperature of the propellant to determine the state, that determine the remaining propellant in the storage tank. |

The medium fidelity concepts selected for our project are concepts #21, #27, #31, #93, and #103. These concepts focus on the some of the most promising ideas we explored during our concept generation process, highlighting the innovative ideas about redefining the geometry of the support system that are further explored in the high-fidelity table below. By examining the various concepts during our concept generation, these medium-fidelity ideas propose feasible concepts but are not as accredited as the high-fidelity concepts due to uncertainty in the technology, cost, or overall success.

Concept #21 details how we may be able to use light dispersed in a prism that is then

refracted through the liquid and gas, the refracted angle is then measured to determine the state

of the propellant. Concept #27 utilizes lasers that are aligned at one another. These lasers will be pointed through the longest cross section of the tank, and the angle of misalignment can determine the refraction from the fluid and determine the fluid’s state. Concept #31 uses radio frequency waves that are sent through the propellant. With the speed of sound being different in a liquid than in a gas, we may be able to tell which fluids the waves have passed through.

Concept #93 utilizes a magnet field that guides a sensor through the tank in order to map out the tank and determine the remaining propellant. As we are not overly familiar with magnetic technology, this was not considered a high-fidelity concept. Concept #103 uses a circuit of thermistors, something we are unfamiliar with and could be complex in nature. These thermistors can measure the temperature of the fluid to determine its state, and then back out the volume of propellant.

**1.5.2.2 High Fidelity Concepts**

High fidelity concepts are ideas that are more suitable for the problem and have high potential. These concepts are analyzed in concept generation in order to select the best option to pursue.

|  |  |
| --- | --- |
| Concept Number | High Fidelity Concept |
| 1 | Vertical bars on the outside of a circular platform, and some inside, with fiberoptic cables wrapped around every vertical bar (concentric helical sweeps). |
| 18 | Triangular truss system in a series of inverted structural orientations similar to that of cacti to create a structural support system. |
| 20 | Use a honeycomb structure base to absorb shock and vibration. Use small rings on the outside of the structure to hold the cable |

The high-fidelity concepts selected were concepts #1, #18, and #20. These concepts all relate to redefining the geometry of a support system for the FOSS cable. These are high fidelity because they will likely be the most efficient and we are already provided with the FOSS system. Redefining the way the liquid and gas states are determined may lead to incomplete or unreliable work, so staying consistent by using the FOSS system allows for a more efficient technique. These concepts all utilize the FOSS system and layering it along the inside of the storage tank to then work out the volume of the fluid.

Concept #1 utilizes a series of helical sweeps that are connected to increase the stability of the structure and the depth of the sensors in the tank. This design allows for the FOSS cable to be weaved through the tank in order to measure the propellant and determine its state. From mapping the gas bubble formation, the volume can be calculated and then subtracted from the overall tank volume to determine the amount of remaining propellant. Concepts #18 and #20 utilize similar designs to supporting the FOSS cable. These concepts redefine the geometry of the structure but use the FOSS cable in a similar way to concept #1.

The full list of the concepts generated is listed below:

**1.5.3 Full List of Concepts**

1. Vertical bars on the outside of a circular platform, and some inside, with fiberoptic cables wrapped around every vertical bar (concentric helical sweeps).

2. One large vertical bar in the middle, several small ones on the outside. The fiberoptic cable is suspended between the small and large bars.

3. Ribbed support structure similar to that of the Amazon water lily in a rectangular prism formation to support the fiberoptic cable as it connects to the bars via linkage.

4. Long, skinny support structures similar to that of seaweed stalks (Stipe) that experience lower stress forces when pulled rather than bent to hold the fiberoptic cable.

5. Structure made of composite mesoglea similar to that of jellyfish providing structural support using collagen fibers in a simple gel matrix to support the cable.

6. Lattice structured truss system, with FOSS System placed along the beams.

7. Fiberoptic cables suspended from top of the vat, free hanging like moss.

8. “Shape-changing” formation similar to that of the supportive gel-like substance (mesoglea) of sea anemones that allows for extreme shape changing due to its viscoelasticity.

9. Fiberoptic cables fixed on both sides of the vat, like a tightrope creating a spider-web shape to interweave and suspend the cable.

10. Two concentric helical sweeps of the cable, wrapping in opposite directions.

11. A support system made of ligaments similar to that of the nuchal ligament of large grazing mammals suspending the cable in an “X-like” formation.

12. Arch like formation support system similar to that of termite housing providing support for the fiberoptic cable in a series of semi-circle-oriented curves.

13. Use nested oblique shapes to span entire tank, use small rings to keep the cable suspended in the oblique shape.

14. Suspension system similar to that of the spicular skeleton of sponges to provide structural support in the form of dispersed struts.

15. Utilize snowflake designs and use that as the basis for the FOSS System shape.

16. Utilizing a spider web and constructing a support structure that mimics the base for the FOSS System shape.

17. Introduce a harmless dye to the fluid in the tank. When the fluid boils off, the gas will be clear. Color-tracking sensors can be used to distinguish the areas of gas and liquid.

18. Triangular truss system in a series of inverted structural orientations similar to that of cacti to create a structural support system.

19. Similar to baffles in a shell and tube heat exchanger (or a mesh), use vertical bars with many small openings to weave the cable, or multiple cables, through in a helical shape.

20. Use a honeycomb structure base to absorb shock and vibration. Use small rings on the outside of the structure to hold the cable.

21. Light dispersed in a prism that is then refracted through the liquid and gas, the refracted angle is then measured to determine the state of the propellant.

22. Light source on all surrounding sides that emit towards the center of the tank containing a sensor that determines the state of the propellant.

23. Light source at the center of the tank emits light from the center of the tank that is then reflected into sensors to determine the amount of propellant.

24. Lasers that are stationed a certain amount of distance around the tank in order to send beams that cover all of the propellant to determine its state.

25. Cameras that photograph the tank, and then send the pictures to a data acquisition system that determines the amount of propellant in the storage tank.

26. Lasers that are stationed around the tank that are reflected along the edges to cover the entire tank, the amount of light reflected then determines the state of the propellant and the remaining amount.

27. Lasers on either side of the tank that are aligned at each other, and the angle of misalignment corresponds to the index of refraction, this can then back out the state of the liquid and the amount of remaining propellant.

28. Light source that is pointed towards the middle of the tank, and the amount of light that reaches the center determines the amount of propellant in the tank.

29. Light source and a reflective material surrounding the tank that allows light to travel through the tank to determine the amount of propellant left in the tank.

30. Lasers that read the amount of propellant remaining in the storage tank.

31. Radio frequency waves are sent through the propellant to determine the state of the propellant by determining their deflection at the base of the collector on the opposite side.

32. Find interference on a radio signal playing a single note of music to measure tank volume.

33. Launch a projectile through the tank and get the velocity at different points on the flight path. The top and bottom of the tank will have elastic qualities that can pulse the projectile to the other side to check again.

34. Use an initial thermal probe in the center of the tank to check if there is boil-off. If there is, introduce the cable into the tank by use of simple linkages.

35. Spin the tank and record how much torque is needed to move it at constant velocity. From that, the mass can be calculated.

36. Use a thermally reactive coating that changes colors inside the tank to see where fluid is.

37. Use a piston-like system to compress the fluid to see how much there is by measuring the amount of fuel displaced by the compression system.

38. Multiple radio frequency emitters and collectors located in a spider-web like formation to emit and collect the data to display how much interference has been calculated to determine the state of the fuel.

39. Using a piston-like system, compress the fluid but build-in a small ventilation path for the boil off to escape out of.

40. Tell the US Government there’s oil in it.

41. Thermistors that are positioned across from one another in a circuit to determine the temperature of the propellant to determine the state, that determine the remaining propellant in the storage tank.

42. Anchored heat sensing rods that can determine the state of the propellant to then determine the amount of propellant left.

43. Placed at several distinct orientations in the tank and deploy signals at different time intervals. This will allow for a continuous read on the fuel levels in the tank.

44. Put a window on the tank to use in tandem with the laser systems discussed for mass gauging.

45. Make the lid of the tank transparent for easy monitoring.

46. Align thermal imaging sensors inside the tank that can graph the orientation of the propellant bubble in the storage tank to determine its volume to subtract from the overall volume.

47. Align resistors that run along the edge of the tank to determine the state of the propellant to then determine the remaining propellant in the storage tank.

48. Use a thermocouple to measure the temperatures of the propellant to determine its state and then find the volume of propellant.

49. Suspend a series of cameras into the tank to observe any changes in the fuel.

50. Suspend thermal sensors (like stalagmites) anchored on the top and bottom of the tank.

51. Small pipe flow system that determines the state of the propellant to then determine the amount of propellant in the tank.

52. Determine the mass flow rate of the boil-off being ventilated from the tank. The amount calculated will tell how much propellant is left in the tank.

53. Use a series of laser beams (at the top) and collectors (at the bottom) in a wedge pattern around the tank.

54. Create a ventilation system that extracts the gas from the fuel to determine how much gas has been removed and calculate the amount of fluid remaining in the tank.

55. Create a fluid piping system that constantly circulates the fuel and passes a pressure gauge measuring the amount of fluid that passes through the pipe,

56. Create a suction piping system the extends and retracts into the fluid taking a sample of the fluid to see how much fluid is being extracted at a given time.

57. Create a churning system that moves the fluid and gas combination around and “organizes” it by phase to then use another system to measure the amount of fluid or gas in each state.

58. Suspend a heating orb into the middle of the fuel tank that is slightly warmer than the surrounding fuel to create a gas later around it to then control the amount of gas in the tank.

59. Use a mapping tool that is able to “scan” the entire tank vertically and horizontally and create a digital mapping software that is able to display exactly what state the fuel is in at each part of the tank.

60. Use a vertical bar to suspend the cable inside the tank. Once it has passed through launch and it is in space, unfurl the cable in branching patterns that minimize the strain on the cable.

61. Probe sensors that hang from the top of the propellant tank that detect the amount of propellant in the tank.

62. Probe systems that move around in the fluid to determine its properties and then back out the state of the propellant.

63. Send robotic arm inside the tank with a probe system to measure the propellant in the tank to measure the remaining propellant. The arm can be moved to any position in the tank to sense the temperature.

64. Send Juan inside the tank with a probe system to measure the propellant in the tank to measure the remaining propellant.

65. Send Catherine inside the tank with a probe system to measure the propellant in the tank to measure the remaining propellant.

66. Send Dane inside the tank with a probe system to measure the propellant in the tank to measure the remaining propellant.

67. Send Trevor inside the tank with a probe system to measure the propellant in the tank to measure the remaining propellant.

68. Send Zafer inside the tank with a probe system to measure the propellant in the tank to measure the remaining propellant.

69. Send Bryson inside the tank with a probe system to measure the propellant in the tank to measure the remaining propellant.

70. Introduce harmless particles into the tank and use PIV imaging to capture the flow of particles in the tank. The particles will have different flow patterns if they are in a liquid or gas.

71. 3D print a flexible helical sweep to act as a frame for the cable. Use small pins to suspend the cable around the design.

72. Use an upside-down U-shape, anchored to lid, to suspend the cables in the center of the tank.

73. Review the pulley system previously tested and integrate a more flexible rotation mechanism that is able to reliably contract under the conditions.

74. Create small wheel mechanisms inside the tank with collection valves that rotates to capture any liquid fuel that is comes in contact with to create a map of how much liquid was displaced.

75. Create a “space scale” that can measure the mass of a tank in space.

76. Create a structure similar to the Eiffel tower to string the cables in the center of the tank.

77. Take a sample of the fluid in order to determine the ratios of gas to liquid to extrapolate a volume for the tank.

78. Observe the behavior of fluid in the dewar to produce a math function that accurately describes the loss of propellant as a function of time.

79. Create a Dyson sphere around the sun that is able to power an interplanetary station that rotates simulating gravity to measure the amount of fluid in the tank.

80. Introduce a small robotic probe (i.e. a capybara) into the tank that can be remotely controlled. The FOSS system could be kept in a small bale at the bottom of the tank for the robot to pull through the propellant. The user can then direct the probe to swim around various areas of the tank to sense the temperature and state of the fluid.

81. Store the fluid in progressively smaller containers in the tank to gauge how much fluid there is by means of compression.

82. Use a barometer to determine the pressure within the tank. This, combined with the mass of the fluid could measure the amount of propellant.

83. Just measure the fluid by thinking really hard how much you believe would have been lost.

84. Create a reflective device that reflects the amount of light from a source that determines the propellant’s state.

85. Create a buoyancy device to float within the tank and measure the propellant.

86. Use a capacitance transmitter to measure the total capacitance of the fluid. The more fluid, the greater the capacitance.

87. Use a flow meter with temperature probes instead of pressure probes to measure the speed and temperature of the fluid.

88. Attach poles onto the sides of the side of the tank with loops on the end to run the fiberoptic cable throughout the tank in a circular design in order to capture the inner circle of the fuel.

89. Redefine the inner tank and create “cells” that each individually store liquid fuel. As the fuel is being used, only one cell is used at a time until it is depleted, thus making measurement much more accurate and controlled.

90. Create a new fuel gauge that measures the fluid as it exits the tank. On Earth, we will know how much fluid is added and as it enters orbit and beyond, and as we extract from it, we can calculate how much fluid is left by simple arithmetic.

91. Wrap cable in an accordion-style shape, keep the mechanism compressed during launch, then extend into the fluid once the tank is stable in space.

92. Set up a magnet system that can determine the amount of propellant in the tank to determine the amount left in the tank.

93. Use magnets on the outside of the tank to control a membrane that “combs” through the fluid and gas mixture and using thermal sensors is able to determine which part of the fuel is gas or liquid.

94. Use magnets that attract one another to determine the resistance of the propellant to determine its state and back out the volume of remaining propellant.

95. Utilize the magnetic force of a strong magnet to attract the gas bubble that can then be measured utilizing a light or refraction technique.

96. Use magnets of different strengths to attract a medium through the propellant to determine the fluid properties and then back out the volume from that data.

97. Use a magnet system that pushes and pulls on a thermocouple that allows for reaching most of the tank and use the temperature data to determine the state of the propellant.

98. Use a magnet system that pushes and pulls on a thermistor that allows for reaching most of the tank and use the temperature data to determine the state of the propellant.

99. Place a strong magnet in the center that allows fluid flow along the attractive side, this can then determine the fluid properties and back out the state of the propellant.

100. Put iron filings in the fluid and use a magnet to pull the fluid to the bottom. Then measure how long it takes them to reach the bottom with a camera and force sensors.

101. Design a system that will read a series of values pertaining to the fuel level and as it is depleted, measure the rate of depletion and display the results on a screen.

102. Create a system that measures the amount of boil off and displays the value on a gauge that is capable of lowering the value displayed.

103. Thermistors that are aligned in a circuit to determine the temperature of the propellant to determine the state, that determine the remaining propellant in the storage tank.

104. Scale-like systems that operate by creating a ridge on the inside of the tank to help control the formation of air and liquid states of fuel.

105. Intricately woven structural support system that intertwines allowing for greater suppor of the fiberoptic cable.

106. Constructing “bubble-like” devices in five positions in the tank that are attached to poles on the base of the tank with the fiberoptic cable wrapped around it to measure the thermal levels at each of the bubbles.

107. “Airfoil-like” formations interjecting into the fluid with thermal sensors at the tips that measure the change in temperature as the fluid flows around the surface.

108. Small device that is released into the fuel that emits lasers at preordained locations and measures the amount of deflected light in the fuel tank.

109. Triangle-like formations similar to those in sound-proof rooms that “break-up” the air-layer on the bottom integrated with the fiberoptic cable surrounding both these ridges and the interior bubble.

110. Creating a system that is able to map the fuel level by separating the gas from the liquid using a strainer-like system that extracts the air bubbles from the liquid.

111. Create a measurement system that analyzes the thermal properties of the fluid by examining the internal temperatures using probes extending from four centralized pillars in the middle of the tank.

112. Utilizing various methods provided above and creating a conglomeration of different techniques to form various methods of testing.

113. Making a geometrical track that extends the length of the tank and create a device that travels on the track sending out a laser signal to the opposite side to collect this data and measure the disturbance in the signal.

114. Creating a device that emits a radio wave at the top of the tank and on pillars situated throughout the middle of the tank with receivers to measure how the signal is disrupted.

115. A triangular lattice structure with multiple “exploded” arms that reach out with sensors in a variety of differing directions that rotate around the base thus spanning the length of the tank.

116. Devising a method of extracting a sample of the fuel through the use of a probe that travels around the tank and retrieves quantitative data.

117. Ridges that create a greater surface area inside the tank that allows for new interior design to allow us to look at fluid dynamics.

118. Developing a measurement system using lasers refracting through a prism at the top, sides, and bottom of the tank that will each have their own respective sensor located on the opposite end to measure the difference between the readings.

119. Creating a mechanism inside the tank that expands, moving the liquid and gas to the sides the pushes down to move the gas bubbles to the top to then take measurements of the different states of the fuel.

120. Constructing “bubble-like” devices in five positions in the tank that are attached to poles on the base of the tank with a variety of thermal, radio, and light sensors surrounding it.

121. A concentric circular base that allows for signals to travel back and forth along the circle that moves from the base of the tank to the top utilizing magnetized ball bearings.

122. Devising a method of analysis by determining the torque on a rotating lever arm to determine the amount of liquid displaced.

123. Creating a cylindrical capsule inside the tank that “floats” around the tank and has an intake and a release valve and measures the ratio of the state of the fuel as it enters and exits.

124. Devise a system of interwoven links in a series of “X-patterns” that can allow a vessel to traverse the entirety of the tank taking thermal measurements.

125. Creating a support structure made of four pillars shaped in an octangular shape that extend from the base to the top of the tank with links between and loops to hold the fiberoptic cable as well as thermocouples.

## 1.6 Concept Selection

**1.6.1 Introduction**

After determining our five medium fidelity concepts and three high fidelity concepts, different tools will be used to help with the selection process. These selection tools include binary pairwise comparison, house of quality, Pugh chart(s), and the analytical hierarchy process (AHP). These selection tools allow the project’s objectives to be quantified and ranked. With quantifiable characteristics, the concepts can be objectively compared and help to determine a final concept selection.

**1.6.2 Binary Pairwise Comparison**

Binary pairwise comparison is a method that takes customer needs and produces a numerical ‘importance factor’ for each need. The customer needs are aligned in both the vertical and horizontal axes of the table and are compared to one another, column by row. If the need in the column is more important than the need in the row, it receives a 1. If the requirement is less important, it receives a 0 in that cell. The corresponding cell across the diagonal of the matrix will then receive the opposite value. The values are then summated for each row and used to determine the importance factor for each project requirement. Below is our binary pairwise comparison matrix shown in Figure 6.2.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Customer Need** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **Total** |
| **1) Fits Inside of the Dewar** | - | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| **2) Low Conductivity Material** | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **3) Ductile Material** | 0 | 1 | - | 0 | 0 | 0 | 0 | 0 | 1 |
| **4) Scalable Design** | 1 | 1 | 1 | - | 0 | 0 | 0 | 0 | 3 |
| **5) Operates Under Cryogenic Conditions** | 1 | 1 | 1 | 1 | - | 1 | 1 | 1 | 7 |
| **6) Testable Under Cryogenic Conditions** | 1 | 1 | 1 | 1 | 0 | - | 0 | 0 | 4 |
| **7) Supports FOSS System** | 1 | 1 | 1 | 1 | 0 | 1 | - | 0 | 5 |
| **8) Measure the Volume of Propellant** | 1 | 1 | 1 | 1 | 0 | 1 | 1 | - | 6 |
| **Total** | 5 | 7 | 6 | 4 | 0 | 3 | 2 | 1 | n - 1 = 7 |

Figure 6.2: Binary Pairwise Comparison Matrix

The corresponding hierarchy for weight factors is as follows:

1. Operates under cryogenic conditions (7)
2. Measure the volume of propellant (6)
3. Supports FOSS system (5)
4. Testable under cryogenic conditions (4)
5. Scalable design (3)
6. Fits inside of the dewar (2)
7. Ductile material (1)
8. Low conductivity material (0)

Utilizing the binary pairwise comparison, we now have “importance weight factors” for all our customer needs, which will be used later in our House of Quality.

**1.6.3 House of Quality**

A house of quality translates project requirements into design specifications. The requirements are presented in the vertical column and each requirement is assigned its importance weight factor derived from the binary pairwise comparison. The horizontal row presents the engineering characteristics that will be referenced when working on the device. The numbers in the interacting cells correspond to the relativity between the project requirements and the engineering characteristics.

This relativity is exponentially ranked as 1, 3, or 9. A 1 represents no relationship, 3 represents a minimal relationship, and 9 represents a highly dependent relationship. The horizontal rows under this chart represent the ranking system. Raw score is the summation of all relativity scores multiplied by the importance weight factor. The relative weight is the percentage of how each characteristic compares to the total. The rank order is the ranking of the highest relative weight and raw score. Below is our House of Quality shown in Figure 6.3.

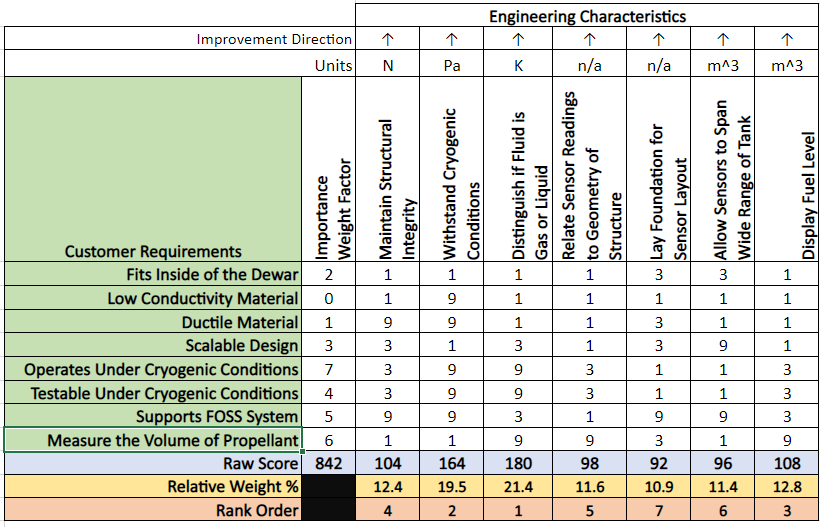


Figure 6.3: House of Quality Table

The resulting rank order is as follows:

1. Distinguish if fluid is gas or liquid
2. Withstand cryogenic conditions
3. Measure fuel level
4. Maintain structural integrity
5. Relate sensor readings to geometry of structure
6. Sensors span a wide range of the tank
7. Lay foundation for sensor layout

This rank order derived from the House of Quality presents us with an order of importance for the main engineering characteristics encompassed in our project. The most important characteristics were “distinguish if fluid is gas or liquid,” “withstand cryogenic conditions,” and “measure fuel level.” Knowing that these are the characteristics most vital to our project, future design ideas and methods of testing can be discussed and evaluated. As we continue future work, we will develop a method of measuring the fuel level by means of using a FOSS system that is capable of distinguishing where gas and liquid exist in the tank. From these initial findings, it is more important to prioritize the system measuring properly over making sure it can withstand launch or other extreme conditions.

**1.6.4 Pugh Chart**

The Pugh charts shown below in Figure 6.4.1, Figure 6.4.2, and Figure 6.4.3, compare the concepts to a selected datum concept. The concepts used are the previously determined medium and high-fidelity concepts from concept generation, and are presented in the top horizontal row, with the selection criteria presented in the vertical column. When a concept receives a ‘+’, it is perceived to outperform the datum concept in that selection criteria. When a concept receives an ‘S’, that concept is perceived to be on par with the datum concept in that selection criteria. When a concept receives a ‘-’, that concept is perceived to underperform the datum concept in that selection criteria.

The number of plusses and minuses are then summated for each concept, with a ‘+’ taking a value of 1 and a ‘-’ taking a value of –1. The summated values are used to select the next datum concept, which should have an almost equal amount of ‘+’ and ‘-’. A total of three Pugh charts are utilized, each with a different datum concept derived from the preceding Pugh chart.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Concepts | | | | | | | |
| **Selection Criteria** | Pulley  System | 1 | 18 | 20 | 21 | 27 | 31 | 93 | 103 |
| **Maintain Structural Integrity** | Datum | + | + | + | + | + | + | + | + |
| **Withstand Cryogenic Conditions** | + | + | + | + | + | + | + | + |
| **Distinguish if Fluid is Gas or Liquid** | S | S | S | S | S | - | - | S |
| **Relate Sensor Readings to Geometry of Structure** | + | + | + | + | S | S | S | S |
| **Lay Foundation for Sensor Layout** | + | + | + | - | - | - | - | - |
| **Allow Sensors to Span a Wide Range of Tank** | + | S | S | - | - | - | - | - |
| **Display Fuel Level** | + | + | + | S | S | S | S | S |
|  | # of Plus(+) | 6 | 5 | 5 | 3 | 2 | 2 | 2 | 2 |
|  | # of Minus(-) | 0 | 0 | 0 | 2 | 2 | 3 | 3 | 2 |
|  |  | **6** | **5** | **5** | **1** | **0** | **-1** | **-1** | **0** |

Figure 6.4.1: First Pugh Chart

The first Pugh chart compared all our designs to the pre-existing pulley design tested by NASA. This narrowed down our selection to our three high-fidelity concepts (highlighted in green) and two of our medium fidelity concepts (highlighted in blue), with our new selected datum being concept 21. Concepts 31 and 93 had a net negative plus-minus value, resulting in them being eliminated from the selection process.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Concepts | | | | |
| **Selection Criteria** | 21 | 1 | 18 | 20 | 27 | 103 |
| **Maintain Structural Integrity** | Datum | + | + | + | S | S |
| **Withstand Cryogenic Conditions** | - |  | - | S | - |
| **Distinguish if Fluid is Gas or Liquid** | + | + | + | S | S |
| **Relate Sensor Readings to Geometry of Structure** | + | + | + | S | S |
| **Lay Foundation for Sensor Layout** | + | - | + | S | S |
| **Allow Sensors to Span a Wide Range of Tank** | + | + | + | S | + |
|  | # of Plus(+) | 5 | 4 | 5 | 0 | 1 |
|  | # of Minus(-) | 1 | 2 | 1 | 0 | 1 |
|  |  | **4** | **2** | **4** | **0** | **0** |

Figure 6.4.2: Second Pugh Chart

The second Pugh chart utilizes concept 21 as the new datum and compares the remaining concepts. Both medium fidelity concepts had a net zero while all three high fidelity concepts were a net positive, leading to the elimination of the two medium fidelity concepts. Because concept 18 was the closest to net zero plus-minus (+2), it is the new selected datum for the next iteration. The two remaining concepts are concepts 1 and 20.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Concepts | |
| **Selection Criteria** | 18 | 1 | 20 |
| **Maintain Structural Integrity** | Datum | - | - |
| **Withstand Cryogenic Conditions** | S | S |
| **Distinguish if Fluid is Gas or Liquid** | S | S |
| **Relate Sensor Readings to Geometry of Structure** | + | S |
| **Lay Foundation for Sensor Layout** | + | + |
| **Allow Sensors to Span a Wide Range of Tank** | + | S |
|  | # of Plus (+) | 3 | 1 |
|  | # of Minus (-) | 1 | 1 |
|  |  | **2** | **0** |

Figure 6.4.3: Final Pugh Chart

The final Pugh chart uses concept 18 as the datum and compares concepts 1 and 20. After going through all the selection criteria, concept 1 had the highest plus-minus (+2) of the two remaining concepts. As a result, concept 1 is now the frontrunner. To finalize the selection, the Analytical Hierarchy Process and Alternative Value matrices were used.

**1.6.5 AHP Chart**

The Analytical Hierarchy Process (AHP) was completed in order to determine the relative importance of project requirements. Once the concept has been selected, an order of importance of our customer needs must be derived to proceed with the project. In the AHP matrix, the horizontal row and vertical column both present the project requirements. The requirements are compared similarly to the binary pairwise comparison, with a numerical criterion of odd numbers spanning from 1 to 9. These values are then reflected over the diagonal and represented as the reciprocal. The values across each row are then summated, and the total weights are represented in the last row as the ‘Total’.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Criteria Comparison Matrix [C] | | | | | | | | |
| **Customer Need** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| **1) Fits Inside of the Dewar** | 1.00 | 3.00 | 3.00 | 3.00 | 0.33 | 0.33 | 0.33 | 0.33 |
| **2) Low Conductivity Material** | 0.33 | 1.00 | 1.00 | 0.33 | 0.20 | 0.33 | 0.33 | 0.20 |
| **3) Ductile Material** | 0.33 | 1.00 | 1.00 | 0.33 | 0.14 | 0.33 | 0.20 | 0.33 |
| **4) Scalable Design** | 0.33 | 3.00 | 3.00 | 1.00 | 0.20 | 1.00 | 0.33 | 0.33 |
| **5) Operates Under Cryogenic Conditions** | 3.00 | 3.00 | 7.00 | 5.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **6) Testable Under Cryogenic Conditions** | 3.00 | 3.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **7) Supports FOSS System** | 3.00 | 3.00 | 3.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **8) Measure the Volume of Propellant** | 3.00 | 5.00 | 3.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Total** | 14.00 | 22.00 | 24.00 | 16.67 | 4.88 | 6.00 | 5.20 | 5.20 |

Figure 6.5.1: AHP Matrix

The above AHP Matrix is shown above in Figure 6.5.1 generates a total in the bottom row which produces the order of importance for each of the customer needs. The lower the total value is, the larger a priority the need in the respective column becomes. The customer need hierarchy is as follows:

1. Operates Under Cryogenic Conditions
2. Supports FOSS System
3. Measure the Volume of Propellant
4. Testable Under Cryogenic Conditions
5. Fits Inside the Dewar
6. Scalable Design
7. Low Conductivity Material
8. Ductile Material

The normalized criteria comparison matrix, final rating matrix, and alternative value matrix shown below in Figures 6.5.2, 6.5.3, and 6.5.4 respectively, are then used to select the final concept. These matrices use the values found in the binary pairwise comparison to rank against the project requirements. Figure 6.5.5 shows the final consistency table of our project producing a consistency index of 0 and with a consistency ratio of –1.125 leading us to the conclusion that our tables are reasonable and unbiased.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Normalized Criteria Comparison Matrix [NormC] | | | | | | | | | |
| **Customer Need** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | Criteria Weights |
| **1) Fits Inside of the Dewar** | 0.071 | 0.136 | 0.125 | 0.180 | 0.068 | 0.056 | 0.064 | 0.064 | 0.096 |
| **2) Low Conductivity Material** | 0.024 | 0.045 | 0.042 | 0.020 | 0.041 | 0.056 | 0.064 | 0.038 | 0.041 |
| **3) Ductile Material** | 0.024 | 0.045 | 0.042 | 0.020 | 0.029 | 0.056 | 0.038 | 0.064 | 0.040 |
| **4) Scalable Design** | 0.024 | 0.136 | 0.125 | 0.060 | 0.041 | 0.167 | 0.064 | 0.064 | 0.085 |
| **5) Operates Under Cryogenic Conditions** | 0.214 | 0.136 | 0.292 | 0.300 | 0.205 | 0.167 | 0.192 | 0.192 | 0.212 |
| **6) Testable Under Cryogenic Conditions** | 0.214 | 0.136 | 0.125 | 0.060 | 0.205 | 0.167 | 0.192 | 0.192 | 0.162 |
| **7) Supports FOSS System** | 0.214 | 0.136 | 0.125 | 0.180 | 0.205 | 0.167 | 0.192 | 0.192 | 0.177 |
| **8) Measure the Volume of Propellant** | 0.214 | 0.227 | 0.125 | 0.180 | 0.205 | 0.167 | 0.192 | 0.192 | 0.188 |
| **Total** | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Figure 6.5.2: Normalized Criteria Comparison Matrix

|  |  |  |
| --- | --- | --- |
| Weighted Sum Vector | Criteria Weights | Consistency Vector |
| 0.8402 | 0.096 | 8.79 |
| 0.3340 | 0.041 | 8.10 |
| 0.3234 | 0.040 | 8.13 |
| 0.6856 | 0.085 | 8.05 |
| 1.8530 | 0.212 | 8.73 |
| 1.3533 | 0.162 | 8.38 |
| 1.5236 | 0.177 | 8.63 |
| 1.6061 | 0.188 | 8.55 |
|  | AVG (λ) | 8.42 |
|  |  |  |
| Consistency Index: | 0.059844921 |  |
| Consistency Ratio: | 0.041272359 | Needs to be <0.1 |

Figure 6.5.3: Consistency tables

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Distinguish if Fluid is Gas or Liquid** | | |
| **Concepts** | **1** | **18** | **20** |
| **1** | 1 | 3 | 3 |
| **18** | 0.33 | 1 | 1 |
| **20** | 0.33 | 1 | 1 |
| **Total** | 1.67 | 5 | 5 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Distinguish if Fluid is Gas or Liquid** | | | |
| **Concepts** | **1** | **18** | **20** | **Alternative Priorities** |
| **1** | 0.6 | 0.6 | 0.6 | 0.6 |
| **18** | 0.2 | 0.2 | 0.2 | 0.2 |
| **20** | 0.2 | 0.2 | 0.2 | 0.2 |
| **Total** | 1 | 1 | 1 | 1 |

Figure 6.5.4: Alternative Priority Table

|  |  |  |
| --- | --- | --- |
| Weighted Sum Vector | Alternative Priorities | Consistency Vector |
| 1.8 | **0.6** | 3 |
| 0.6 | 0.2 | 3 |
| 0.6 | 0.2 | 3 |
|  |  |  |
|  |  |  |
|  | Consistency Index | 0 |
|  | Consistency Ratio | -1.125 |

Figure 6.5.5: Final Consistency Table

**1.6.6 Final Selection**

As determined from data in the preceding charts, namely the alternative matrix, Concept 1 is our final selection. Concept 1 is given as “Vertical bars on the outside of a circular platform, and some inside, with fiberoptic cables wrapped around every vertical bar in concentric helical sweeps.” This concept is similar to last year’s project, but some important differences include nested helical sweeps and additional structural supports to resist strain and compression forces.

According to our analysis, Concept 1 outperformed the other designs. This is most visible in the Pugh charts where it was the top performer against the older NASA design and went on to be the top contender in the last iteration. In terms of our AHP chart, this design was most likely to fulfill the top requirements in the most cost-effective way. While all ideas had the capability of withstanding cryogenic conditions, the honeycomb and truss designs may have required more material and more complex machining. However, our plainer nested helical sweeps would have required minimal machining in that most parts could be used as purchased.

This idea would also optimize the comparison of this and last year's designs when it comes time to do our data analysis comparison and would allow for a deeper insight into the overall accuracy of the helical layout. While we may be able to incorporate some of our other designs for a stronger structure, like honeycombs to reduce strain, the current idea for the base is the same as last year with two circular platforms and vertical bars.

Some challenges we are already anticipating are primarily regarding testing procedures. For instance, how the platforms will attach to the lid of the tank is unknown, as well as what complications will come along with open-dewar testing. If there is no lid on the dewar, we will not be able to turn it to change the locations of gas bubbles to measure the efficiency of our testing system. Additionally, we are unsure how we will anchor the model in the tank, but we plan to address these uncertainties with our advisor and make changes as necessary to our concept.

## 1.8 Spring Project Plan

## Milestone: Confirm Bill of Materials (Week of January 13)

Deliverables:

* Meet with sponsor and advisor to confirm the bill of materials and proper material selection, as well as lab ability to vacuum seal epoxy
* Meet with machine shop to discuss any drill bits we may need to buy or other complications with our design

**Milestone: Order Parts (Week of January 20)**

Deliverables:

* Order the parts from the appropriate vendors through FAMU-FSU College of Engineering. If vendors do not have the parts needed, they will be ordered through a third party

**Milestone: Complete MagLab Safety Training (Week of Janurary 23)**

Deliverables:

* All team members must complete the required cryogenic safety training online course from the MagLab

**Milestone: Advisor Meeting 1 (Week of February 3)**

Deliverables:

* Meet with Dr. Vanderlaan to confirm testing procedure(s) and schedules

**Milestone: Create Testable Prototype (Week of February 17)**

Deliverables:

* Create a testable prototype with the purchased materials in order to test the design and experimental procedure

**Milestone: Test Prototype (Week of February 24)**

Deliverables:

* Run tests to confirm that the F.O.S.S system is accurate, and that the design can map the liquid nitrogen in the dewar

**Milestone: Advisor Meeting 2 (Week of February 27)**

Deliverables:

* Meet with Dr. Vanderlaan to discuss testing results and potential reworking of design or experiments

**Milestone: Confirm Design (Week of March 3)**

Deliverables:

* If necessary, alter the testing procedure or design to improve the operation
* Finalize this new design and testing procedure

**Milestone: Build Final Design (Week of March 17)**

Deliverables:

* Use the alterations to confirm a final design and test through the new test procedure
* If using epoxy, must go to MagLab for vacuum sealing

**Milestone: Advisor Meeting 3 (Week of March 20)**

Deliverables:

* Meet with Dr. Vanderlaan to assess our final design

**Milestone: Final Meetings with Sponsor (Week of March 22)**

Deliverables:

* Have final meeting with sponsor to confirm final design and operation prior to senior design day

**Milestone: Final Testing (Week of March 22)**

Deliverables:

* Complete last round of testing with finalized design and procedure

**Milestone: Create Website and Posters (Week of March 24)**

Deliverables:

* Create a website and poster that showcase our work and final designs

**Milestone: Prepare Prototype and Display for Engineering Design Day (March 27-30)**

Deliverables:

* Make sure prototype is ready to present (i.e. clean and fully assembled)
* Procure any other props needed for demonstrations
* Do a few test-runs of poster presentations and demonstrations

**Milestone: Engineering Design Day (April 1)**

Deliverables:

* Get to the college on time so that there is ample time to set up
* Present the poster and final design at engineering design day

**Milestone: Finals Week (Week of 5)**

Deliverables:

* Study and show up on time to all required examinations
* Don’t fail

**Milestone: Graduation (May 6)**

Deliverables:

* Walk and enjoy time with family

# Chapter Two: EML 4552C

## 2.1 Spring Plan

### Project Plan.

### Build Plan.

# Appendices

# Appendix A: Code of Conduct

**FAMU/FSU College of Engineering**

**Department of Mechanical Engineering**

**Code of Conduct**

**Team 516: NASA-MSFC Cryogenic**

Names: Contact Email:

Bryson Peters [btp20@fsu.edu](mailto:btp20@fsu.edu)

Zafer Jesri [zj18a@fsu.edu](mailto:zj18a@fsu.edu)

Dane Seal [ds18k@fsu.edu](mailto:ds18h@fsu.edu)

Catherine Potts [cp19s@fsu.edu](mailto:cp19s@fsu.edu)

Trevor Lay [tjl19b@fsu.edu](mailto:tjl19b@fsu.edu)

Date 09/09/2022

**Mission Statement**

Team 516 is committed to producing the best solution to the given problem statement. The goal is not only to produce the best solution, but to learn skills and assets that are viable in real world engineering applications. This project will provide the team members with experience of how engineering projects work and how the engineering field operates. The team members will employ the concepts and skills learned at FAMU-FSU College of Engineering to best solve the problem at hand.

**Outside Obligations**

All outside obligations are to be respected by every team member. If there is a recurring obligation, the team member will notify the team ahead of time so recurring meetings can be scheduled. All known obligations at this time have been established and are listed below. If a new obligation is to arise, the team member will notify the rest of the team as soon as possible, so rescheduling of meetings can occur to include every team member. Team meetings are expected to be a high priority for each team member. If a team member repeatedly fails to notify the group of outside obligations, or fails to treat group meetings as obligations themselves, the team member will be addressed.

Obligations per member are as follows:

* Bryson Peters: None currently
* Zafer Jesri: None currently
* Dane Seal: Marching Chiefs (Monday/Wednesday/Friday 4:00 – 6:00 pm), Marching Chiefs (Some Saturdays), Office Hours (Wednesday 6:30 – 8:30 pm)
* Catherine Potts: Work (Mondays/Fridays 8:30 am – 1:30 pm)
* Trevor Lay: Fraternity Obligations (Saturday)

**Team Roles**

Team roles are subject to change as the project progresses. All team members are expected to contribute to each branch of the project even if it is not their role to do so. The roles are assigned based on the member’s interests and skills. The current team roles are as follows:

* Bryson Peters – Fluids Engineer
  + Responsible for the fluid dynamics and heat transfer aspects of the project. Expected to use computational fluid dynamics and/or finite element analysis if necessary for prototyping and simulation.
* Zafer Jesri – Systems Engineer
  + Responsible for the systems and operations of the models. Expected to know the compatibility of each part in the assembly to ensure smooth operation and a successful model.
* Dane Seal – Design Engineer
  + Responsible for the computer aided design aspect of the project. Expected to replicate the models in programs such as CREO or SOLIDWORKS to help visualize and/or analyze the desired properties.
* Catherine Potts – Manufacturing Engineer
  + Responsible for materials research to produce reliable suggestions for material selection. Expected to produce reliable machining drawings for future manufacturing of prototypes.
* Trevor Lay - Thermal Engineer
  + Responsible for the thermodynamics of the project, assists in fluid dynamics and heat transfer aspects. Expected to know how fluids operate at very low temperatures and cryogenic conditions.

The responsibilities listed for each role are subject to change depending on the future work of the project. Other duties and expectations will be given based on the members’ preferences and skills. All team members are expected to not only perform their responsibilities, but also assist their teammates if troubles arise, even if it does not apply to their specific role.

**Communication**

The primary method of communication will be email. Text message may also be used for quick communication. Weekly scheduled meetings will occur on Wednesdays at 12:00 PM. Any other meetings are to be requested by group members at any time using email, phone call, or text message and must be agreed upon unanimously to qualify as an official scheduled meeting. Meetings may be canceled or rescheduled if a request is made to the group via email or text at least 24 hours prior. Time conflicts (at which a member is not expected to make a meeting or be available for communication) are listed above under “Outside Obligations.” Delay in response to communication is expected. However, any communication needing a response sent during the weekdays is expected to have a response within 12 hours. Any communication needing a response sent during the weekends is expected to have a response within 24 hours.

**Dress Code**

For sponsor/professional interactions and presentations, a minimum of business casual attire is expected to be worn by all group members present physically or virtually. More formal attire may be agreed upon by the group for certain events or circumstances. No dress code is required for internal meetings of the group.

**Attendance**

Attendance of official scheduled meetings is mandatory and will be kept using a spreadsheet managed by the entire group where changes to the document are monitored and must be agreed upon by the group. If a group member is absent from a scheduled meeting without explanation and/or warning, it is the responsibility of the group to note their absence in the spreadsheet and notify the absent member of the number of absences they’ve accumulated. If a group member accumulates 3 unexplained and/or unwarned absences, it is the responsibility of the group to notify Dr. McConomy of the members' repeated absences. Absences may only be waived if warning and/or explanation is given. Absences may only be waived by unanimous agreement of the present members of the group.

**How to Notify the Group**

To notify the group of potential deadlines, meeting times, or other important circumstances, the individual is responsible for ensuring that their message to the group is received and understood. The means by which these notifications will be exchanged are either through text messaging through the group chat, or for more formal notifications such as absences (see above), the individual will contact the group through email as to better document and keep track of such professional notifications.

**How to Respond to People in Professional Meetings**

When responding to others in professional meetings, all communication by the individual will be respectful, orderly, and punctual to the utmost of their abilities. If information is unclear or lacking in any regards, the individual will fill in the rest of the information through email, zoom, or through more demanding means if necessary.

**What Do We Do Before Contacting Dr. McConomy or TAs**

If conflicts arise, we will attempt to solve them on our own by use of direct communication and compromise. Depending on the situation, this could entail a group meeting or just a few text messages between the conflicting group members. If additional help is needed, we will reach out to the TAs.

**At What Point Do We Contact Dr. McConomy**

We will contact Dr. McConomy if we are unable to come to a solution, or make any progress, after at least one week of working to solve the conflict on our own.

**What Do You Want Dr. McConomy to Do When You Come**

Assess the problem at hand and conclude as to whether a penalty shall be administered to the group member(s) at fault. If deemed necessary, potential penalties may include grade deductions, written apology notes, or singing a song of the rest of the group's choosing.

**How to Amend**

This living document shall be amended by a group majority vote with all members present. No signatures will be needed for future amendments.

**Statement of Understanding**

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\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

X Bryson Peters Date

Shape

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X Catherine Potts Date

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X Dane Seal Date

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X Trevor Lay Date

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X Zafer Jesri Date

By signing this statement, the individual acknowledges that they have read and understood the list of guidelines set forth in the Code of Conduct. Failing to adhere to the rules and regulations above will result in consequences set forth both in the Code of Conduct as well as the course itself.

# Appendix B: Functional Decomposition

# 

# Table Description automatically generatedAppendix C: Target Catalog

# Appendix B Figures and Tables (delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 1 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.



Figure 1. Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table 1  
*The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase*

|  |  |
| --- | --- |
| Level of heading | Format |
| 1 | **Centered, Boldface, Uppercase and Lowercase Heading** |
| 2 | Flush Left, Boldface, Uppercase and Lowercase |
| 3 | Indented, boldface lowercase paragraph heading ending with a period |
| 4 | Indented, boldface, italicized, lowercase paragraph heading ending with a period. |
| 5 | Indented, italicized, lowercase paragraph heading ending with a period. |

# References

**There are no sources in the current document.**