1.6 Concept Selection

Once the concept generation phase was finished, tools such as Binary Pairwise Comparison, House of Quality, Pugh Charts, and the Analytical Hierarchy Process (AHP) were employed to assess the options. These methods utilize an analytical approach to quantitatively identify the best concepts in relation to customer needs. In essence, they convert qualitative ideas into a numerical format, facilitating informed design choices.

1.6.1 Binary Pairwise Comparison

The binary pairwise comparison chart is utilized to establish the importance weight factor for each customer need and to rank them accordingly. The figure below illustrates the binary pairwise comparison used to calculate these weight factors for the House of Quality. This approach assisted Team 518 in identifying which customer needs should be prioritized in the final design. The process involved comparing each need in the rows against those in the columns, assigning a value of 1 if the row's need was deemed more important, 0 if it was less important, and a dash (-) if they were equal. This assignment also applied to the main diagonal of the matrix, with the transposed positions receiving the opposite values. This comparison was repeated until the entire matrix was filled. Finally, the sums of the columns and rows were calculated to determine an "Importance Weight Factor," which was then reflected in the House of Quality Chart.

Binary Pairwise Comparison									
Customer Needs	1	2	3	4	5	6	7	8	Total
1. Sand between 70 and 100 microns	-	1	0	0	0	0	0	0	1
2. Maintains atmospheric properties	0	-	0	0	0	0	1	0	1
3. Multiple Nozzle Sizes	1	1	-	0	1	0	1	0	4
4. Depth, area and profile measurements of crater	1	1	1	-	1	0	1	1	6
5. Data analysis	1	1	0	0	-	0	1	1	4
6. Nozzle must achieve supersonic speeds	1	1	1	1	1	-	1	1	7
7. Sturdy structure	1	0	0	0	0	0	-	0	1
8. Underexpanded jet	1	1	1	0	0	0	1	-	4
	6	6	3	1	3	0	6	3	n-1 = 7

Using this chart, we determined that the most important customer needs were that the nozzle must achieve supersonic speed and that the team must have measurements and profiles of the crater.

1.6.2 House of Quality

The purpose of the House of Quality is to convert customer needs into measurable design variables known as engineering characteristics. These characteristics are crucial for the final design. The figure below displays the generated House of Quality chart. A 1-3-5-7-9 scale was utilized, assigning values based on how effectively each characteristic addresses the corresponding customer need. To identify the most important characteristics for inclusion in the Pugh chart, the top five engineering characteristics were selected, characteristics that ranked 5 and 6 were combined as they both had to do with measurements of the crater. These characteristics were determined to be most important because their relative weight to the project was higher than the criteria average of 7.7%. This gave way to the top 5 engineering characteristics of the pressure of the gas supplied, holding the jet steady, the velocity of the gas exiting the nozzle, adjustable nozzle height, and precision of the nozzle. This eliminated

House of Quality														
		Engineering Characteristics												
Improvement Direction					↓	↓	↓		↓		↓	↓	↑	↑
Units		meters	meters	meters	kilograms	meters	meters	seconds	kiloPascals	seconds	meters	Microns	kiloPascals	m/s
Customer Requirements	Importance Weight Factor	Gather Depth Data	Gather Width Data	Adjustable Nozzle Height	Contains debris	Holds sensors steady	Holds jet steady	Gather time data	Minimizes enclosure effects	Ease of experimental setup	Precision of nozzle	Particle Size of Sand	Pressure of Gas Supp	Velocity of Gas at nozzle exit
Sand between 70 and 100 microns	1	0	0	0	5	1	0	0	0	0	0	9	0	0
Maintains atmospheric properties	1	0	0	0	5	0	1	0	9	0	0	0	1	1
Multiple nozzle sizes	4	0	0	9	0	0	5	0	0	9	0	0	0	1
Depth, area and profile measurements of crater	6	9	9	7	5	9	5	5	0	0	3	3	0	3
Data analysis	4	9	9	1	0	0	1	9	5	5	9	1	0	5
Nozzle must achieve supersonic speeds	7	0	0	5	0	0	7	0	0	0	9	0	9	9
Sturdy structure	1	0	0	3	9	9	9	0	3	0	0	0	0	0
Underexpanded Jet	4	0	0	0	0	0	0	0	9	0	5	0	9	9
Raw score	1126	90	90	120	49	64	113	66	68	56	137	31	100	142
Relative Weight %		8.0	8.0	10.7	4.4	5.7	10.0	5.9	6.0	5.0	12.2	2.8	8.9	12.6
Rank Order		6	7	3	12	10	4	9	8	11	2	13	5	1

1.6.3 Pugh Charts

The Pugh chart evaluates the key engineering characteristics derived from the house of quality across various design concepts. The figure below shows the initial Pugh Chart, using a research project from Auburn University as the datum. The project was a variant of what our team is planning to perform, in their project they had a singular nozzle and didn't vary the scale of the nozzle but instead varied the height of the nozzle from the bed of simulant. The goal of their project was slightly different than Team 518's project goals, however similar rigging would be needed to achieve an experimental procedure. The Pugh charts incorporate medium and high-fidelity concepts derived from concept generation. Each row represents an engineering characteristic, while each column corresponds to a specific concept, with the leftmost column serving as the datum (last year's design) against which the concepts are evaluated. Each cell is marked with an "S," "+," or "-" symbol: "S" signifies similarity between the concept and the datum for the characteristic, "+" indicates the concept is superior to the datum, and "-" suggests it is inferior. These values are then totaled and displayed at the bottom of the chart.

Pugh Chart: Iteration 1									
Engineering Characteristic	Auburn Experimental Setup	Concepts							
		10	15	30	47	54	42	43	51
Pressure of Gas Supplied	Datum	-	-	-	S	S	+	S	S
Holds Jet Steady		+	+	+	-	-	S	-	S
Velocity of Gas at Nozzle Exit		S	S	S	S	S	S	S	S
Adjustable Nozzle Height		S	S	S	S	S	S	S	S
Precision of Nozzle		+	+	S	-	-	-	-	S
Plus (+)		2	2	1	0	0	1	0	0
Satisfactory (S)		2	2	3	3	3	3	3	5
Minus (-)		1	1	1	2	2	1	2	0
		4	4	3	-1	-1	3	-1	5

The top 5 concepts from the first Pugh Chart were concepts 51, 10, 15, 30 and 42, these concepts were then fed into the second iteration of the Pugh Chart and were then compared to concept 43 as the new datum this resulted in the Pugh Chart below. From there the top two concepts were easy to determine. However, choosing the third concept needed some deliberation as the remaining three concepts were all tied at 1 point. In the end our team decided to go with concept 15 because it proposed a steel frame which would provide a sturdier product, and it used a Schlieren DAQ. Concepts 51, 42, and 15 were then fed into the Analytical Hierarchy Process.

Pugh Chart: Iteration 2						
Engineering Characteristic	43	Concepts				
		51	10	15	30	42
Pressure of Gas Supplied	Datum	S	-	-	-	S
Holds Jet Steady		+	+	+	+	+
Velocity of Gas at Nozzle Exit		S	-	-	-	S
Adjustable Nozzle Height		S	S	S	S	S
Precision of Nozzle		+	+	+	+	S
Plus (+)		2	2	2	2	1
Satisfactory (S)		3	1	1	1	4
Minus (-)		0	2	2	2	0
		7	1	1	1	6

1.6.4 Analytical Hierarchy Process

The analytical hierarchy process consists of several different matrices resulting in a numerical rating of the designs. This process starts with the creation of a criteria comparison matrix (CCM), which compares the criteria against each other to determine the most important one. The criteria are ranked on a 1-3-5-7-9 scale based on how much more important the column criteria are compared to the row criteria. If the row was less important, then the inverse of the 1-3-5-7-9 scale was used. The resulting ranks were reflected across the diagonal of the matrix to fill out the rest of the matrix. All the rankings in the matrix were then summed vertically, for use in the normalized criteria comparison matrix (NCCM).

Development of Candidate Set of Criteria Weights {W}					
Criteria Comparison [C]					
	1	2	3	4	5
Pressure of Gas Supplied	1.00	0.20	1.00	0.20	0.33
Holds Jet Steady	5.00	1.00	9.00	1.00	1.00
Velocity of Gas at Nozzle Exit	1.00	0.11	1.00	0.33	0.20
Adjustable Nozzle Height	5.00	1.00	3.00	1.00	1.00
Precision of Nozzle	3.00	1.00	5.00	1.00	1.00
Sum	15.00	3.31	19.00	3.53	3.53

The NCCM uses the sum calculated in the CCM to normalize the ranking of each criterion, such that each column adds up to one. The sum of each row is then taken to determine the criteria weights. This process resulted in the highest weighted criteria being the need to keep the jet steady, and the lowest weighted criteria being the velocity of the gas at the nozzle exit.

Normalized Criteria Comparison Matrix [NormC]						
	1	2	3	4	5	Criteria Weights {W}
Pressure of Gas Supplied	0.067	0.060	0.053	0.057	0.094	0.066
Holds Jet Steady	0.333	0.302	0.474	0.283	0.283	0.335
Velocity of Gas at Nozzle Exit	0.067	0.034	0.053	0.094	0.057	0.061
Adjustable Nozzle Height	0.333	0.302	0.158	0.283	0.283	0.272
Precision of Nozzle	0.200	0.302	0.263	0.283	0.283	0.266
Sum	1	1	1	1	1	1

To ensure that biases were kept to a minimum, further checks were done. The weighted sum vector, computed by multiplying the CCM with the criteria weights vector, is divided elementwise by the criteria weights vector to obtain a consistency vector.

Weighted Sum Vector {Ws}=[C]{W}	Criteria Weights {W}	Consistency Vector {Cons}={Ws}./{W}
0.337	0.066	5.10
1.751	0.335	5.23
0.308	0.061	5.07
1.386	0.272	5.10
1.375	0.266	5.17

The average of the consistency vector, λ, is taken and used to calculate the consistency index (CI) using the equation $CI = \frac{\lambda - n}{n-1}$, where n is the number of elements. Using the CI, the consistency ratio (CR) is found using the equation $CR = \frac{CI}{RI}$, where RI is the random index value, determined from a table.

If CR < 0.1, the criteria selection and ranking process was unbiased. By going through this process, Team 518 found a CR = 0.029, allowing for the determination that the process was unbiased and valid.

Average Consistency	Consistency Index	Consistency Ratio
5.13	0.033	0.029

Each high-ranking alternative from the Pugh chart was then compared against each other based on their ability to fulfil the criteria in the AHP Design Alternatives matrices. This resulted in design alternative priorities, which were then multiplied by the criteria weight vector to give a final alternative value.

1.6.5 Final Selection

Concepts 51 and 42 were tied with alternative values of 0.403 while concept 15 had an alternative value of 0.195. These values were determined from the AHP design alternatives combined with the weights of each criterion. Because there is a tie, there must be some justification for the final selection.

Team 518 chose concept 51. Concepts 51 and 42 are similar in how they meet criteria but ultimately 51 has the edge because of its ability to take clear images of the results. Because a knife will separate the flow, and half the jet will impinge on the surface, the half crater's profile may be observed easily. This is not possible with any other concept, which rely on taking measurements from above and adds complexity in the analysis process. There are also few disadvantages in the construction and design of concept 51's experimental setup versus alternatives.