Team 518: NASA MSFC - Powder Removal in Microgravity Environments Experiment

Evidence Manual

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Project Scope

Project Description

The objective of this project is to develop a proof of concept for removing powder residue in microgravity environments from parts made with selective laser melting/sintering or direct energy deposition.

Key Goals

1. The design will be able to clean internal features of the parts.
2. The design will be able to clean multiple parts without requiring maintenance or cleaning.
3. The design will be functional in low gravity conditions.
4. The design will not require continuous user attention while it is cleaning the part.
5. A physical prototype will be produced.

Market

1. The primary market is the aerospace industry because the goal of this project is to clean metal additive manufacturing parts in little to no gravity. Notable companies and organizations include NASA, Blue Origin, Relativity, JPL, and SpaceX.
2. Another primary market is the manufacturing industry. As additive manufacturing (AM) is becoming more and more popular, creating a process to streamline AM parts is beneficial to the industry.
3. A secondary market is the construction industry. Printing complex geometry parts using metal can create new diverse buildings. Cleaning these parts is essential in creating consistent clean parts. Companies such as Whiting-Turner, and Ajax Building Corporation will be the beneficiaries of this technology.

4. Another secondary market is education. Additive manufacturing curriculums would benefit from the ability to clean metal printed parts. Organizations that will benefit are public and private schools, and educational organizations.

Assumptions

1. The design operates in an environment around 1 atm of pressure.
2. The design has access to a 120V, 15A outlet.
3. The part is under 6 x 6 x 6 inches.
4. The part does not have supports.

Stakeholders

1. Our primary stakeholder is NASA because NASA is the project sponsor and main customer.
2. The senior design teaching staff are stakeholders because of their advisory role for the team.
3. Our academic advisor would also act as a stakeholder because they will provide guidance and contribute advice towards our project.

Customer Needs

To determine the customer needs team 518 generated a list of questions and interviewed the project sponsor, Justin McElderry. Mr. McElderry was selected for the interview because his role as an engineer at NASA makes him an employee of a primary market, and he is a stakeholder in the project.

The team determined the questions for the interview based on the information the team felt was missing from the project brief and from questions that arose while conducting background research.

The questions, a summary of the sponsor response, and the interpreted need are shown in table (1).

Table 1: Sponsor interview questions, responses, and interpreted needs

Question	Summarized Sponsor Response	Interpreted Customer Need
Is there a maximum size for the design?	Because this is a prototype, we are not very concerned with the size. A good goal would be to fit in a glovebox, so about 2.5ft x 2.5ft x 2ft	The design will fit in a glovebox.
What are some of the limitations of the current design?	The current design uses a vacuum pump. 1. The pump requires lots of equipment 2. The pump requires a functioning vacuum chamber 3. The pump requires a sealant 4. The cyclic vacuum can wear seals quickly 5. The dirty solvent is challenging to collect and remove 6. The valves do not hold a vacuum well	The design will be able to capture dirty solvent. It will be easy for the user to remove the dirty solvent from the design.
Do you want the powder to be recycled from the solvent and reused?	Recycling solvent is outside of the scope of the project. The dirty solvent needs to be captured and disposed of.	The design will be able to capture dirty solvent. It will be easy for the user to remove the dirty solvent from the design.
Are there mass constraints for the design?	25lbs for the ground prototype.	The design will be light.

Question	Summarized Sponsor Response	Interpreted Customer Need
Is there a limited amount of solvent or water available?	This project is for research and design, so the solvent limit is not incredibly strict. Over a gallon of solvent per part would be excessive.	The design will use little solvent
What aspects of the current design do you like?	The current design has a window on the vacuum chamber where you can watch the part being cleaned. The current design has a nice user interface.	The user will be able to see the part while the design is cleaning it. It will be easy for the user to operate the design. The user will not require any training to operate the design.
What materials are the parts to be cleaned made of?	Aluminum, copper, possibly iron, Inconel, and titanium.	The design will be able to clean aluminum, copper, iron, Inconel, and titanium parts.
What power specifications will the design have access to?	A standard outlet. Lower Amperage is beneficial.	The design will work with a 120V 15A outlet.
How quickly should the design be able to clean parts.	Because this is a research and design project, there is no manufacturing quota. Around 20 minutes per part would be nice.	The design will be able to clean one part in under 20 minutes.
How large are the parts that must be cleaned?	The parts are about 6in x 6in x 6in	The design will be able to clean parts that are 6in x 6in x 6in and smaller.

Explanation of Results

The team also interpreted several customer needs from the project brief. The customer needs from the project brief are listed below:

1. The design will work in microgravity.
2. The design will be able to clean small internal features of the parts

The interpreted needs from the interview process are useful for determining the design's functions and identifying the project's scope further. Based on the customer statements, the design will clean parts of various metal compositions in microgravity environments. The design will be easy to use and fit in a glovebox with standard US outlets.

Functional Decomposition

The objective of the functional decomposition is to list what the final design must do. The functions that the design must accomplish are determined from the customer needs and are organized into subsystems.

Figure 1 shows the functional decomposition tree for the design. The higher a function is in the image, the higher the function is in the hierarchy.

Figure 1: Functional Decomposition Tree

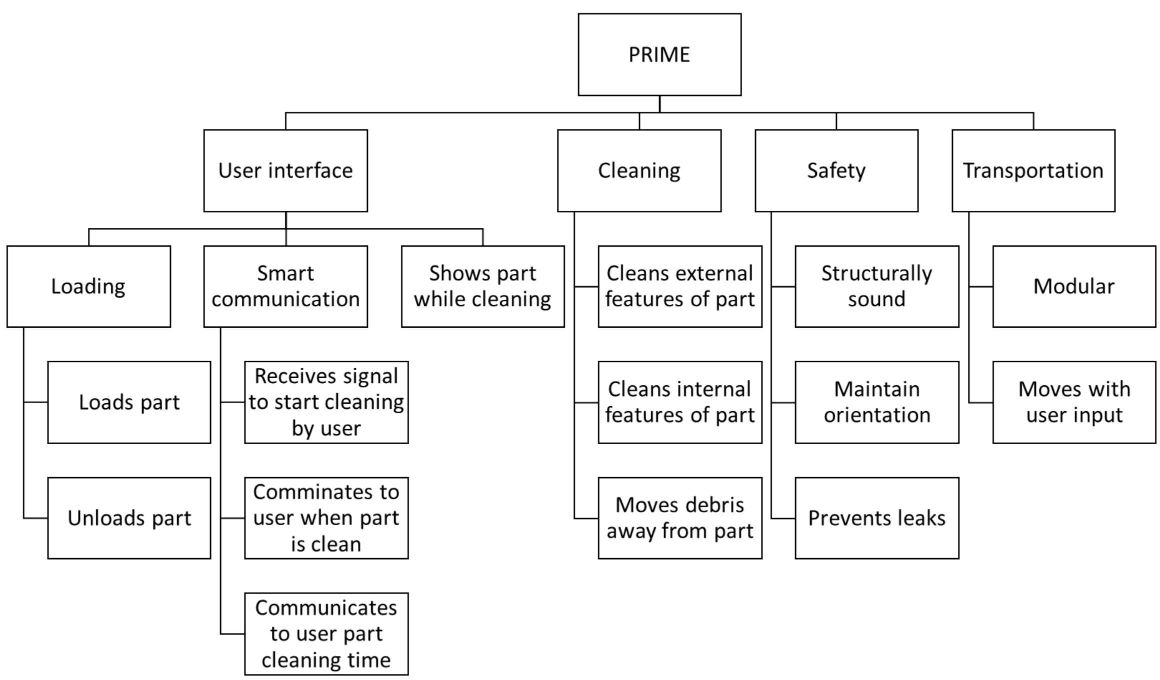


Table 2 is the cross-reference table for the functional decomposition. In the table, each row represents a minor function of the design, and each column represents a major function. Each cell in the table can have a value of “0” or “1.” A one indicates the minor function is relevant to the major function, and a 0 indicates no relevance. At the bottom of the table the totals for each major function of the design are taken to determine the importance of each major function.

Table 2: Functional decomposition cross-reference chart

Function	User Interface	Cleaning	Safety	Transportation
Load parts	1	1	0	0
Unload parts	1	1	0	0
Receives signal to start cleaning from user	1	1	0	0
Communicates to user when cleaning is complete	1	1	0	0
Communicates with user to know how long to clean part	1	1	0	0
Times duration of part being cleaned	1	1	0	0
Cleans external features of part	0	1	0	0
Cleans internal features of part	0	1	0	0
Moves debris away from part	0	1	1	1
Contain debris	0	1	1	0
Structurally sound	0	0	1	1
Prevents leaks	0	1	1	0
Modular	0	0	0	1
Moves with user input	1	0	0	1
Totals:	7	11	5	4

Explanation of Results

The PRIME project is broken down into 4 major functions. The design must be clean the parts, interface with the user, be safe, and be portable. The cleaning function is the main goal of the project, and thus has the most minor functions. Cleaning involves loading and unloading the part to be cleaned, as well as the actual removing of residue and debris from the part. The debris must then be moved away from the part and contained.

User interface is also a major function of the design. User interface handles how the user will load parts into the design, but also how the design will let the user know when parts are clean. User interface must also be able to communicate with the user to know how long to clean the parts for. There is overlap between minor functions in the user interface and cleaning major function categories. This is because the information from the user is necessary for cleaning, and the user must load the part to be cleaned.

Safety is also a major function of the design. The design will be able to contain debris from cleaning. This is a cleaning function, but also serves as a safety function because airborne debris is dangerous. Other minor functions like being structurally sound also contribute to the safety function.

Finally, transportation is a major function of the design. Because the aims to function in microgravity environments like the International Space Station, the design must be made with transportation to these environments in mind. For this reason, modularity, and the ability to be moved by the user are needed.

Connection To Systems

The use of ones and zeros indicate which part of the system corresponds with its respective function. When developing the machine, these functions must work with their respective parts. The cleaning function correlates with “receiving the signal” and “communication to the user” because it is an input to the response. In other words, these processes are necessary for outputting a clean specimen.

Smart Integration

The completion of one function corresponds to its proceeding to the next. Table 2 shows the functions going in sequential order. The user interface and cleaning function correspond to one another because it is important for the user to have direct involvement with completing the clean part. These two functions have the most in common with one another for that reason. Safety also connects with the cleaning process because the structural integrity of the part must remain intact for the cleaning process to continue. If the system cannot guarantee safety to the user, it cannot run.

Action And Outcome

The action of the project is to successfully clean additive manufactured parts in microgravity components. The outcome of this success is a safer environment with less risk of combustion and healthier air.

Function Resolution

The product needs to safely clean additive manufactured parts and notify the user when finished.

Targets and Metrics

Metrics are the measurements taken to evaluate the design. Targets are the numbers the design hopes to score in each metric. Targets and metrics are important because they allow engineers to compare different concepts before selecting one based on how well each concept will satisfy the targets. Targets and metrics also allow engineers to evaluate their final design. If the design meets the targets, it is a successful design. From each function given in functional decomposition, at least one target/metric is assigned as shown in Table 3.

Table 3: Targets and Metrics

	Function	Metric	Target	Improvement Direction
1.	Load parts	Time to load a part	45 seconds	Decrease
2.	Unload parts	Time to unload a part	45 seconds	Decrease
3.	Receives signal to start cleaning from user	Number of inputs needed from user to start cleaning	2 inputs	Decrease
4.	Communicates when cleaning is complete	Number of methods for communicating with user	4 outputs	Increase
5.	Communicates with user to know how long to clean each part	Cleaning times	15-20 minutes for every part	Decrease
6.	Times duration of part cleaning	Difference between user selected clean time and measured clean time	Within 5% of user selected time	Decrease
7.	Cleans external features	Volume percent of debris collected	Collect 85-90% of debris	Increase
8.	Cleans internal features			
9.	Move debris away from part			
10.	Contain debris			Decrease

	Function	Metric	Target	Improvement Direction
11.	Prevent leaks	Pressure changes after 1 hour at a test pressure	Within 5% of test pressure	
12.	Structurally sound			
13.	Moves with user input	Ground mass	20 - 25 lb.	Decrease
14.	Functions independent of direction of acceleration due to gravity	Number of orientations where volume of dirt collected in solvent metric is also met	6 orientations	Increase
15.	Be modular	Volume of modules	Less than 8x8x8inches	Decrease
16.		Voltage Usage	120V	Decrease
17.		Number of loose cables	0 Cables	Decrease
18.		Current Usage	15A	Decrease
19.		Fit within Fume hood	4 by 3 ft	decrease

Critical Targets/Metrics

The critical targets and metrics are those most directly connected to the project's main objective, to clean powder in additive manufactured parts in various orientations. This means that the critical metrics are 7, 10, and 14 (“Volume of dirt collected”, “Pressure change after one hour at a test pressure,” and “Number of orientations the device satisfies the volume of dirt collected target.”)

The target for metric 14 (Number of orientations) was chosen to be 6 because the device should be tested in enough orientations so that each face is the lowest face on the design in at least one orientation. For a final design of rectangular shape there will be six faces, so the design must be tested in six orientations. If the device functions in many orientations, then its functionality is independent of the direction of the acceleration due to gravity, so the device should work in microgravity. No additional equipment is needed for this target.

The metric for needs 10, 11, and 12 is the change in pressure in the system after one hour. By pressurizing the design to a test pressure, waiting one hour, then measuring the final pressure, the change in pressure can be measured. If there is a change in pressure, this indicates a leak. A leaking device is not able to satisfy the functions “Contain debris”, “Prevent leaks”, or “Structurally sound” separately. To measure the design’s performance in this metric, a barometer and a timer are needed.

The metric for functions 7, 8, 9 is the volume percent of debris collected. Because the geometry of the part to be cleaned is known, it is possible to calculate the volume of debris entering the system with the part. After cleaning is completed, the volume of debris collected is measured and divided by the initial amount of debris. The volume percent of debris was chosen of mass percent because in a microgravity environment it may not be possible to record the mass. To record the volume, a graduated cylinder is needed. Additionally, if given the opportunity to measure in a microgravity environment, a centrifuge will be needed to septate the debris and the medium. If measuring in a gravitational environment, the gravity and different densities of debris and medium will cause separation, so no centrifuge is needed.

Method of Validation and Discussion Measurement

Targets and metrics for function 1 will be validated with a time trial. Each one of the project engineers will load and unload a part into the device. The central tendency of the recorded times will be used. A stopwatch will be used to document the times.

To validate the targets and metrics for functions 3 and 4, the number of inputs and outputs will be counted. Documenting the measurements in a book will be used to determine.

To validate the target and metric for function 5, a timer will be used to record the time it takes the design to collect 85-90% of the debris. Once 85-90% of the debris is collected, the part is considered clean. This time will be recorded and compared to the target. A stopwatch will be used to validate this target.

For function 6, the metric is the difference in time between the selected cleaning time and the time the device takes to clean the part. To validate this, the user selects a cleaning time, and the time the design cleans for is measured. The difference in these times is recorded and compared to the target.

For function 13, the metric is the weight. The final design will be weighed and compared to the target to validate. The device will be put on a scale and the total weight will be documented. A scale will be used.

To validate function 15, the volume of each module will be calculated. The volume should satisfy the target. The length of each module along each principal direction will also be recorded and the lengths should not exceed the target. The measurement device used will be the CAD file. The lengths will be checked to make sure it is within the target amount.

Targets and metrics 16 and 18 have no associated functions. The voltage will be measured, and amperage will be measured and compared to the target to validate these. A multimeter will be used to determine the voltage and current the device is producing. To determine the target, the voltage and current will be measured during idle and working conditions.

Target 17 will be validated by counting the number of loose wires and comparing them to the target. Visually counting the number of loose cables and documented in a notebook will be the measuring method.

Finally target 18 will be validated to account for the powder cleanup. To clean up the powder a fume hood is needed for safety reasons. Target 18 will be measured by ruler and the CAD file to determine dimensions.

Derivation of Targets/Metrics

Each target was created individually for their metric, which is taken from their function, with various methods of experimentation and research. The following targets are those beyond the critical targets and metrics. Targets 1 and 2 were generated by a small group experiment of timing how long it would take each member to open a watertight storage box, place something inside, and close the storage box. This replicated the amount of time it takes to load a part into the device. The average time for each member to complete this task was 45 seconds. This function should be as seamless as possible, so this target would improve by decreasing that time. Similarly, to improve function 3 the target should decrease because this function reflects the number of inputs needed to start the cleaning process. The target for function 3 is 1 input because this would make the user interface simple. One way to improve this target is to have the cleaning process automatically start once the part is loaded into the device.

Function 4 requires an alert system to notify the user when the cleaning process is complete. The target selected for this function is two methods of communication: a sound alarm and a light to replicate a siren. To improve this target, additional methods of communication would be required. Target 5 was created under the influence of the sponsor's requests. Justin McElderry, the NASA sponsor, gave a range of 15-20 minutes per cleaning cycle. This target could be improved by decreasing the time needed to complete a cleaning cycle. A key factor to consider is that one cycle may not be enough to fully clean a part. To address this, target 6 states that each part will be completely cleaned after two cycles. This target was selected because the team is aware that each part will have different amounts of dirt/debris due to their varied sizes and materials. While the goal is to clean in one cycle, this function serves to accommodate parts that may need two cycles.

Function 13 determines the mass limit for the device. McElderry requested that the design be below 25lb with a 10% range of error. Based on the calculation of an aluminum box similar in size to the expected design, a reasonable range for the design's mass is 20-25lb. The final function that goes beyond the critical metrics is function 15, which was also determined by McElderry. This function suggests a size limit for each module, McElderry requests that each module does not exceed the size of the part that holds pressure which leads to a target of less than 8x8x8 inches.

Targets and Metrics Go Beyond Functions

The targets and metrics in blue in table 2 are important to the project, but do not come from a function of the design. These targets have been given based off ISS standards.

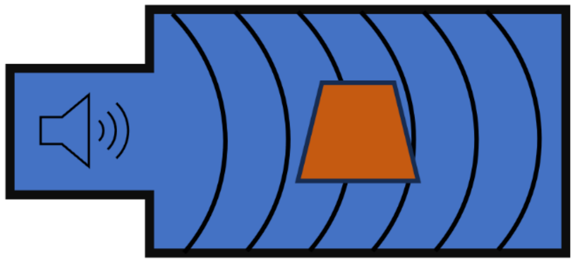
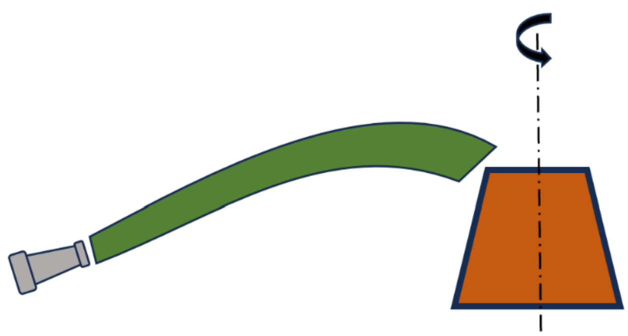
Concept Generation

Concept generation is important because outside the box thinking during concept generation sets the design team up for future success. To encourage outside the box thinking, team 518 generated 100 concepts using various concept generation techniques before conducting detailed design or evaluation of any concept. One final concept will be selected using various comparison techniques.

The concept generation techniques used include biomimicry, forced analogy, and anti-problem.

From the generated concepts, 3 high fidelity and 5 medium fidelity concepts were chosen. The high and medium fidelity concepts are concepts that the group selected based on feasibility. The feasibility was determined from prior knowledge of the team and research papers and existing technology in the field.

Table 4: High Fidelity Concepts

1. Sonic Wave Cleaning	This concept submerges the part in a fluid medium. An ultrasound speaker is then used to agitate the cleaning medium. The fluid motion caused by the ultrasound speaker cleans the part. Ultrasonic cleaning technology is already commonly used to sterilize medical equipment, clean automotive parts, and clean jewelry. 
2. Liquid Nitrogen Spray	This concept sprays the part with liquid nitrogen to clean it. The momentum of the liquid nitrogen is responsible for the cleaning. Liquid nitrogen is used because it is a low-density cleaning medium. In this design the jet source is fixed and the part is moved. This technology has been tested during a NASA Big Idea challenge to clean regolith from space suits. This is an impressive application because regolith is a smaller particle size than the SLM particles in PRIME. 
3. Pulsing Vacuum Nucleation	This idea submerges the part in a cleaning medium. A vacuum is then pulsed to cause bulk fluid motion which cleans the part. This technique is particularly strong because the cavitation bubbles from pulsing the vacuum disrupt the boundary layer, which enhances the bulk fluid motion near the parts surface, improving cleaning.

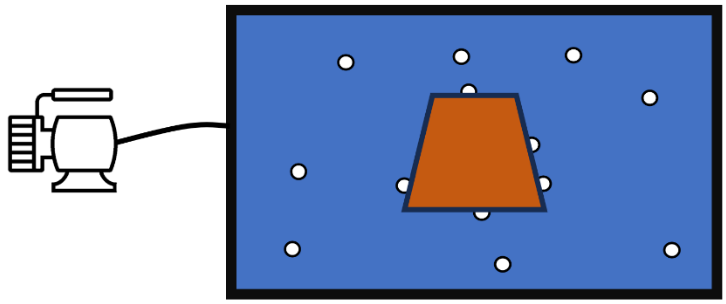
	This technology has already been prototyped by NASA, if selected, the team will aim to improve the technology. 

Table 5: Medium Fidelity Concepts

1. Vacuum Cleaner	This design uses a vacuum to clean the part. The part is not submerged in a medium. Vacuum is delivered to the part via a hose and nozzle and the targeted vacuum is responsible for cleaning.
2. Cleaning Fluid Medium Shaker	This design submerges the part in a fluid medium. The container holding the fluid medium, and part is then violently shaken. The shaking causes bulk fluid motion relative to the part. The bulk fluid motion cleans the part.
3. Dishwasher	This design cleans the part using a fluid medium jet. In this design the nozzle delivers the jet moves. The momentum of the fluid in the jet colliding with the part is responsible for cleaning.
4. Rotating Part	This design spins the part to be cleaned at high speeds. At high speeds, the debris' inertia is large, and the forces responsible for adhering the debris to the part are no longer able to do so.
5. Boiling Cleaning Medium	Cyclic vacuum nucleation is an effective technique because the bubbles formed at the parts surface when the vacuum is pulsed disrupt the boundary layer, causing bulk fluid motion at the surface of the part cleaning it. This Idea causes bubbles to form at the parts surface, but by boiling the cleaning medium rather than pulsing a vacuum.

Concept Selection

Concept selection uses a house of quality, Pugh chart, and analytical hierarchy process to objectively select a final design. Each of the following charts and their results are discussed below.

Binary Pairwise Comparison

To determine what customer requirements given to the team were most important to the project, the team compared each given requirement against every other requirement in a binary fashion. This is shown in Table 1. The team compared the requirements listed in the first column of each row against the rest of the requirements in the remaining columns of that row. If the requirement in the first column was more important than its comparison, a "1" was given in the column of the comparison. If it was not as important, a "0" was given. This was done for every row. When comparing a requirement against itself, no comparison could be made. Because of this, a "-" was given everywhere that occurred.

Table 6: Binary Pairwise Chart

Binary Pairwise Comparison											
Customer Needs	1	2	3	4	5	6	7	8	9	10	Total
1. Size Constraint	-	1	1	0	1	1	1	1	0	1	7
2. Removes solvent	0	-	0	0	0	1	1	1	0	1	4
3. Self containment	0	1	-	0	1	1	1	1	1	1	7
4. Ground Mass	1	1	1	-	1	1	1	1	1	1	9
5. Limited amount of cleaning solution	0	1	0	0	-	1	1	1	1	1	6
6. Reusable design from current protype	0	0	0	0	0	-	1	1	0	0	2
7. Cleans different materials	0	0	0	0	0	0	-	1	0	1	2
8. Universal power consumption	0	0	0	0	0	0	0	-	0	1	1
9. Cleans quickly and efficiently	1	1	0	0	0	1	1	1	-	1	6
10. Different size of parts	0	0	0	0	0	1	0	0	0	-	1
Total:	2	5	2	0	3	7	7	8	3	8	n-1=9

House of Quality

The objective of the house of quality is to connect the customer needs to the engineering characteristics.

House of quality first uses a binary pairwise comparison to compare the customer needs. By doing so, the most important customer needs are identified.

Using the house of quality, it is possible to tell which engineering characteristics are the most important because they satisfy the most customer needs. House of quality also considers the importance of each customer need. The results of house of quality are shown below in table 6. Based on the binary pairwise comparison, ground mass, size constraint, and containment are some of the most important customer needs. The importance weight factor of each customer need is then used in the house of quality to determine the most important engineering characteristics. The house of quality indicates the most important engineering characteristics are size of design, volume of debris collected, cleaning time, and ground mass.

Table 7: House of Quality

		Engineering Characteristics								
Improvement Direction		=	↓	↓	↑	↓	↑	↓	↓	↓
Units		sec.	m	#	#	min	mm^3	N	V	A
Customer Requirements	Importance Weight Factor	Time to load and unload part	Size of design	Inputs needed to start cleaning process	Outputs for communication to user	Cleaning time	Volume of debris collected	Ground mass	Voltage Usage	Current Usage
1. Size Constraint	7	0	9	0	0	0	1	3	1	1
2. Removes solvent	4	0	0	3	3	9	3	0	0	0
3. Self containment	7	0	3	0	0	1	9	1	0	0
4. Ground Mass	9	1	9	0	0	0	0	3	0	0
5. Limited amount of cleaning solution	6	0	3	0	0	1	1	3	0	0
6. Reusable design from current protype	2	3	1	0	0	0	0	1	3	3
7. Cleans different materials	2	0	1	0	0	1	1	0	0	0
8. Universal power consumption	1	0	1	3	1	3	0	0	9	3
9. Cleans quickly and efficiently	6	1	0	0	0	9	3	0	1	1
10. Different size of parts	1	3	3	0	0	1	3	1	0	0
Raw Score	589	24	191	15	13	109	111	76	28	22
Relative Weight %	100.00%	4.07%	32.43%	2.55%	2.21%	18.51%	18.85%	12.90%	4.75%	3.74%
Rank Order		6	1	8	9	3	2	4	5	7

Pugh Chart

The Pugh chart is conducted to compare designs based on how well they fulfill engineering requirements. The Pugh chart is a relative comparison technique to compare concepts and determine if they are better than, worse than, or equal to an assigned datum concept. The goal of the Pugh chart is to reduce the number of concepts before analytical hierarchy process and final selection.

First, a datum is chosen based off currently available technology. Comparing to a market datum ensures that the designs selected are an improvement over the currently available technology and fulfill the engineering requirements. The first datum used is a compressed air blower. After comparing to the market datum, a Pugh chart is used to compare to a datum selected from the design concepts.

Table 8: Pugh Chart Against Industry Datum

Engineering Characteristics	Datum	Concepts							
		Sonic Wave Vibrational Cleaning	Liquid Nitrogen Spray	Pulsing Vacuum Nucleation	Dishwasher	Momentum Shaker	Shop-Vac Hose	Spinning Plate	Boiling Water
1 - Size of Design	Compressed Air Blower	+	+	+	+	S	S	+	S
2 - Volume of debris collected		+	S	S	-	-	+	-	-
3 - Cleaning Time		-	+	S	S	-	+	-	+
4 - Total Mass		+	+	+	-	S	-	-	-
Number of Pluses (+)		3	3	2	1	0	2	1	1
Number of Satisfactory (S)		0	1	2	1	2	1	0	1
Number of Minuses (-)		1	0	0	2	2	1	3	2

The first Pugh chart concluded that the dishwasher concept is the most similar to the market datum because it has an unexceptional number of plusses, minuses, and satisfactories. For this reason, the dishwater is chosen as the new datum for the second Pugh chart, and the remaining concepts were compared using the same criteria and functions.

Table 9: Pugh Chart Against Average Performing Concept

Function	Datum	Concepts			
		Sonic Wave Vibrational Cleaning	Liquid Nitrogen Spray	Pulsing Vacuum Nucleation	Shop-Vac Hose
1- Size of Design	Dishwasher	+	S	+	-
2- Volume of debris collected		S	+	S	+
3- Cleaning Time		+	+	S	+
4- Total Mass		S	S	S	-
Number of Pluses (+)		2	2	1	2
Number of Satisfactory (S)		2	2	3	0
Number of Minuses (-)		0	0	0	2

The Pugh chart process concluded the top two concepts are the sonic wave vibrational cleaning concept and the liquid nitrogen spray. These two concepts have equal ratings of effectiveness for the engineering characteristics shown. The highest rated concepts in the Pugh chart will be evaluated using an analytical hierarchy process to make a final selection. The selected design will be evaluated for possible improvements.

Analytical Hierarchy Process

The analytical hierarchy process is a pairwise comparison process. AHP is valuable to concept selection because it can be used to check for bias. AHP is used to evaluate which engineering characteristics are the most important, and then evaluate which designs satisfy the engineering characteristics the best.

Table 10: Engineering Characteristics Comparison Chart

Engineering Characteristic Comparison Chart				
	1	2	3	4
1- Size of Design	1	0.333	0.2	1
2- Volume of debris collected	3	1	1	3
3- Cleaning Time	5	1	1	1
4- Ground Mass	1	0.333	1	1
SUM	**10**	**2.666**	**3.2**	**6**

Table 11: Normal Criteria Comparison Matrix

Normalized Criteria Comparison Matrix[NORMC]					
	1	2	3	4	Criteria Weight
1- Size of Design	0.1000	0.1249	0.0625	0.1667	0.1135
2- Volume of debris collected	0.3000	0.3751	0.3125	0.5000	0.3719
3- Cleaning Time	0.5000	0.3751	0.3125	0.1667	0.3386
4- Ground Mass	0.1000	0.1249	0.3125	0.1667	0.1760
SUM	**1**	**1**	**1**	**1**	**1**

Table 12: Bias Comparison Chart

Ws	W	Cons	Lambda	CI	CR
0.4811	0.1135	4.2380	4.2627	0.0876	**0.0984**
1.5791	0.3719	4.2460			
1.4541	0.3386	4.2948			
0.7519	0.1760	4.2720			

Table 11 is a normalized version of Table 10. This is done by taking each cell's value in Table 10 and dividing it by the column total. This is repeated for every cell until all of them are normalized. Each row is averaged together to receive a criteria weight. This step will determine if one of the functions is biased.

Table 13: Size of Design Comparison

[C] Size of design Compairison				
Concepts	Sonic Wave Vibrational Cleaning	Liquid Nitrogen Spray	Pulsing Vacuum Nucleation	Average
Sonic Wave Vibrational Cleaning	1	0.333	0.142	0.4917
Liquid Nitrogen Spray	3	1	1	1.6667
Pulsing Vacuum Nucleation	7	1	1	3.0000
SUM	11.0000	2.3330	2.1420	5.1583
Average	3.6667	0.7777	0.7140	

Table 14: Normalized Cleaning Time Comparison

[normC] Normalized Cleaning Time Compairison				
Concepts	Sonic Wave Vibrational Cleaning	Liquid Nitrogen Spray	Pulsing Vacuum Nucleation	PI
Sonic Wave Vibrational Cleaning	0.0909	0.1427	0.0663	0.1000
Liquid Nitrogen Spray	0.2727	0.4286	0.4669	0.3894
Pulsing Vacuum Nucleation	0.6364	0.4286	0.4669	0.5106
SUM	1	1	1	1

Final Selection

The final selection is the high-fidelity concept sonic wave cleaning. This concept will submerge the part in a cleaning medium and use an ultrasonic speaker to cause bulk fluid motion. The bulk fluid motion of the cleaning medium will clean the part. An illustration of sonic wave cleaning can be seen in table 4.

Table 15: Final Rating Matrix

Final Rating Matrix			
Selection Criteria	Sonic Wave Vibrational Cleaning	Liquid Nitrogen Sprayer	Pulsing Vacuume Nucleation
Size of Design	0.1000	0.3894	0.5106
Cleaning Time	0.6334	0.2604	0.1061
Ground Mass	0.6436	0.2828	0.0736
Volume of debris collected	0.5094	0.4205	0.0701

Table 16: Final Selection

Final Selection	
Concept	Alternative Value
Sonic Wave Vibrational Cleaning	0.532668056
Liquid Nitrogen Sprayer	0.333223494
Pulsing Vacuume Nucleation	0.13410845

Appendix

Code of Conduct

Mission Statement

The goal of the group is to fulfill the project scope to the best of our ability.

Outside obligations

Missing meetings due to outside obligations is expected. To keep the group organized and able to maintain their time commitments the following policy will be used. The group will strive to have at least 5 of 6 members present at each group meeting. Once a group member agrees to a meeting time, it is expected that they will keep that time available for the meeting. If a group member has a scheduling conflict before the meeting time agreement, their absence is excused. Scheduling conflicts arranged after the agreement of a meeting time but before the meeting are not excused absences.

Team Roles

The following table shows the roles agreed upon for each team member. These roles may be reassigned and/or altered as deemed necessary. Additional roles may be assigned throughout the project. Any alterations to team roles will be discussed with the entire team.

Team Role	**Team Member**
Project & Test Engineer, Point of Contact	Alexander Fryer
Software & Design Engineer	Cole Daly
Systems Engineer	Lauren McNealy
Thermal & Fluids Engineer	Kyle Evans
Manufacturing & Design Engineer	Tripp Lappalainen
Quality & Design Engineer	Chelsea Kiselewski

Communication

Teams will be used for internal communication amongst the team and Outlook will be used for external communication with the sponsors and Dr. McConomy. Meetings must be given at least

12 hours' notice. If the meeting is longer than 15 minutes, they must be given at least 24 hours' notice. Lack of response in the group chat, with a 24-hour grace period, will be addressed by the other teammates before or after class time. If there is no improvement with the lack of communication after three confrontations, the Senior Design teaching staff will be asked to get involved.

Dress code

Business Professional (for design reviews) business casual for sponsor meetings. Professional for engineering design day. FSU/FAMU dress code for internal group meetings or class times.

Attendance Policy

2 unexcused absences will be allowed for group meetings. These cannot be used back-to-back. After 2 offences a warning and after 3 notify Dr. McConomy. The meeting dates and attendance will be recorded on the team's calendar.

How to notify group

Microsoft Teams chat, calls, and general posts will be used for communication amongst the team.

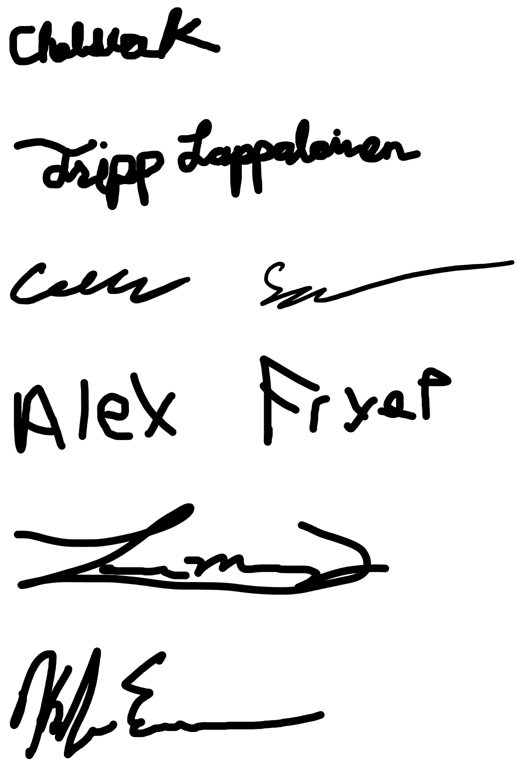
How to respond to people in professional meetings

For professional meetings formal language will be used, business casual will be worn, and all members must take meeting minutes. When communicating via Outlook, all members must be cc'd to any emails regarding the project.

Statement of Understanding

I understand and comply with this Code of Conduct as a member of Senior Design group 518.

Signatures:



What do we do before contacting Teaching Staff

The group members will be alerted a maximum of 3 times of their failure to meet group expectations. If the problem persists, the group will involve the EDM teaching staff.

When to Contact Teaching Staff with an Issue

Dr. McConomy will be contacted if the problem cannot be resolved by our peers, the TAs, and/or communicating with the sponsor.

Teaching Staff Intervention

The group will provide Dr. McConomy with the communications that occurred within the group and expect Dr. McConomy to hold a personal meeting with the team member that is causing issues.

How to Amend

If an amendment is proposed the team will hold a vote. The majority must vote for said amendment for the change to be made. If any team member feels personally targeted by the amendment, that team member should inform Dr. McConomy.

Concept Number	Concept	Concept Generation Method Used
1.	Have a snake (pipe cleaner) move through the internal cavities to brush off the powder	Biomimicry
2	An elephant like trunk pushes fluid at a high pressure at the part	Biomimicry
3	Have a pufferfish-like suction device to suck up the dust	Biomimicry
4	Gecko-Inspired Cleaning Pads	Biomimicry
5	Sharkskin-Inspired Surface: Emulate the texture of sharkskin, which is known for its self-cleaning and drag-reduction properties	Biomimicry
6	Lotus Leaf-Inspired Superhydrophobic Coating	Biomimicry
7	Bristle Bot Cleaners	Biomimicry
8	Dust-Mite-Inspired Cleaning Swarms	Biomimicry
9	Microbial Bioremediation	Biomimicry
10	Electrostatic Cleaning: Mimic the cleaning mechanism of certain insects and animals that use electrostatic forces to repel or attract particles	Biomimicry
11	Mussel Adhesive Cleaning: Take inspiration from the adhesive properties of mussels' byssal threads	Biomimicry
12	Bee Pollination Cleaning: Design micro-drones inspired by bees to pollinate and remove	Biomimicry

Concept Number	Concept	Concept Generation Method Used
	contaminants from the 3D printed parts.	
13	Octopus-Inspired Soft Robotics: Develop soft robotic arms inspired by the dexterity and flexibility of an octopus's tentacles	Biomimicry
14	Firefly Bioluminescence-Inspired Cleaning Indicator: Create cleaning agents or tools that emit bioluminescent signals, like fireflies, to indicate when a surface or area is thoroughly cleaned.	Biomimicry
15	Echolocation-Inspired Navigation: Design cleaning drones that use echolocation,	Biomimicry
16	Roomba Vacuum Cleaner Concept	Force Analogy
17	Car Wash	Force Analogy
18	Dishwasher	Force Analogy
19	Oral Hygiene Probe	Force Analogy
20	Aerospace Pressure Washer	Force Analogy
21	Microgravity Roll Cleaner	Force Analogy
22	Magnetic Feather Duster	Force Analogy
23	Space Wax Shield	Force Analogy
24	Microgravity Wiper Blade	Force Analogy
25	Swiffer Space Sweeper	Force Analogy
26	Spray part with SLM dust	Anti-Problem
27	Powder coat	Anti-Problem
28	Repellent Shield Coating Develop a coating for 3D printed parts that actively repels contaminants	Anti-Problem
29	Magnetic Debris Attraction	Anti-Problem
30	Sonic Wave Vibrational Cleaning	Anti-Problem
31	Pneumatic Tube System	Anti-Problem
32	Cleaning Nanobots	Anti-Problem
33	Origami Cleaning Tools	Anti-Problem
34	Dry Ice Blasting	Anti-Problem

Concept Number	Concept	Concept Generation Method Used
35	Soft Magnetic Cleaning Sponges	Anti-Problem
36	Ultrasonic Cavitation Cleaning	Anti-Problem
37	Dry Ionized Gas Cleaning	Anti-Problem
38	Using vacuum at the bottom and have the part slowly rotate with the vacuum on to suck the particles down	Battle of Perspectives
39	Use compressed gas to jet the debris	Battle of Perspectives
40	Using momentum, the object moves and suddenly stops causing the particles to move in a direction.	Battle of Perspectives
41	Have a carwash style automation for the part	Battle of Perspectives
42	Magnet collects dust through the microscopic pockets of threads around the specimen.	Battle of Perspectives
43	Use a vacuum hose to capture dust through the threads of the specimen.	Battle of Perspectives
44	Use a photodiode to detect dust across the specimen's surface by flashing a light while it's moving around.	Battle of Perspectives
45	Use a force sensor to detect a discrepancy in the weight	Battle of Perspectives
46	Have the machine target a specific type of metal dust through the touchscreen input	Battle of Perspectives
47	Have the specimen spin around a plate.	Battle of Perspectives
48	Have a rope that holds the part in place while being sprayed	Other
49	Hold the part down with glue, rotate and spray.	Other
50	Hold the part down with an adhesive, rotate and spray.	Other
51	Use a hot liquid to dissolve the metal powder	Other

Concept Number	Concept	Concept Generation Method Used
52	Hang the specimen via a rope and have the part spray the specimen in mid-air.	Other
53	Cover the part with a rubber coating and place it in the machine.	Other
54	Print part in space	Other
55	Dog paw cleaner	Other
56	Furnace printing	Other
57	Hydrochloride wash	Other
58	Ultrasonic cleaning	Other
59	Automated brush	Other
60	Powder agitator	Other
61	Electro Field	Other
62	Shaking platform	Other
63	Liquid Nitrogen Spray	Other
64	Vacuum glove box	Other
65	Water-Based jets	Other
66	Dirt cleaning slime	Other
67	Shake the part in a box with water	Other
68	Spray cleaning foam	Other
69	Using Proponal-2 jet	Other
70	Boiling water cleaning	Other
71	Magnetic Contaminant Capture and Retrieval	Other
72	Sterile Gas Cleaning Chamber	Other
73	Miniature Air Compressor Jet	Other
74	Cryogenic Cleaning	Other
75	Ionic Liquid Cleaning	Other
76	Laser Ablation Cleaning	Other
77	Space-Grade Adhesive Tapes	Other
78	Microgravity Electrostatic Sweeper	Other

Concept Number	Concept	Concept Generation Method Used
79	Programmable Vibrational Cleaning:	Other
80	Contaminant Capture with Nanomaterials	Other
81	Electrodynamic Dust Repulsion	Other
82	Sonic Waves and Resonance	Other
83	Magnetic Microfiber Swabs	Other
84	Automated Microgravity Blower	Other
85	Particle Agglomeration and Release	Other
86	Light-Based Cleaning	Other
87	Smart Cleaning Robots	Other
88	Adaptive Contaminant Analysis	Other
89	Contaminant Capture and Reuse	Other
90	Microgravity-Compatible Cleaning Gels	Other
91	Magnetic Pulse Cleaning	Other
92	Electromagnetic Induction Cleaning	Other
93	Holographic Cleaning Probes	Other
94	Self-Healing Surface Coatings	Other
95	Pulsing Vacuum Nucleation	Other
96	Use data attained from previous cleaning experiments and make a machine that cleans the dirtiest areas on average for a specimen.	Other
97	Use a controller and have the user move the spray wherever they see fit.	Other
98	Use a robotic arm and have it move autonomously based on the dirtiest areas of the part.	Other
99	Use a smartphone app and have the user interact with the machine through their phone.	Other
100	A brush on a stick with automation	Other