1.5 Concept Generation

1.5.1 Introduction

Concept generation involves using tools and activities to brainstorm and outline initial project ideas. Many methods can be used to generate ideas to help accomplish the key goals of the project, some of the tools include morphological charts, biomimicry, crapshoot, forced analogy, anti-problem, and battle of perspectives. Because of the three major systems of the project having many subsystems, this allows for many changes to be applied to each idea; by using these tools the team can visualize a large quantity of concepts which will allow for the selection of the best concept that achieves the key goals of the project.

1.5.2 Tools

Morphological Chart

The morphological chart provides different solutions to multiple design features. Team 518 identified 7 different systems with 5 solutions for each. These solutions were then varied among the systems to generate multiple concepts.

System	**Solutions**				
Nozzle Material	Steel	Aluminum	PLA	Titanium	Wood

Frame Material	Steel	Aluminum	Plexi-Glass	Titanium	Wood
Measurement System	Schlieren	PIV	Camera	Lidar	Hand Measurement
Pressure Gradient Production	Air Tank	Compressor	Compressed Air Can	Fan	Pump
Debris Reduction	Vacuum	Large Enclosure	Square Enclosure	Hemisphere Enclosure	No Enclosure
Data Analysis	Matlab	Python	RStudio	Excel	Hand Calculations
Type of Gas	Air	Heated gas	Nitrogen	Cold gas	Carbon Dioxide

Forced Analogy

Forced Analogy is a concept generation technique where a list of random nouns is generated. Attributes of these random nouns are then listed, and solutions are forced by incorporating those attributes into the concepts. These nouns were ideated with a similar relation to a flow or objects impacting on a surface.

Selected Words	**Attributes**				
Volcano Eruption	Hot	Slow	Erodes Materials	Leaves traces of Combusted materials	Destructive
Rain Drops	Wet	Small	Abundant	High-impact frequency	Soft impacts
Meteor	Fast	Intense Force	Wide Crater Formation	Creates Shocks When Impacting	Heavy
Water Jet	Sharp	Powerful	Pressurized	High flow rate	Long duration of Impact
Paint Splatter	Messy	Colorful	Viscous	Leaves surface texture	Consistent

Anti-Problem

Anti-problem allows for concepts to be generated based on what does not work. They allow the team to gain a deeper understanding of the issues that need to be addressed for a concept to function properly. To accomplish this, the team created concepts that drastically fail to achieve the desired techniques.

1.5.3 Medium Fidelity

The medium fidelity concepts are concepts that the team feels may be able to work, but have some drawbacks that make them less desirable when compared to some of the high fidelity concepts.

#	**Concept Description**
10	Steel nozzle, steel frame, PIV DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
15	Steel nozzle, steel frame, Schlieren based DAQ, a can of compressed air provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
30	Aluminum nozzle, aluminum frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
47	PLA nozzle, plexiglass frame, PIV based DAQ, a compressor provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
54	Construct the enclosure out of wood and baseboard. Set up the jet testing with interchangeable 3D printed nozzles. Track the measurements with stereophotography.

Concept 10 is considered medium fidelity since it provides a clear outcome of the experimental setup and describes all function aspects of it. Additionally, this concept provides tools that are at attainable availability for the team. Steel is a material that is feasible to be machined, an air tank and gas vacuum are easily attainable, and a PIV data acquisition system can be provided through several cameras, and MATLAB is a software the team is familiar with and could process data properly. However, the speed of the flow from an air tank will likely not achieve the desired speed to simulate the plume of the landing system, resulting in data with not most fidelity in comparison to more accurate models that simulate PSI.

Concept 15 is medium fidelity because it uses strong materials for the structure and nozzle, this will minimize any shifting of the apparatus and increase the accuracy of the data, by using a can of compressed air this allows for the experiment to be performed in different locations easily, using these cans would also reduce cost. Using a vacuum to contain the sand would be much more efficient and would ensure that any sand that is ejected from the crater does not affect the measurements or the data acquisition system. This concept also uses a Schlieren type DAQ which would provide an ease of use for our team as the experimental PI’s have experience with such systems. The data would be processed in MATLAB to create 3D modeling and any correlation factors most of the medium and high-fidelity concepts use MATLAB this contributes to the ease of use as all team members have experience with MATLAB. This concept didn’t make high fidelity because of the material used for the structure and nozzle, the team strategized that using steel would be less ideal than other materials, in addition using a vacuum would cause the design to be more complex and would waste the sand.

Concept 30 was deemed medium fidelity because of the use of aluminum being an easily machinable material and easy to get access to, in addition aluminum would provide a stronger base than many other materials that way the data acquisition is not affect by the structure falling apart. This concept uses an air tank to provide the gas which means that our experiment would be limited in time to how long it takes for the tank to reach equilibrium with the outside pressure, this was of the distinguishing factors that made it medium fidelity over high fidelity.

Concept 47 is a medium fidelity concept because it uses a PLA nozzle which can be easily produced by three-dimensional printing. It also uses a plexiglass frame which is strong but can be expensive. PIV is also advantageous because it is non-intrusive, and the measurements are simultaneous and accurate. Using a compressor to provide the gas is also convenient because they can easily be obtained but may have trouble producing supersonic flow at larger nozzle diameters. The use of a vacuum so clean ejected soil simulant also makes running the experiment efficient because of its speed and ease of use. MATLAB is also a helpful tool for data analysis.

Concept 54 is a medium fidelity concept due to its use of cheap materials that are easy to work with; by using wood for the structure our team could build the apparatus without having to outsource any of the work to a machine shop. This concept also allowed for the use of interchangeable nozzles, which is a requirement of the design. This concept used stereolithography to take raw data that would have to be processed by a program. It did not make it to high fidelity however due to the vague nature of how it would be constructed, for example it would be less than ideal that the entire structure be made of wood as this would be an imprecise way to build the apparatus.

1.5.4 High Fidelity

High fidelity concepts are the concepts that the team feels will perform the best, considering factors like cost, ease of use, quality of the data collected, and feasibility of construction.

#	**Concept Description**
42	PLA nozzle, aluminum frame, PIV based DAQ, a compressor provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.

43	PLA nozzle, wood frame, Lidar based DAQ, a compressor provides air, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
51	Use clear baffles with a knife edge to separate the flow from the jet. Take images of the half-crater formed at a fixed distance to obtain crater depth and width measurements. The rest of the data can be extrapolated in some software.

Concept 42 is a high fidelity concept because of its overall robustness and detailed data. The PIV allows for 3D data to be obtained, although it will require much more effort and code to successfully accomplish. The vacuum will also ensure maximum containment of the debris, but adds some complexity to the design. The PLA nozzle is the easiest but still accurate nozzle to manufacture and will allow for adjustments to be made for less cost than if they were machined. The data can be processed to produce 3D maps of the crater, but the data processing will take longer to set up.

Concept 43 is considered due to the ease of manufacture combined with the high-quality data that can be gathered. Lidar allows for accurate measurements of the crater, and the wood frame ensures that the frame is relatively easy to make while still being sturdy and fairly cheap. The 3D printed PLA nozzle is also easy to manufacture and can be done at FSU or in the AME building for a lesser cost than other options, while still providing supersonic flows. The vacuum also allows for debris to be mitigated easily, but will add complexity in ensuring that it continues to function as it collects the fine sand. Air is preferred as the jet gas, as it does not require additional tanks.

Concept 51 is high fidelity because it allows for data to be collected very easily with a single camera. The camera will need a relatively high frame rate to ensure the progression of the crater is tracked, but other than that it does not need to be special. The baffle with a knife edge will split the jet flow, which will cause some additional effects, but NASA has already run some tests using similar conditions and consider the effects to be minimal. These effects could also be studied by running a test with no baffles and measuring the final dimensions of the crater, to be compared to data from tests with baffles. Creating a 3D map of the collected data will require extrapolation, but 2D profiles can be generated with much more ease while still conveying information about the crater formation.

1.5.5 All Concepts

#	**Concept Description**
	Morphological Chart
1	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
2	Aluminum nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
3	PLA nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
4	Titanium nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
5	Wood nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
6	Steel nozzle, aluminum frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
7	Steel nozzle, plexiglass frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.

8	Steel nozzle, titanium frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
9	Steel nozzle, wood frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
10	Steel nozzle, steel frame, PIV DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
11	Steel nozzle, steel frame, camera based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
12	Steel nozzle, steel frame, Lidar based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
13	Steel nozzle, steel frame, hand measurement based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
14	Steel nozzle, steel frame, Schlieren based DAQ, compressor provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
15	Steel nozzle, steel frame, Schlieren based DAQ, a can of compressed air provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
16	Steel nozzle, steel frame, Schlieren based DAQ, a fan provides the moving gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
17	Steel nozzle, steel frame, Schlieren based DAQ, a pump provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
18	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a large enclosure ensures excess regolith does not affect results, Matlab is used to analyze the data, and air is the type of gas used.

19	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a spherical enclosure ensures excess regolith collects outside the crater, Matlab is used to analyze the data, and air is the type of gas used.
20	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a square enclosure ensures excess regolith collects in the corners, Matlab is used to analyze the data, and air is the type of gas used.
21	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, using no enclosure would allow the excess regolith to leave the testing are without effecting the crater formation, Matlab is used to analyze the data, and air is the type of gas used.
22	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Python is used to analyze the data, and air is the type of gas used.
23	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, RStudio is used to analyze the data, and air is the type of gas used.
24	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Excel is used to analyze the data, and air is the type of gas used.
25	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, hand calculations is used to analyze the data, and air is the type of gas used.
26	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and heated gas is the type of gas used.
27	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and nitrogen is the type of gas used.
28	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and cold gas is the type of gas used.

29	Steel nozzle, steel frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and carbon dioxide is the type of gas used.
30	Aluminum nozzle, aluminum frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
31	Aluminum nozzle, plexiglass frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
32	Aluminum nozzle, titanium frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
33	Aluminum nozzle, steel frame, PIV based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
34	Aluminum nozzle, steel frame, camera based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
35	Aluminum nozzle, steel frame, Lidar based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
36	Aluminum nozzle, steel frame, hand measurement based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
37	Aluminum nozzle, aluminum frame, Schlieren based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
38	Aluminum nozzle, aluminum frame, PIV based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
39	Aluminum nozzle, aluminum frame, Lidar based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.

40	Aluminum nozzle, aluminum frame, hand measurement based DAQ, air tank provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
41	PLA nozzle, aluminum frame, Schlieren based DAQ, a compressor provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
42	PLA nozzle, aluminum frame, PIV based DAQ, a compressor provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
43	PLA nozzle, wood frame, Lidar based DAQ, a compressor provides air, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
44	PLA nozzle, titanium frame, PIV based DAQ, a compressor provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
45	PLA nozzle, aluminum frame, Lidar based DAQ, a compressor provides gas, a vacuum removes excess regolith, Python is used to analyze the data, and air is the type of gas used.
46	PLA nozzle, aluminum frame, Schlieren based DAQ, a compressor provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and cooled gas is the type of gas used.
47	PLA nozzle, plexiglass frame, PIV based DAQ, a compressor provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
48	PLA nozzle, aluminum frame, Schlieren based DAQ, a can of compressed air provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
49	PLA nozzle, aluminum frame, PIV based DAQ, a can of compressed air provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.
50	PLA nozzle, aluminum frame, Lidar based DAQ, a can of compressed air provides gas, a vacuum removes excess regolith, Matlab is used to analyze the data, and air is the type of gas used.

	Brainstorming
51	Use clear baffles with a knife edge to separate the flow from the jet. Take images of the half-crater formed at a fixed distance to obtain crater depth and width measurements. The rest of the data can be extrapolated in some software.
52	Run the test in an enclosure isolated on every side but the top, with enough room for the sand to disperse. Measure the crater by hand and keep track of the results in excel.
53	Use dirt instead of fine sand to simulate regolith to increase simplicity. Generate the plume from a can of compressed air and construct the frame out of wood and cardboard where it can be for ease of construction. Take measurements by hand and record them in a notebook for the easiest option.
54	Construct the enclosure out of wood and baseboard. Set up the jet testing with interchangeable 3D printed nozzles. Track the measurements with stereophotography.
55	Construct the enclosure out of extruded aluminum, use a raw hose end to test nozzle dimensions.
56	Construct all experiment setup out of PLA, including nozzle and frame and have nozzle connected to compressed air.
57	Carve the entire experimental setup out of a block of marble.
58	Use a bagpipe to produce supersonic jet flow.
59	Use a hand-held pump to fill up a large balloon and release the air onto a sandbox.
60	Construct molds and form the nozzles and frame by pouring molten lava.
61	Use a tarp with a frame to create a tent. Then evacuate the tent and run the experiment inside the tent to mimic lunar conditions.
62	Use a household fan and place a funnel over it to create supersonic jet flow.
63	Use a hamster wheel with a very athletic hamster to power a compressor or fan for the pressure gradient production.
64	Give every team member a straw to blow into the nozzle to create a pressure gradient, an observer will hold the nozzle over the exposed sand bed and once the crater is formed the team will take hand measurements.

65	Make the entire structure out of toothpicks and popsicle sticks.
66	Use candles to heat up compressed air and release the air to mimic a hot jet.
67	Use concrete to create the entire structure and use a compressor to accelerate the air into the nozzle.
68	Attach the nozzle to woodwind instruments such as a clarinet or flute to produce a supersonic jet.
69	Use a football air pump to accelerate the gas into the nozzle.
70	Use several controlled explosions in a containment unit to produce a continuous jet.
71	Execute the experiment under water and use a water jet instead of air.
72	Contain the experiment within a vacuum chamber to simulate the conditions on the moon
73	Simulate the entire experiment in COMSOL and don't worry about the physical model
74	Create a large enough pressure gradient such that a nozzle is not needed, and a tube will be enough to produce a supersonic flow
75	Coat the walls of the enclosure in an adhesive material to catch any sand/debris
76	Bring the experimental set up to Colorado to reduce atmospheric pressure to better represent conditions on the moon
77	Use a potato cannon like design to create the pressure difference and get supersonic flows for a brief period of time.
78	Perform the experiment above a slope so ejected regolith will slide down and be collected in a trough.
	Anti-Problem
79	Make the walls of the enclosure out of solid wood so that nothing can be seen by the camera/sensors. Relevance: Visibility
80	Remove cage to let sand go everywhere and have the janitor clean everything up. Relevance: Containment

81	Take pictures at random locations of the crater and count the pixels to get the measurements to get the worst possible measurements. Relevance: Alignment and accuracy of sensors
82	Build the frame of the rig out of cardboard to decrease stability, accuracy, visibility, and increase vibrations throughout the frame. Relevance: Accuracy and reproducibility
83	Place the jet 100 feet away from the surface and measure the crater, to ensure there are no measurable effects. Relevance: Need to keep jet close to the surface to be able to measure the effects
84	Have the jet pressure gradient be created by the atmosphere so that the jet has no velocity. Relevance: Need the jet to have supersonic velocity for data collection, which a significant pressure gradient is required for
85	Build the entire setup for the experiment but don't put the sand in the containment so there is nothing to measure. Relevance: No data can be recorded if there is no sand.
86	Build the structure without full enclosure and perform the experiment outside during a hurricane so that the sand gets soaked in water and the jet stream of air is interrupted by wind. Relevance: There is no atmosphere on the moon, therefore having atmospheric effects will ruin the experiment.
87	Build the structure upside down so that all sand falls into the nozzle and compressor. Relevance: The nozzle won't be able to achieve supersonic velocity if there are blockages.
	Forced Analogy
88	Create a nozzle able to shoot hot and high-speed flow to leave traces of a crater formed by erosion of regolith.
89	Create a nozzle able to shoot hot and high-speed flow to leave traces of a crater formed by heating and combusting regolith.
90	High Pressurized nozzle with long duration of flow impacting on the surface.
91	Intense Flow with high mass flow rate able to create a wide crater.
92	Measure Crater formation by observing how the texture of the regolith tested changed.
93	Use flow with different levels of viscosity affects crater formation.

94	Simulate repeated impacts of the flow against the surface to create a crater.
95	Analyze how surface moisture affect crater formation when impacted by flow from the plume.
96	Comparing how crater forms with continuous vs pulsed plume impacts
97	Generate a flow that can impact the surface with shockwaves and thus creating a crater.
98	Measure how clustering in particles affect crater formation when impacted by the flow.
99	Measure crater formation with a computational fluid dynamic simulator, with its colors showing different temperature variations of the crater.
100	Test nozzle with different flow temperatures and analyzing the different form of craters with different flows.