95	Many thin supports between the two tank layers would allow for structural integrity and small, localized sources of heat transfer.

Table 5: High Fidelity Concepts

1.5.4 Eliminating Concepts

In order to find medium and high fidelity concepts, some ideas were eliminated. The first set of idea eliminations included eliminating the thin-walled ideas from the morphological chart. The team found that a thicker wall on the tank would perform better in reducing heat leak into the system. While looking at the morphological chart ideas, the team also found the pill-shaped container would perform better in maximizing the volume of storage while reducing surface area contact of the fluid to the tank compared to the cylindrical shape.

The second set of eliminations led the team to eliminate the triple-shelled idea. The third shell would cost more, weigh more, and wouldn't be necessary since the double-shell will eliminate the conduction and convection that the third shell would target.

1.6 Concept Selection

The concept selection process is the part of the design process where the generated concepts are weighed against each other to determine a final design. This design will move forward as the team's main concept for a prototype. This process is completed on Microsoft Excel where values can be quickly calculated and tables can be created. The process and calculated values are explained in the following sections.

1.6.1 House of Quality

The House of Quality chart compares the eight customer requirements we were given with the engineering characteristics that are relevant to the project. The priority of each customer need was found using the Binary Pairwise Comparison chart that can be found in Appendix E. The engineering characteristics that we found to be the most important are volume, surface area, time, safety, durability, ease of use, and cost.

House of Quality						
		Engineering Characteristics				
	Improvement Direction	↑	↓	↑	↑	↑
	Units	m^3	m^2	hours		
Customer Needs	**Priority**	**a**	**b**	**c**	**d**	**e**
1	7	1	1	9	3	3
2	1	0	0	0	0	3
3	2	9	9	3	3	9
4	2	3	3	9	9	9
5	6	9	9	9	9	1
6	4	9	3	9	9	1
7	3	3	9	3	3	1
8	3	0	0	0	1	3
	Raw Score	**130**	**124**	**186**	**147**	**82**
	Relative Weight %	**17.59**	**16.78**	**25.17**	**19.89**	**11.10**
	Rank Order	**3**	**4**	**1**	**2**	**5**

Table 6: House of Quality

1 – Increase Storage Time	a – Volume
2 – Validate Design Choices	b – Surface Area
3 – Use of Hypothetical Mission	c – Time
4 – Store Cryogenic Propellant	d – Safety
5 – Maintain Temperature	e – Durability
6 – Maintain Pressure	f – Ease of Use
7 – Reduce Heat Transfer	g - Cost
8 – Connect to Existing Systems	

Table 7: Variables from House of Quality

The customer requirements and engineering characteristics were compared to one another using the numbers 0, 1, 3, and 9. A zero means that the two are not related, a one means they are barely related, a three means they are mildly related, and a nine means they directly depend on one another. Once the columns are filled, each number is multiplied by the priority number of the customer need in the corresponding row. These numbers are then summed together to obtain a raw score for each engineering characteristic. Next, the raw scores for each engineering characteristics are added together. Each raw score is then divided by the total of the raw scores to obtain the relative weight for each column. This number is multiplied by 100 to get the value into a percentage. The sum of the relative weights should equal 100%. Based on their relative weights, the engineering characteristics can also be ranked in order of determined importance.

The results of the House of Quality indicate that the time under cryogenic temperatures is the most important engineering characteristic to this project, followed by safety and volume. Time under cryogenic temperature is the most important characteristic to this project because of the fluid's temperature increases beyond an acceptable level it will boil and will have to be released as a gas. Safety is also important to the project because if a system fails or the tank fractures it would endanger the ship and lives of any crewmember. Lastly, the volume is another important characteristic because the tank must hold enough cryogenic fuel to complete the mission.

1.6.2 Pugh Charts

The engineering characteristics along with their relative weights were then placed in the first Pugh Chart, seen below in Table 8. We gathered our medium and high-fidelity concepts that were chosen in concept selection and placed them in the table to be compared with the current state of the art cryogenic tank design.

If the design choice would perform better than the state of the art in terms of the engineering characteristic, then the box will get a “plus” sign. If it would perform worse, a "minus sign" is inserted. If it does not change, it is assigned an “S”. The number of plusses and minuses are summed for each design choice, then compared. The designs with the overall most minuses and least plusses are ruled out. In this case, Pugh Chart 1 eliminated glass bead insulation.

Pugh Chart 1

Criteria	Weight	SOTA	A	B	C	D	E	F	G
a	17.59		S	S	S	S	S	+	S
b	16.78		S	S	S	S	S	+	S
c	25.17		+	-	-	-	+	S	-
d	19.89		S	S	S	S	S	-	S
e	11.10		S	+	+	+	+	-	-
f	5.95		+	+	+	S	S	-	-
g	3.52		+	+	+	+	-	S	S
Pluses			3	3	3	2	2	2	0
Minuses			0	1	1	1	1	3	3

Table 8: Pugh Chart 1

A – MLI in a Vacuum, Pill Shape	E – Powder Insulation – Pill Shape
B – Foam Insulation – Pill shape	F – Spherical Shape
C – Film Insulation – Pill Shape	G – Glass Bead Insulation – Pill Shape
D – Double Shell Vacuum – Pill Shape	

Table 9: Variables for Pugh Chart

The criteria variables can be found in Table 7. The designs that did not get ruled out then move on to the second Pugh chart found in Appendix E. In this chart, the designs will be compared with the design that received the average amount of plusses and minuses in the first Pugh chart, film insulation. Each box is again filled with plusses, minuses, and S's. After each box was filled, we had three designs that performed better than the others, those will to the next step in the concept selection process. These three concepts are multi-layer insulation, foam insulation, and powder insulation.

1.6.3 Hierarchy Chart

For the hierarchy chart, we took the seven engineering characteristics used in the previous charts and compared them with each other. The box is filled with a 1 if they have equal importance, a 3 if one is moderately more important than the other, a 5 if one is strongly more important than the other, a 7 if one is much more important, and a 9 if one is significantly more important than the other. When the characteristic is compared with itself, it receives a 1, which creates a diagonal of 1's in the table. Corresponding values on either side of this diagonal are the inverse of each other. Once all boxes are filled, the values in each column are summed. The labels for the rows and columns are represented by variables that can be found in Table 9.

AHP Chart							
	a	b	c	d	e	f	g
a	1.00	3.03	1.00	1.00	1.00	3.03	9.09
b	0.33	1.00	1.00	0.33	0.33	7.00	7.14
c	1.00	1.00	1.00	1.00	1.00	7.14	9.09
d	1.00	3.00	1.00	1.00	1.00	3.03	7.14
e	1.00	3.00	1.00	1.00	1.00	9.09	9.09
f	0.33	0.14	0.14	0.33	0.11	1.00	3.03
g	0.11	0.14	0.11	0.14	0.11	0.33	1.00
Sum	**4.77**	**11.31**	**5.25**	**4.80**	**4.55**	**30.62**	**45.59**

Table 10: Analytical Hierarchy Process Chart

a – Volume
b – Surface Area
c – Time
d – Safety
e – Durability
f – Ease of Use
g - Cost

Table 11: Variables of the Hierarchy Chart

In this chart, characteristics such as ease of use and cost score very highly and all other characteristics receive low sums. This data will be taken to the normalized matrix in the next step to clearly depict the meaning of the data.

1.6.4 Normalized Matrix

The hierarchy chart must then be normalized. To do this, each value in the column is divided by the sum of the values in the column. This operation is done for each value in each column and placed in a new normalized chart. When the values in each column in the normalized chart are added, they should equal 1. The variables in this table can also be found in Table 10.

	Check Normalization							Criteria Weight
	a	b	c	d	e	f	g	
a	0.21	0.27	0.19	0.21	0.22	0.10	0.20	0.20
b	0.07	0.09	0.19	0.07	0.07	0.23	0.16	0.13
c	0.21	0.09	0.19	0.21	0.22	0.23	0.20	0.19
d	0.21	0.27	0.19	0.21	0.22	0.10	0.16	0.19
e	0.21	0.27	0.19	0.21	0.22	0.30	0.20	0.23
f	0.07	0.01	0.03	0.07	0.02	0.03	0.07	0.04
g	0.02	0.01	0.02	0.03	0.02	0.01	0.02	0.02
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	1.00

Table 12: Normalization Chart

The normalized chart reveals that criteria such as volume, time, and safety are very important while cost and ease of use are secondary. This helps the design team recognize which characteristics are important to design for in this project.

The consistency check was completed to ensure that the comparisons of concepts and engineering characteristics is consistent. This was done by using the criteria from the normalized matrix, as well as the weighted sum vector. The weighted sum vector was found by matrix operation between the rows of the criteria comparison matrix by the column of criteria. The consistency vector was found by dividing the weighted sum vector by the criteria weight. After this, the average from the consistency vector was found and used to find the consistency index. Then, finding the random index value from the reference chart, the consistency ratio was found to be less than 0.1, which indicates our comparisons are consistent.

1.6.5 Final Rating Matrix

Before creating the final rating matrix, the alternative analytical hierarchy process had to be completed for each engineering characteristic for all the design concepts. For each characteristic, the concepts were compared against each other one at a time, similar to the previous process. After each column is summed, the normalized matrix for each characteristic was created by dividing each entry by the column sum. The average of each row in the normalized matrix is used as the criteria weight in the consistency check. A consistency check was completed for each engineering characteristic, ensuring the comparisons have remained consistent. The weighted sum vector and consistency vector were found using the same process as mentioned in section 1.6.4, and each characteristic was found to be compared consistently.

The criteria weights from each engineering characteristic in the alternative AHP chart were entered into the final decision matrix horizontally across, with the characteristics listed along the vertical and the design concepts along the horizontal. The final decision matrix was then transposed and using the same matrix math as the weighted sum vector, multiplying the row by the original criteria weight as found from the original AHP chart. This returned individual values for each idea, the highest value indicating the best-fit idea for the project, with each idea ranked in order of best-fit to worst-fit. The final results are listed below. The individual alternative value tables, normalized tables, and consistency tables can be found in Appendix E.

Concept	Alternative Value	Rank
MLI - Pill Shape	0.444	1
Foam Insulation - Pill Shape	0.283	2
Powder Insulation Supports	0.274	3

Table 13: Final Ranking with Alternative Designs

As shown in Table 13, multi-layer insulation (MLI) is the best candidate for us to utilize in our final design. We will be further investigating this concept as we move forward in the semester. A rough sketch of this can be seen below.

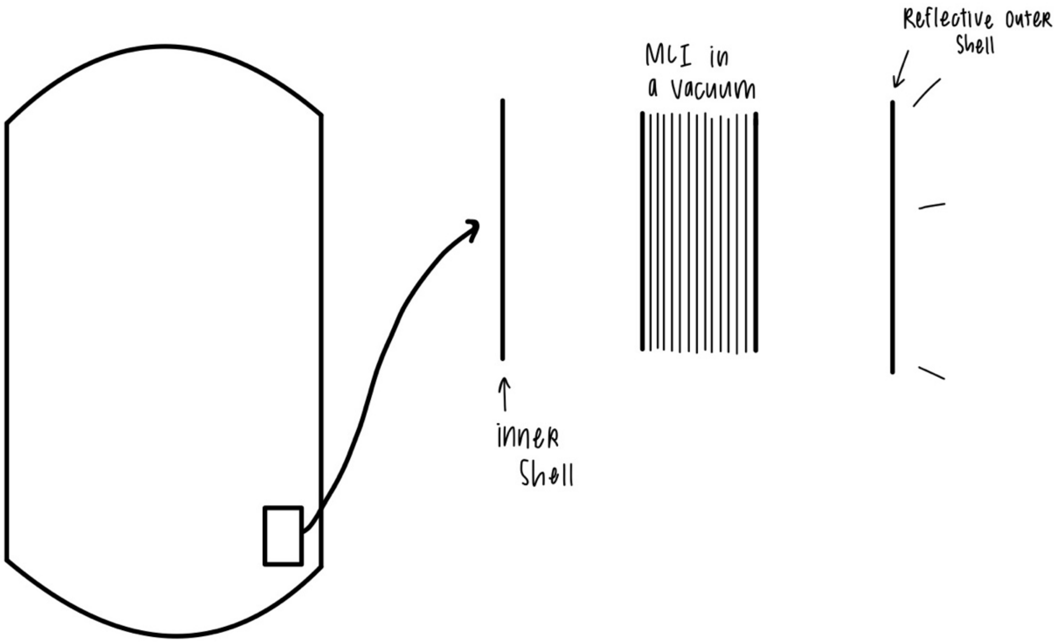

Figure 2: Final Design Concept Sketch