4/21/2020

Team 501: Powder Recovery for Metal Additive Manufacturing

Joshua Dorfman, Vincent J. Giannetti, Kevin E. Richter, Arlan G. Ohrt, Noah R. Tipton

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

Abstract

The Air Force Research Laboratory (AFRL) at Eglin Air Force Base, Florida uses a metal 3D printer to make parts. This printer uses a laser to fuse metal powder together to form desired shapes. This leaves some unfused metal powder trapped inside cavities in the part. Any remaining powder is waste because of contamination after the part is taken out of the printer. The lab is tasking us with creating a device to help remove the unfused powder from the part. This recovered powder should be captured and stored for reuse.

Knowing how to best handle metal powder is key to this project's success. The metal powder at AFRL has individual pieces that are about 10 times smaller than the thickness of a standard piece of paper. The powder particles easily catch on the surface and corners of the printed part. The powder must always be isolated because of safety concerns. Airborne powder can catch on fire and is dangerous to inhale.

Our system vibrates the part upside-down to remove powder. This powder falls and is funneled into a storage container. To account for the dangers of small metal powder, our vibrating system is placed inside a sand blasting cabinet. These cabinets already meet AFRL's safety standards. The designed system proves to be effective in recovering additional powder.

Keywords: Additive Manufacturing, Laser Powder Bed Fusion, Stainless Steel, Vibration, Air Force Research Lab

Acknowledgement

Team 501 would like to thank out sponsor Dr. Philip Flater with the Damage Mechanisms Branch at the Air Force Research Lab (AFRL/RWMW). He is the coordinator and technical lead for the metal additive manufacturing laboratory at the Munitions Directorate. Dr. Philip Flater has provided Team 501 with clear guidelines and expectations, and has been a fantastic mentor throughout the duration of the project.

Team 501 would also like to thank the FAMU-FSU College of Engineering faculty who served as advisors for the project. Dr. Simone Peterson Hruda has encouraged the team to strive for higher quality work and has inspired the team to ask questions about the project that led to integral decisions. Dr. Shayne McConomy has also been a fantastic resource for our team, going above and beyond for the sake of our project on multiple occasions. Our staff advisors have done so much for our project, and for that, Team 501 is sincerely thankful.

Table of Contents

List of Tables

List of Figures

Notation

AFRL	Air Force Research Lab (Eglin Air Force Base)
LPBF	Laser Powder Bed Fusion
PAPR	Powered Air Purifying Respirator
PLA	Polylactic Acid
STL	Stereolithography
CAD	Computer-Aided Design

Chapter One: EML 4551C

1.1 Project Scope

Project Background.

The AFRL (Air Force Research Lab) operates a laser powder bed fusion (LPBF) printer for the additive manufacturing of complex metal parts. Unused powder is either recovered and recycled or disposed. AFRL's interest is to develop hardware and procedures for increasing the amount of recycled powder. The proposed solution should be compatible with existing hardware and processes.

The existing process is broken into three phases. The first phase is built into the LPBF printer to recover bulk, unused, powder. The second phase is implemented when the part is removed from the printer. A “wet vacuum” is used to remove excess bulk material. This powder is deemed waste once it is saturated in the vacuum. The third phase takes place in a powder coating type enclosure, or a “sand blasting cabinet”. The part is loaded into the enclosure and is then blown with compressed air to remove residual powder caught in the geometric features. This powder is contaminated with other types of particles (sand, etc.) in the enclosure and is therefore also deemed waste.

Project Description.

The objective of this project is to design a device which increases the amount of recycled 17-4PH steel powder in a LPBF process. This device should be compatible with existing hardware and processes, while ensuring the safety of the operators.

Key Goals.

The key goals of this project were determined by breaking the project description into a list of achievable objectives. This helps to ensure that the project stays on track with the project description.

- Increase the amount of recycled powder in the LPBF process.
- Ensure the safety of any personnel using the powder recovery tools.
- Maintain compatibility with existing AFRL hardware and resources.
- Distinguish the location of the developed solution in the current process (systems engineering).

Markets.

This project is relevant to a few markets. These were determined using the question: “where will this product be used?” Primary markets are the markets that are directly going to use our product, and the secondary markets are those that could use the product if they had access to it.

- Primary Markets:
    - The project sponsor, Dr. Flater
    - Other users of the LPBF printer at AFRL
- Secondary Markets:
    - Facilities that have similar LPBF printers
    - 3D printing enthusiast and shops that wish to use industrial 3D printers

Assumptions.

The assumptions for this product are stated to help direct the project towards the project description, and to state what can and cannot be utilized.

- The 3D Systems ProX 300 is the operating LPBF printer, featuring a build plate volume of (W x D x H): 250 x 250 x 330 mm (9.84 x 9.84 x 12.99 in) (3DSystems, 2019).
- The only material to be used in the 3D printer for AFRL's purposes is 17-4PH steel.
- Any project solution has access to a 110 psi air compressor and a 110V wall outlet in the lab.
- The particle size of the 17-4PH steel powder is between 10 and 15 micrometers.

Stakeholders.

- The stakeholders for this project were determined by people with investment, interest, and control in the project. This is important to show who the project effects.
- Air Force Research Lab - AFRL is our key investor in this project, so a functioning product will be delivered to them.
- Dr. Flater - As our sponsor and investor, Dr. Flater has investment, interest, and control over the project's operations.
- College of Engineering - The success of this project will reflect well on the college, as the college has invested in our instructors and educational tools.
- Dr. McConomy - As our Senior Design professor and adviser, Dr. McConomy has a time investment in us, and has control over the program.
- Dr. Hruda - As our project adviser, Dr. Hruda has interest in the project and a time investment in us.

1.2 Customer Needs

Customer needs are interpreted statements that show what the customer wants from a project. It is important to quantify the customer needs to direct the success of the project. The project brief gives engineers the basic need of the project, but the customer possesses further detailed needs that must be obtained. Many different methods of gathering customer needs exist, but a teleconference was all that was needed for this project.

A teleconference was held between our design team and our sponsor Dr. Flatter (on 9/17/2019). During this call, the current steel powder recycling process was broken down into three basic phases, and all pertinent information was recorded. Additionally, with the permission of our sponsor, a voice recording was taken for further analysis. It may be noted that while our team had begun the conference with pre-written questions, most were not asked as they had been unknowingly answered by our sponsor. Customer statements must be translated into simpler, tangible, design statements. These interpretations must reflect the customer's statements, not specify solutions, and be worded in such a way to not impede the design team's innovative freedom. The statements from Dr. Flater were interpreted and can be seen in Table 1.

The teleconference started with a project introduction from Dr. Flater. This was initiated by the question, "What are the specific uses of the current method?" Dr. Flater then explained what the current process is. During this explanation, it was made clear that the main needs are increasing the recycled powder (needs number 1 and 5) and continuity with the existing process (needs number 2 and 4). These are main needs because they were stated multiple times in different ways.

The next two questions were related to the likes and dislikes of the current system. These customer statements further showed the importance of increased powder recycled (needs number 6, 8, and 9) and further enforces safety (needs number 3 and 7). Need number 9 is specifically important to note. This is important because it specified a scenario that is a problem area for the current process. Removing powder from tight areas must be a topic of research.

Table 1. Synthesized customer needs from sponsor's statements.

Customer Needs - Synthesizing Customer Data		
Question/Prompt	Customer Statement	Interpreted Needs
What are the specific uses of the current method?	Recover as much powder through stage 1, 2 and 3	1.The amount of powder recovered is increased somewhere in the process
	Device is connected or not connected to an existing process, preferably integrated	2. The product interfaces with existing processes
	Must be safe for operators to use	3. The product is safe for operators to use
	Should be compatible with existing hardware	4. The product is compatible with existing hardware
	Should recycle powder more efficiently and effectively	5. The product recovers an increased quantity of powder
What do you like about the current method?	The current system currently has approximately 90% recovery, but we want more	6. The product increases the total percentage of recycled powder
What do you not like about the current method?	Dry methods are less safe, (fire and explosion hazard) but you should consider them	7. The product considers dry method if they are safe
	The wet method is effective but the powder that it removes is wasted	8. The product considers methods that helps recover more recyclable powder
	Big problem is cylinder filled with lattice is that there are a ton of little nooks and a vacuum can't pull it out	9. The product improves the quantity of powder removed from tight areas

Many of the interpreted needs overlap in such a way that they can be narrowed down into three fundamental needs. These needs are:

1. The product increases the amount of recycled powder in the process.
2. The product does not impede the existing process or hardware.

3. The product operates with safety in mind.

Using these fundamental needs, the customer satisfaction can be ensured in this project. These needs will be kept in mind for project targets and concept selection.

1.3 Functional Decomposition

Introduction.

Functional decomposition is important to break a system down into its simplest components. These components each perform an action and contribute to the system. To better understand the product being developed, a flow chart, hierarchal decomposition, and a cross reference table were used.

The purpose of the product being developed is to maximize the amount of metal powder recovered from a part after it has been printed in a laser powder bed fusion (LPBF) process. The product will support the part, manage the powder, and inhibit the powder.

The Current Process.

The generalized functions were determined by breaking down the current process used to remove powder from the parts. This break down formed a function structure as seen in Figure 1. It is fundamental to analyze the current process to determine its functions. These functions will help further integrate our product using systems engineering. The structure diagram is effective because it determines the best fitment of our product in the current process. It also highlights weak points in the current process. We can then innovate to improve the weak areas.

The functional decomposition was constructed using both the existing process and the powder recovery product we are designing. The physics and functionality of the systems in the metal powder recovery method at AFRL were noted and broken down to the most basic operations. Many of AFRL's current powder-removal methods involve air. Air is used as a vacuum and a compressor to remove powder. These air-based systems were then decomposed to formulate the function structure of the existing process. Beyond that, the user is responsible for physically moving the plate/part to each phase of the existing process. The recovered metal powder enters a hopper system integrated in the LPBF printer if it is not contaminated. A series of graphics were created to demonstrate the functional decomposition of both the existing method and the minimum required functionality of the powder recovery method our team is tasked with creating. In Figure 1, the functional decomposition flow chart of the process used at AFRL is broken down.

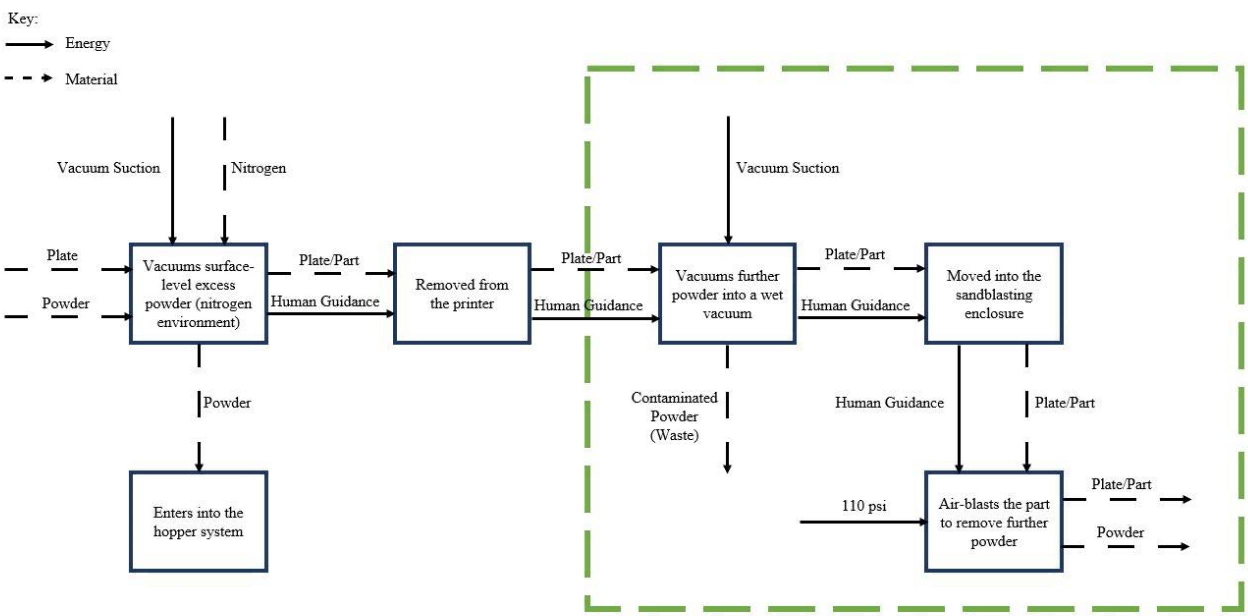


Figure 1: Functional decomposition flow chart of AFRL's existing process.

Figure 1 shows that the plate/part goes through a series of powder removal operations involving air suction, air pressure, and human guidance. The powder itself is typically taken out of the flow chart. The powder is either sent into a hopper system for collection or is contaminated in the wet vacuum stage. The area signified by a dashed green outline is likely where our powder recovery method will be implemented. This is where our method will be utilized because it is after the integrated recovery system of the printer. The “wet vacuum” stage is where most of the powder is contaminated and lost, and the sandblasting stage is where our sponsor believes the process can be most improved. In Figure 2, a hierarchical functional decomposition breaks down the requirements of our powder recovery solution.

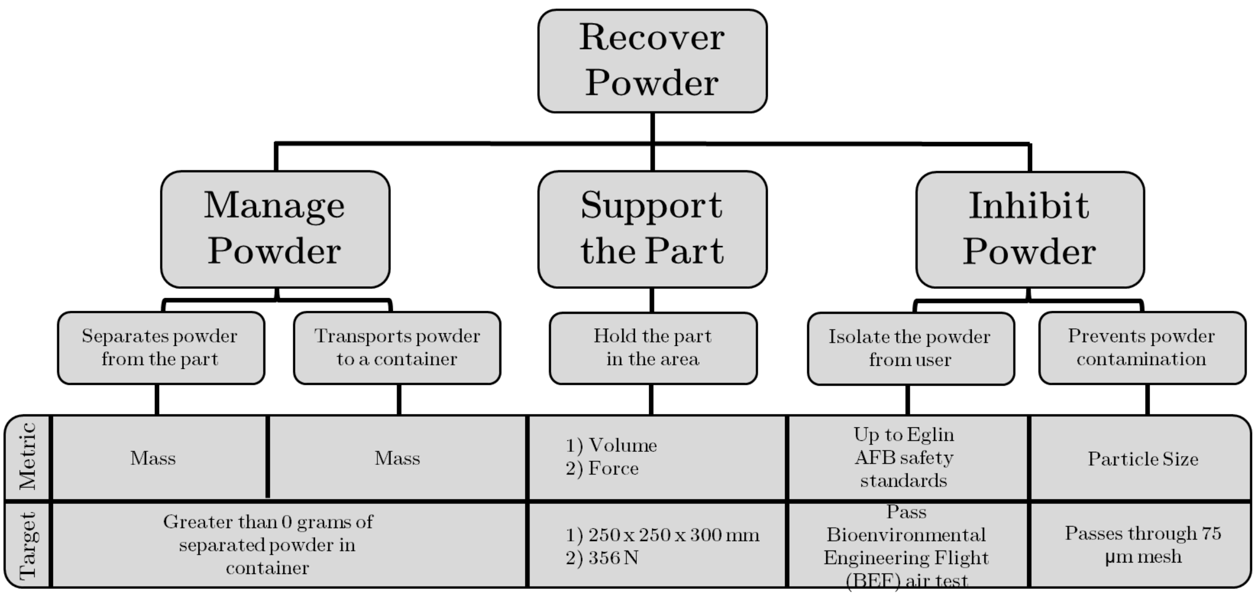


Figure 2: Hierarchical functional decomposition breakdown of the proposed product.

The Future Product.

As described in the hierarchical chart above, the major functions required of the powder recovery system are to support the part, manage the powder, and inhibit the powder. The subfunctions of each of these major functions further describe the necessary performance expected for the powder recovery system.

The function of supporting the part has one key goal. The product can hold the part in place at the time of powder recovery. This can be something as simple as allowing the user to hold the part with their hands, or as complex as a holding cell containing the part. Managing the powder is a more complex operation, as the powder must be successfully separated from any lattices or crevices in the part, and then properly transported to a containment area. The last important function is preventing the powder from ending up somewhere it shouldn't be. Allowing the ability to insulate the user from the powder is a major safety concern, especially if the powder is subjected to compressed air. Such an action is performed in the current process in a sandblasting chamber to separate the operator from the powder. Additionally, preventing the powder from being contaminated is important for recycling purposes. Contamination occurs in the existing process during the wet vacuum stage so mitigating the contamination is an important function in powder recovery.

Function Integration.

The functions of the product need to be designed to work with each other. For example, the part must be held to allow safe separation of the powder from the part. Supporting the part must not interfere with the transportation of powder to the final collection area. The powder collection should be insulated from the user, so the implementation of each of these functions is integral to having a successful product. Focusing on one more than the other may be detrimental.

Smart integration of the proposed functions could greatly increase the overall success of the project. Holding the part in the collection area shouldn't impede the overall goal of recovering powder. When it comes to managing powder, separating the powder and transporting the powder can be incorporated intelligently. The same process used to separate the powder can be used to implement the transportation of the powder. When inhibiting the powder, the same process which is used to insulate the user can also protect the powder from contamination.

Ranking Function Importance.

A cross-reference table was constructed for each of the powder recovery functions described in the hierarchical chart. These functions were compared to each other to scale their relative importance. A "1" was assigned to cells in which the function in the row was more desired than the function in the column, and a "0" was assigned for the inverse. Across the diagonal axis from the top left to the bottom right, zeroes were assigned for all cells as the row and column functions were equivalent. The sum of each row was taken, and the row functions with the highest numbers were determined to be the most critical functions. The cross-reference table can be seen in Table 2.

Table 2: Cross-reference table for the powder recovery device.

Functional Decomposition - Cross-Reference Table						
	Hold the part in the area	Separates the powder from the part	Transports powder to a container	Insulates the user from the powder	Prevents contamination of the powder	**Sum**
Hold the part in the area	0	0	0	0	0	**0**
Separates the powder from the part	1	0	1	1	0	**3**
Transports powder to a container	1	0	0	1	0	**2**
Insulates the user from the powder	1	0	0	0	0	**1**
Prevents contamination of the powder	1	1	1	1	0	**4**
Ranking	**5**	**2**	**3**	**4**	**1**	

As determined from the summing of each function row, the ranking of the five functions from most to least critical is as follows: prevents contamination of the powder, separates the powder from the part, transports powder to a container, insulates the user from the powder, and holds the part in the area. The two highest ranking functions, preventing powder contamination and separating the powder from the part, are critical because the primary goal of this product is to recover as much powder as possible. Therefore, these two functions proved to be the most critical for the project to be successful. However, the prevention of powder contamination was found to be the most important function because it serves the purpose of keeping the recovered powder usable. This covers all stages of the powder recovery system, including potential improvements to the contamination-prone wet vacuum stage.

Powder transportation to a containment system was ranked third as it is an important part of the design for a recovery system. User insulation and part holding were deemed to be the least important functions because these could be manually done. The user can insulate themselves using other means if necessary (i.e. a respiratory system). The user could also hold the part in place manually. Performing these functions manually could be beneficial for some designs. Although these are the least critical functions, it is still beneficial to include them.

1.4 Target Summary

The targets and metrics were generated to identify methods to validate each function. These were found by considering the ways to test if the function's purpose is met and researching a proper value for validation. Three functionless targets were also found that are needed to quantify the cost, time, and size of the product. These targets and metrics will be used to aid in concept selection in the future. The tools needed for validation are a measuring tape, scale, stopwatch, and a CAD program. A catalog of each target can be found on the following page. This catalog includes all the discussed targets, metrics, and their method of validation. The functions that are bolded correspond to the critical functions, and therefore the critical targets as well. The complete target catalog can be found in Appendix C.

1.5 Concept Generation

Concept 1.

This concept is a mounting system for the building plate which can rotate any direction in space and will allow the operator to quickly rotate the part to ease the removal of powder. It would also have a vibration feature, which would vibrate the part in whatever configuration the part is being held at. A sketch of this concept is shown in Figure 3. This concept was chosen instead of the other concepts because this technology is already in use in CNC machines which operate in 5 dimensions and would increase the effectiveness of current methods employed by the customer by allowing more maneuverability of the build plate.

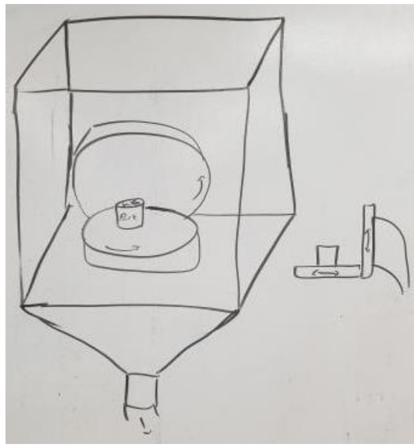


Figure 3. Medium-Fidelity Concept 10: CNC orientation.

Concept 2.

The second medium-fidelity concept, is called “the spinning sifter.” The spinning sifter attaches to the build plate and spins it at a high rate, using centrifugal force to remove the powder from the part. The part is surrounded by a filter which will prevent contaminated powder or parts from leaving the sifting section. Reclaimed powder would be the only material that fits through the filter. A sketch of this concept is shown in Figure 4. This concept was chosen instead of other concepts because the technology needed to develop it would be relatively simple as well as the fact the same filtering method is used in other industries.

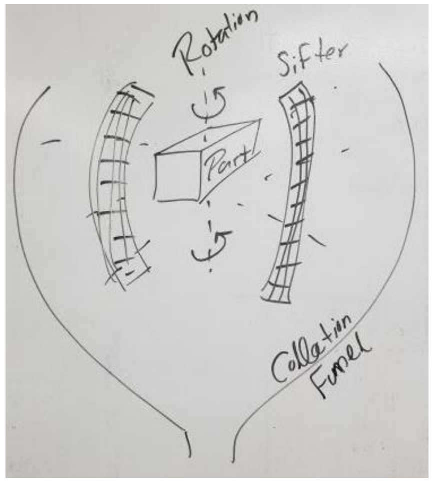


Figure 4. Medium-Fidelity Concept 12: The Spinning Sifter.

Concept 3.

The third medium-fidelity concept, number 14, is called “vibration through all stages.” This concept is exactly what its title states, vibrating the part throughout all collection stages of the recovery process. The general theory behind this concept is that by vibrating the part during all three stages of the recovery process the powder will stay loose during reclamation and thus improve the amount of powder collected from the current method. An image of what this concept would accomplish is shown in Figure 5. This concept was chosen over the others because it incorporates the current process used well.

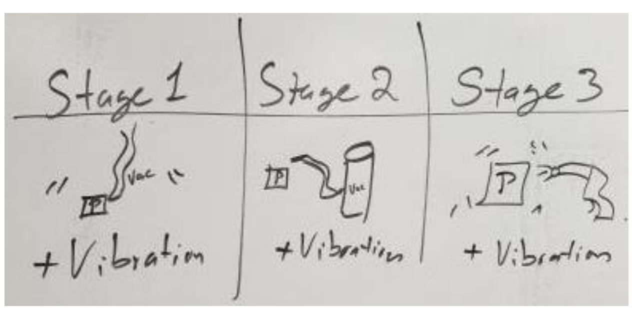


Figure 5. Medium-Fidelity Concept 14: Vibration Through All Stages.

Concept 4.

The fourth medium-fidelity concept, number 6, is called “multi-directional vibration.” This concept is the opposite of the CNC style concept mentioned above, since it focuses more on the vibration directionality than the parts orientation. The vibration direction would be uniquely controlled to vibrate in multiple dimensions to maximize the powder knocked loose. This concept can be seen in Figure 6. This concept was chosen over others because it should remove a large amount of powder without large motion of the part itself.

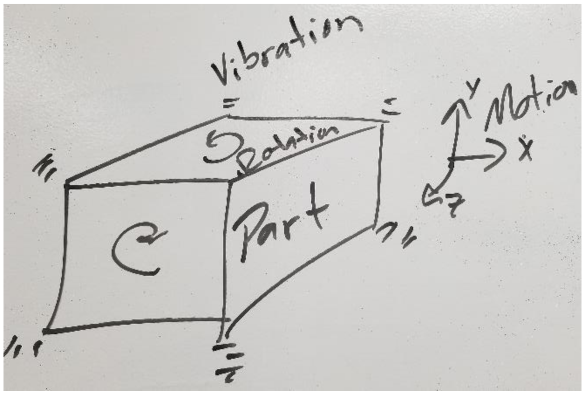


Figure 6. Medium-Fidelity Concept 6: Multi-Directional Vibration

Concept 5.

The fifth and final medium-fidelity concept, number 23, is an electrostatic brush. This concept involves using a brush with fine bristles. The brush would be very small and capable of fitting within most crevices that are printed. The brush would be electrostatically charged so that the fine metal powder would be attracted to it, the brush would be removed from the part and then grounded so the powder would fall from it into a collection area. A sketch of this concept is shown below in Figure 7. This concept was chosen over the others because the use of an electrostatic brush would be able to remove powder from difficult to reach places with minimal effort from the operator.

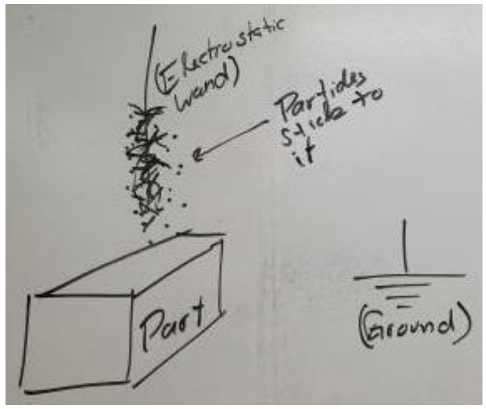


Figure 7. Medium-Fidelity Concept 26: Electrostatic Brush

Concept 6.

The first high-fidelity concept, number 31, is a tiny tube that blows compressed air. This concept was developed by realizing the hardest powder to remove was trapped in tight corners of the part's geometry. A common part printed is a cylinder with a lattice inside. This concept was conceived with this complicated, tight, geometry in mind. This concept is shown in Figure 8. This concept was chosen over the others because using such a small tube would allow the system to work well with any geometry that has hard to reach places. This concept was chosen over the medium-fidelity concepts because it directly attacks the problem of entering the tight geometries that were printed, and physically using air to blow the particles loose.

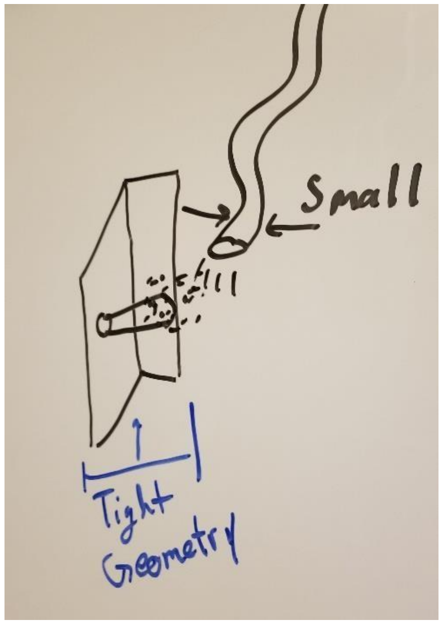


Figure 8. High-Fidelity Concept 31: Tiny Tube

Concept 7.

The second high-fidelity concept, number 20, is called "high to low frequency vibration while enclosed." This concept would involve vibrating the part during a collection portion of the recovery process at different frequencies. The part would begin vibrating at a low frequency and then increase to a much higher frequency before being brought back down to a low frequency. While the part is vibrating, most likely while upside down, a funnel will be used to catch the powder and guide it into a container to keep it uncontaminated. This system would be in some form of an enclosure so that powder cannot escape into the lab atmosphere. The purpose behind this is that the variation in vibration will cause powder which normally wouldn't come out to do so. A sketch of this concept is shown in Figure 9. This concept was chosen over the others because it would allow collection of normally difficult to remove powder with a very feasible solution.

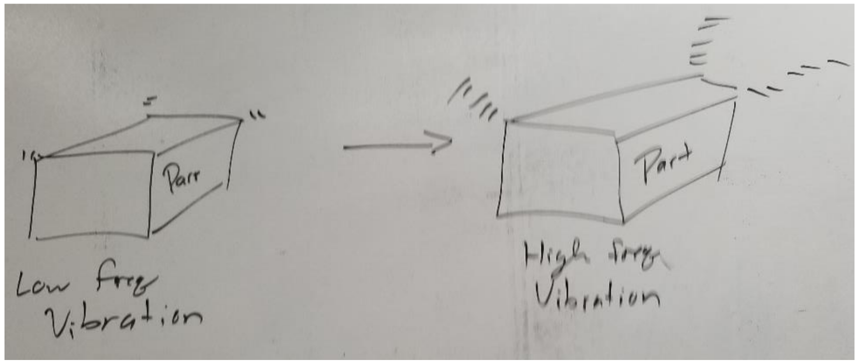


Figure 9. High-Fidelity Concept 20: Low to High Frequency Vibration

Concept 8.

The third and final high-fidelity concept, number 8, is titled “the kitchen magnet.” This concept was generated by thinking of the large kitchen sinks with the hanging faucet. This is a very convenient way to allow a user to use a tool in a work area, such as the faucet at a sink. This concept incorporates an electromagnet that hangs down from above the part. The part would be held down as the user guides the electromagnet around to collect powder. Once a large amount of powder is stuck to the electromagnet, the current would be turned off to drop the powder and recover it. A sketch of this concept is shown in Figure 10. This concept was chosen over others because it uniquely generates a large removal force (magnetic field) to the powder. This concept also would be very easy for an operator to use.

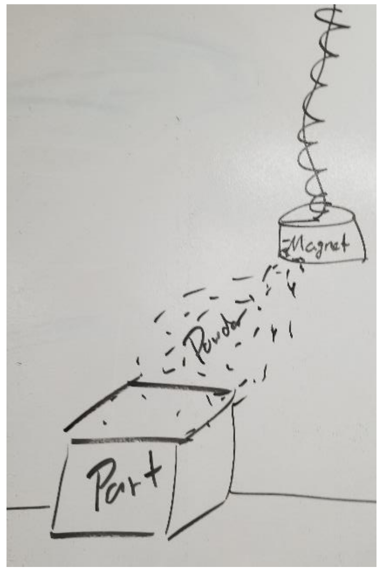


Figure 10. High-Fidelity Concept 8: The Hanging Magnet

1.6 Concept Selection

Concept selection is a vital part of the engineering design process. This is where the design team takes the generated concepts and compares them to one another in a systematic way. Concept selection tools help to remove bias in the selection process. The first step is to use a streamlined "House of Quality" (HOQ) to infuse the voice of the customer into the engineering characteristics. Then, "Pugh Charts" are used to simply compare concepts to a datum and each other. Finally, "Analytical Hierarchy Process" (AHP) is used to select a concept in a very controlled manner. These processes will be discussed and implemented. A concept will be selected after all processed have been completed.

House of Quality (HOQ).

The HOQ is used to infuse the voice of the customer into the design process. This is done by comparing the correlation of engineering characteristics to customer requirements. The correlations and requirements are both ranked in a systematic way, and this results in weighted engineering characteristics. This tells designers which engineering characteristics are a priority over others.

		Engineering Characteristics						
Improvement Direction		↑	↑	↑	↑	↑	↓	↓
Units		Gram	Gram	Newton	Cubic Meter	OSHA	Percent Relative Moisture	Seconds
Customer Requirements	Importance Weight Factor	Amount of Separated Powder	Amount of Contained Powder	Supportable Load	Operable Volume	Met Safety Standards	Contamination	Added Time to Overall Process
Separate More Powder From the Part	4	9	3		1			1
Recover the Separated Powder	3	3	9		1			
Prevent Powder Contamination	5	1	1				9	
Hold the Part During Process	1	3		9	9			
Ensure Operator Safety	5			3		9		
Integrate With Current System	2							9
Raw Score	249	53	44	24	16	45	45	22
Relative Weight %		21.29	17.67	9.64	6.43	18.07	18.07	8.84
Rank Order		1	4	5	7	2	2	6

Figure 11. House of Quality Analysis

The HOQ clearly shows which engineering characteristics are the most important. The most important is the amount of separated powder. Close behind are safety standards and the contamination of the powder. These results were expected since they align with two of the key goals of the project (recycling powder and safety). The ranking of the customer requirements was determined using pairwise comparison. This can be seen in Figure 12. The found comparison values were interpreted into an importance weight factor between one and five. The results of the HOQ will help to focus on the more important engineering characteristics.

	Separate More Powder From the Part	Recover the Separated Powder	Prevent Powder Contamination	Hold the Part During Process	Ensure Operator Safety	Integrate With Current System	Sum	Rank (1-5)
Separate More Powder From the Part	~	1	0	1	0	1	**3**	**3**
Recover the Separated Powder	0	~	0	1	0	1	**2**	**2**
Prevent Powder Contamination	1	1	~	1	0	1	**4**	**5**
Hold the Part During Process	0	0	0	~	0	0	**0**	**1**
Ensure Operator Safety	1	1	1	1	~	1	**5**	**5**
Integrate With Current System	0	0	0	1	0	~	**1**	**1**
Sum	**2**	**3**	**1**	**5**	**0**	**4**		

Figure 12. Pairwise Comparison for Customer Requirement Ranking

Pugh Chart.

Pugh charts are a simple way to select concepts based on engineering characteristics. This is done by comparing a single engineering characteristic of each individual design to that of a datum. The datum used for this project was the current powder recovery process. Eight concepts were compared to this datum (the five medium-fidelity and three high-fidelity concepts). This comparison can be seen in Figure 13.

		Concepts							
Engineering Characteristics	Current Recovery Process	Tiny Tube Blower	Encased Low to High Frequency Vibration	Hanging Faucet Electromagnet	Electrostatic Brush	CNC Axis Part Mover	Spinning Sifter	Vibration Through all Stages	Multi-Directional Vibration
Amount of Separated Powder	**DATUM**	+	+	+	+	+	+	+	+
Amount of Contained Powder		+	+	+	+	+	+	+	+
Supportable Load		S	S	S	S	-	-	-	-
Operable Volume		S	S	S	S	S	S	S	S
Met Safety Standards		S	S	S	S	S	S	S	S
Contamination		S	+	S	S	S	+	S	S
Added Time to Overall Process		-	-	-	S	S	-	-	-
	Total +	2	2	2	2	2	2	2	2
	Total -	1	1	1	0	1	2	2	2

Figure 13. First iteration of the Pugh Chart method.

The first iteration of the Pugh method showed three concepts that had two negatives in the analysis. These concepts were eliminated as options, and the electrostatic brush was decided to be the next datum. This is because it had no negatives and was not the overall best. If the overall best was selected as the datum, the analysis may be indeterminate. The second iteration can be seen in Figure 14.

		Concepts			
Engineering Characteristics	Electrostatic Brush	Tiny Tube Blower	Encased Low to High Frequency Vibration	Hanging Faucet Electromagnet	CNC Axis Part Mover
Amount of Separated Powder	DATUM	S	+	-	S
Amount of Contained Powder		+	+	-	S
Supportable Load		S	S	S	-
Operable Volume		S	S	S	S
Met Safety Standards		S	S	S	S
Contamination		+	+	S	+
Added Time to Overall Process		S	-	S	S
	Total +	2	3	0	1
	Total -	0	1	2	1

Figure 14. The second iteration of the Pugh Chart method.

The second iteration of the Pugh method showed that only one concept received no negatives, but this also did not have the most positives. The tiny tube blower had two positives and no negatives, whereas the encased low to high frequency vibration concept had three positives and one negative. The encased low to high frequency vibration is the best concept because it had the most positives, and its only negative is a low priority engineering characteristic. The added time engineering characteristic ranked to be the 6th most important out of 7. The positives of more important categories negate the single negative of having to run longer.

Analytical Hierarchy Process (AHP).

The analytical hierarchy process (AHP) is a matrix-based method to select the best concept. The method initially has the designer rank evaluation criteria against each other, and then check the validity of this step. Then, top concepts are compared based on a specific evaluation criterion. The first needed comparison is the "criteria comparison matrix." This can be seen in Figure 15.

	Criteria Comparison Matrix [C]					
	Ensure Operator Safety	Prevent Powder Contamination	Separate More Powder From the Part	Recover the Separated Powder	Integrate With Current System	Hold the Part During Process
Ensure Operator Safety	1.00	1.00	0.33	0.33	0.33	3.00
Prevent Powder Contamination	1.00	1.00	0.33	0.33	0.33	3.00
Separate More Powder From the Part	3.00	3.00	1.00	1.00	0.33	3.00
Recover the Separated Powder	3.00	3.00	1.00	1.00	3.00	3.00
Integrate With Current System	3.00	3.00	3.00	0.33	1.00	3.00
Hold the Part During Process	0.33	0.33	0.33	0.33	0.33	1.00
Sum	**11.33**	**11.33**	**6.00**	**3.33**	**5.33**	**16.00**

Figure 15. AHP – Criteria Comparison Matrix.

The criteria comparison matrix is used to compare the evaluation criteria. The ranking is an odd number exaggerated scale. This presents the importance of each more clearly. The inverse of the ranking can be found across the diagonal. This matrix is normalized based off the column sums to show the consistency of the matrix. This normalization can be seen in Figure 16.

	Ensure Operator Safety	Prevent Powder Contamination	Separate More Powder From the Part	Recover the Separated Powder	Integrate With Current System	Hold the Part During Process	Criteria Weight {W}
	Normalized Criteria Comparison Matrix [NormC]						
Ensure Operator Safety	0.09	0.09	0.06	0.10	0.06	0.19	0.10
Prevent Powder Contamination	0.09	0.09	0.06	0.10	0.06	0.19	0.10
Separate More Powder From the Part	0.26	0.26	0.17	0.30	0.06	0.19	0.21
Recover the Separated Powder	0.26	0.26	0.17	0.30	0.56	0.19	0.29
Integrate With Current System	0.26	0.26	0.50	0.10	0.19	0.19	0.25
Hold the Part During Process	0.03	0.03	0.06	0.10	0.06	0.06	0.06
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure 16. AHP – Normalized Criteria Comparison Matrix.

The sum of the normalized matrix columns should add up to one, and they do. The "criteria weight" is then found by averaging the rows. This shows the relative weights of each criteria. A consistency check must be done, and this can be seen in Figure 17.

{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weight	Cons={Ws}./{W} Consistency Vector
0.61	0.10	6.32
0.61	0.10	6.32
1.33	0.21	6.42
2.00	0.29	6.88
1.72	0.25	6.87
0.37	0.06	6.56
		λ = 6.5639

Figure 17. AHP – Consistency Check Matrix.

The calculated consistency vector is averaged and called lambda. This lambda is used with random index values (RI) to check the overall consistency. The calculations to do so are shown below.

$$Consistency\ Index = CI = \frac{\lambda - n}{n - 1} = \frac{6.5639 - 6}{6 - 1} = 0.11278$$

$$Consistency\ Ratio = CR = \frac{CI}{RI} = \frac{0.11278}{1.25} = 0.090$$

$$CR < 0.10$$

The consistency ratio is below one tenth, so the criteria comparison matrix is valid.

The next step is to compare the three high-fidelity concepts to one another based on a specific criterion. The chosen criterion to show is the amount of separated powder. This starts with a comparison matrix. This can be seen in Figure 18.

	Recovered Powder		
	Comparison Matrix [C]		
	Encased Low to High Frequency Vibration	**Tiny Tube Blower**	**Hanging Faucet Electromagnet**
Encased Low to High Frequency Vibration	1.00	3.00	3.00
Tiny Tube Blower	0.33	1.00	1.00
Hanging Faucet Electromagnet	0.33	1.00	1.00
Sum	**1.67**	**5.00**	**5.00**

Figure 18. AHP – Recovered Powder Comparison Matrix.

The basic process for the recovered powder criterion is like the comparison done in Figure 5. The inverse of the ranking can be found across the diagonal and needs to be normalized. This can be seen in Figure 19.

	Recovered Powder Normalized Comparison Matrix [NormC]			
	Encased Low to High Frequency Vibration	Tiny Tube Blower	Hanging Faucet Electromagnet	Design Alternative Priorities {PI}
Encased Low to High Frequency	0.60	0.60	0.60	0.60
Tiny Tube Blower	0.20	0.20	0.20	0.20
Hanging Faucet Electromagnet	0.20	0.20	0.20	0.20
Sum	**1.00**	**1.00**	**1.00**	**1.00**

Figure 19. AHP – Normalized Recovered Powder Comparison Matrix.

The matrix was normalized and summed across the rows to find the "PI" alternative values. The sums of each column should be equal to one, and they are. Now a consistency check must be done. This is done in Figure 20.

{Ws}=[C]{PI} Weighted Sum Vector	{PI} Criteria Weight	Cons={Ws}./{PI} Consistency Vector
1.80	0.60	3.00
0.60	0.20	3.00
0.60	0.20	3.00
		λ = 3.000

Figure 20. AHP – Recovered Powder Consistency Check.

The calculated consistency vector must be used as before to check the validity of this exercise. This can be seen below.

$$Consistency\ Index = CI = \frac{\lambda - n}{n - 1} = \frac{3 - 3}{3 - 1} = 0$$

$$Consistency\ Ratio = CR = \frac{CI}{RI} = \frac{0}{0.54} = 0$$

$$CR < 0.10$$

The consistency ratio is below one tenth, so the comparison is valid.

The next step is to do this for all criteria. The work for each will not be shown, but it is the same as for the recovered powder example. The resulting PIs are tabulated in Figure 21.

Selection Criteria	**Encased Low to High Frequency Vibration**	**Tiny Tube Blower**	**Hanging Faucet Electromagnet**
Ensure Operator Safety	0.33	0.33	0.33
Prevent Powder Contamination	0.43	0.43	0.14
Separate More Powder From the Part	0.60	0.20	0.20
Recover the Separated Powder	0.43	0.43	0.14
Integrate With Current System	0.33	0.33	0.33
Hold the Part During Process	0.60	0.20	0.20

Figure 21. AHP – Resulting PIs for all criteria.

This matrix of values is then transposed and multiplied by the criteria weights vector {W} from Figure 6. This results in the final ranking of the three high-fidelity concepts, which can be seen in Figure 22.

Concept	Alternative Value
Encased Low to High Frequency Vibration	0.440
Tiny Tube Blower	0.334
Hanging Faucet Electromagnet	0.222

Figure 22. AHP – Final Ranking of High-Fidelity Concepts.

The encased high to low frequency vibration ranked the highest from the AHP. This makes sense because it is believed to recycle more powder than the others, while also preventing contamination due to contact to an electromagnet or the tiny tube. This lines up with the results of the Pugh chart method and will be the chosen design.

Final Selection.

The selected design for this project is the encased low to high frequency vibration. The general idea of this concept is relatively simple, and it can be seen in Figure 13. The part will be flipped and mounted upside down. A vibration mechanism with then vibrate at different frequencies. The original concept was to vibrate from low to high frequencies alone. Research showed that the frequency and force both can change dramatically. There is also the concept of ultrasonic cleaners moving at an insensible frequency. The best vibration technique must be explored and selected.

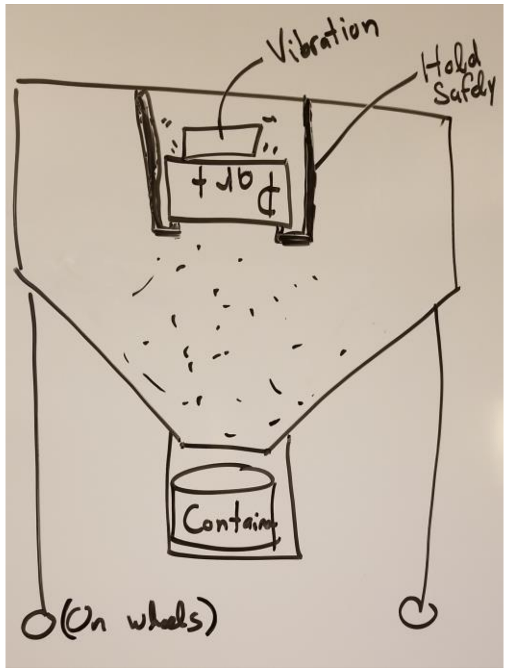


Figure 23. The Selected Design Vibrating an Upside-Down Part in an Enclosure.

Another key aspect of this concept is that the system must be enclosed. The act of vibrating powder off the part would release powder into the nearby atmosphere. This powder must be contained, and restricted from the operator’s atmosphere, as a safety precaution. The enclosure also would act as a contamination free zone. Many enclosures, such as sandblasters, have other particles throughout. The enclosure for this concept would only be used for this metal powder recovery, keeping it clean and contaminate free.

The final key aspect of this concept is a recovered powder guidance and storage system. A funnel type of guidance system is planned to be used, and this could even be part integrated enclosure's geometry. The powder would then drop into the containers currently used by the operators. This funnel system would use gravity as its driving force in the capture of the metal powder.

While the key objectives of this concept are the vibration mechanism and enclosure, other aspects may be introduced as well. For example, it would be very easy and inexpensive to implement compressed air in the enclosure. Very thin, long, tools could be used with the vibration mechanism to remove more powder. Various aspects from other concepts will not be forgotten, as they could work well as a supplementary system. The priority of the project will be on the vibration and enclosure design, but other components may be added as well.

1.7 Spring Project Plan

The Spring project plan is organized using the general "One Page Project Manager" (OPPM) format provided to all senior design groups. The general trend of the timeline allows us to order the components within our first month back from Winter break. We then assemble, test, refine, and alter the design as needed. At this point, we then can order more materials if necessary. An attempt was made to assume the machining time using the college's machine shop. Since only one part must be machined for the current design, (and it will be done early in the semester before the big rush) a full week was assumed for machining time. If more time is needed for machining, we will hurry to get back on the project timeline.

Throughout this process, constant contact will be made with the sponsor (and times for this can be seen in the OPPM). This is crucial for this project because we do not have a formal budget. All purchases go through him, and he has told us we can spend any reasonable amount, depending on the design. He also will order all components for us, so a lag time of 6 days was provided, so he can review and place the orders. All components will be purchased through McMaster Carr (with 2-day shipping on most items).

The only events that were not included in the OPPM were senior design homework and presentations. These will be added at the beginning of the Spring semester. FAMU-FSU College of Engineering academic events were added to the project plan to show important events that must be worked around during the project.

Project Plan.

The plan for the project this semester is to construct the selected design of the upside-down vibrating part design. To accomplish this, a Gantt Chart was created. To view this Gantt Chart, download the excel file "Spring Project Plan Timeline" from the Team 501 website.

The first phase of the project plan was to finalize the general design of the system. This involved deciding on what components would be necessary for creating the system and creating a CAD assembly of the chosen parts. Then, the Bill of Materials would be updated with the corresponding parts that were needed to construct the system. After the parts were ordered, the team confirmed the parts obtained and ensured that all items were accounted for. The building of the system according to the CAD assembly then began, which will be described in more detail in the next section.

It was decided that to test the functionality of the design, powder would need to be removed from test parts in a manner that was both safe and readily available. Flour was determined to be a suitable powder for testing, as it is large enough to pose little harm to the team during testing and is an inexpensive and easily purchased powder. However, flour powder has a diameter of 25-400 μm, which is too large of a range to test our system effectively. By filtering the powder through a 75 μm mesh, the size of the powder was restricted to 25-75 μm in diameter, allowing for a more precise testing process. Polymer-printed test parts were then fabricated using 3D printers made available by the school. These parts had complex geometry similar to the lattice structures our sponsor uses, as the parts had their geometries constructed using the same software, nTopology. These parts were scaled up by a factor of 4 when compared to the size that our sponsor would print them at. This was done to account for the larger diameter of the flour such that a sense of scale was kept. The system would then be run with the test parts hanging upside down, affixed to the build plate attached to our system, to examine the amount of recovered powder our system would be able to shake loose.

Build Plan.

The build plan for the system followed the CAD assembly. The parts which made up this assembly were placed into a Bill of Materials and were ordered such that they could be constructed into the specified design. The Bill of Materials can be found on Team 501's website. The figure below shows the CAD assembly of the design compared to the final constructed version of the design.

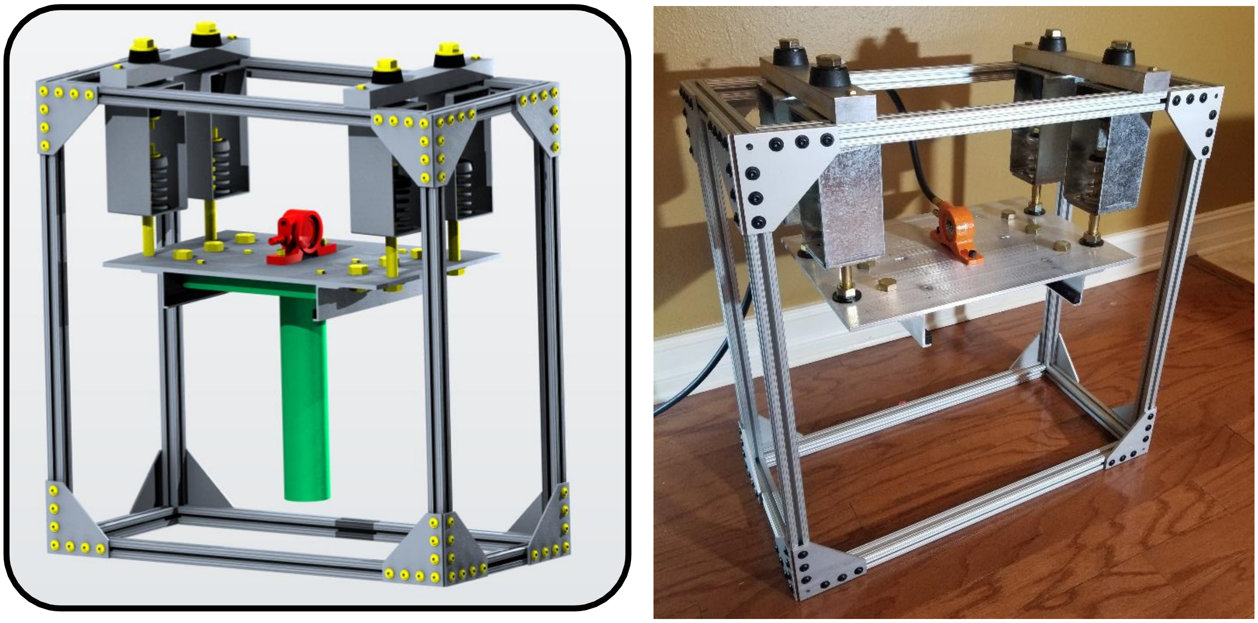


Figure 24: Final design CAD (left) and assembled final design (right)

The design entailed creating an aluminum framing to house the vibration mechanisms of the design. Affixed to the top of the aluminum frame is a vibration damping suspension, which the “mounting plate” hangs from. Attached to the mounting plate is the pneumatic vibrator (Figure 24, colored in red in the CAD, orange in the assembled design), which when activated would vibrate the system, shaking loose the powder in an attached part. The part and build plate (Figure 24, colored in green in the CAD) would attach to the bottom of the mounting plate. Aluminum Z-bars act as a rail for the plate to rest on until the user can screw the build and mounting plates together. The build was carried out during the second semester of the Senior Design project, and was accomplished successfully.

Chapter Two: EML 4552C

To reiterate, the objective of this project is to design a device which increases the amount of recycled 17-4PH steel powder in a LPBF process. This device should be compatible with existing hardware and processes, while ensuring the safety of the operators. The scope of this project entails the removal and recovery of the powder in such a way that it can be recycled, but the recycling and storing of the powder is outside the scope of this project. The following information entails the spring semester of Team 501's project.

2.1 Results

The results from the three runs, one for each geometry test print, can be found in Table 3. This shows that the device removed between 32% and 44% of the powder left on the part. This meets the target of recovering greater than 0 grams of powder mentioned earlier. This proved the validity of the device by showing that it removes powder in general. The extra powder on the large cube didn't seem to alter any results greatly, but it was harder to manage and contain that excess powder.

Table 3: Powder removal results after a 5 minute run time on the device

Run Number	Polymer Geometry	Mass of Powder Added (g)	Mass of Powder Removed (g)	Percent Removed Powder (Mass %)
1	Large Cube	325.3	111.6	34.3 %
2	Large Cylinder	38.0	16.5	43.4 %
3	Small Cylinder	5.5	1.8	32.7 %

The results presented in Table 3 were from the machine running as-is for a duration of 5 minutes. The compressor used was undersized for the vibrator. The vibrator has specifications (force and frequency of vibration) listed when run at 80 psi. The compressor used could start above 80 psi, but it would steadily decrease and stay around 50 psi after the first 30 seconds. This means that the vibrator was run below its specification for a large majority of the run time. The results would likely be different if the 80 psi could be maintained for the full 5 minutes. Despite this, the device was still able to remove powder and meet the needed targets. AFRL has a far superior compressor than the one used for validation which suggests AFRL will have a larger yield percentage of recovered powder.

2.2 Discussion

There were many sources of error in the validation processes. The undersized compressor previously mentioned likely altered the results, but there are other sources as well. The larger particle size of the powder resulted in scaled test prints to lessen the error, but the flour on a polymer surface is not a perfect representation of the actual part and powder. The original build plate (about 25lbs) was used to keep the mass of the system as close as possible to the actual weight, but this is not exact either. Finally, cardboard was used to catch the removed powder. While the flour did fall neatly down, some powder may not have been caught by the platform. Despite these sources of error, the validation process used still is able to prove the device works as intended.

There was an unofficial test run 4 done on the large cube polymer test print. As mentioned earlier, the device is to be used in a sandblasting cabinet. This cabinet would allow the operator to blow the object with compressed air and to pound on the suspended plate of the device while it runs. This unofficial run entailed pounding the suspended plate after the initial, undisturbed, 5 minutes was allowed to happen. This did result in more "puffs" of powder to fall off of the part visually. A dusting can of air was also used, and this seemed to remove more "puffs" of powder as well. It seemed that the impact or compressed air helped loosen the powder from the surfaces, and the vibration helped to carry through the complex geometry. Unfortunately, specific values for masses were not obtained from this because the cardboard did not catch it well. The nature of pounding and blowing the powder made it impossible to contain and measure. This information is important to know for future operators and alterations to the device.

2.3 Conclusions

The validation runs proved that the design performed as needed, despite the large error present. The data collected showed that the device removed between 32\% and 44\% of the powder left on the part, and this easily meets the criteria of recovering greater than 0 grams of powder. The unofficial run 4 also showed some ways the design could be improved in the future, or how an operator could augment the design to remove more powder. Overall, the validation process used was representative of the production of the device, and it led to interesting findings.

2.4 Future Work

One critical element of work left for after Senior Design ends is to deliver the project to our sponsor. Since there were unprecedented constraints this semester, the delivery of Team 501's powder recover device was postponed until after the semester ends. Beyond this, further testing the device using stainless steel powder and parts should be done to determine the efficiency of the product in a stainless steel additive manufacturing environment. This will confirm the powder recovery abilities of the device when compared to the test runs performed with flour and PLA-printed parts.

In addition, there are several ways the final design can be enhanced. Adding a linear actuator to the frame of the product that impacts the plate could be implemented to remove more powder. Adding an automated compressed air device aimed at the underside of the part could also be used to remove more powder from the part. These ideas could be implemented later on to increase the amount of powder removed and recovered from the part.

References

3DSystems. (2019). Retrieved from https://www.3dsystems.com/3d-printers/prox-dmp-300

BADBOY Blasters. (2019). Retrieved from https://badboyblasters.com/product/abrasive-mediasand-blaster-bb1050led-bvr-pr-hv-fl-2/

United States Department of Labor - Occupational Safety and Health Administration. (2019). Retrieved from osha.gov

US Research Nanomaterials. (2019). Retrieved from https://www.us-nano.com/inc/sdetail/29782

M. Cain, “Clam shell blaster bb-2990led-bvr,” April 2020.

BAKERpedia, “Particle size — baking processes — why itmatters,” 2020.

Appendices

Appendix A: Code of Conduct

Mission Statement

Team 501 is committed to facilitating a positive work environment that supports professionalism, respect, and good ethics. Every member of the team will contribute to these goals with hopes of bringing out the best in themselves and the other members to benefit the project.

Team Roles

Any unforeseen "other roles" will be performed by someone decided by the Project Engineer. For example, if there is a task that doesn't fall in the following descriptions, the Project Engineer will decide who performs the task.

- Joshua Dorfman - Field Engineer. Responsible for managing project finances, purchases, and assembly.
- Vincent Giannetti - Manufacturing Engineer. Responsible for manufacturing leadership, additive manufacturing knowledge, and CAD assistance.
- Arlan Ohrt - Project and Systems Engineer. Responsible for project management, sponsor/instructor contact, document refinement, document submission, and system integration.
- Kevin Richter - Field Engineer. Responsible for adviser contact, CAD assistance, general research, and assembly.
- Noah Tipton - Design Engineer. Responsible for leading CAD, design specifications, and recording general information in meetings.

Methods of Communication

Discord will be used for messaging between group members. Acknowledgement of reading a message must be done within 24 hours. Discord will also be the main method of sharing files under 8 Mb. Any files larger than 8 Mb will be shared on Basecamp. Basecamp will also be used to store all copies of documents prior to submission by the project engineer.

Dress Code

The T501 dress code policy applies to all group members. Group members are expected to dress in:

- Casual attire for group and advisor meetings.
- Business casual attire for meetings with sponsor.
- Business attire (suit and tie) for presentations and professional gatherings.

Group members must always present a clean, professional appearance. Facial hair must appear groomed and intentional. Clothing and grooming styles dictated by religion or ethnicity are exempt.

Attendance Policy

All meetings will have group member attendance kept. Reasons for any group member absences will be recorded, as well as how far ahead of time the absent group member notified the rest of the group of the absence. This will be done by Vincent in a discord text channel dedicated to this record.

Weekly meetings with the group adviser, Dr. Simone Hruda, will be every Friday at 12:00pm, held in room A234.

There will be a weekly meeting period scheduled for every Monday at 2:00-5:00pm, which all group members will be present for. If additional time is needed during the week to complete assignments, projects, or any group work, all group members agree to meet on Tuesday and/or Thursday at 12:30-2:00pm. The location of the meeting will not be constant, so the location will be some agreed upon location within the engineering campus unless there are special circumstances.

Submission Policy

All assigned work must be sent to the project engineer at least 48 hours in advance unless extenuating circumstances are present. If such is the case, the project engineer must be informed as soon as possible and a group decision about the continuance of the assignment will be held.

McConomy Vacation Days will only be used for group assignments once a majority of the group agrees. If one group member would like to use a vacation day, they must get three out of five total group members to agree. If majority rule is established, those who are opposed to spending the vacation day still must spend the vacation day. If a group member has consumed all of their vacation days, there will be no grounds for the group to use any more vacation days on group assignments for the remainder of the semester.

Workload Policy

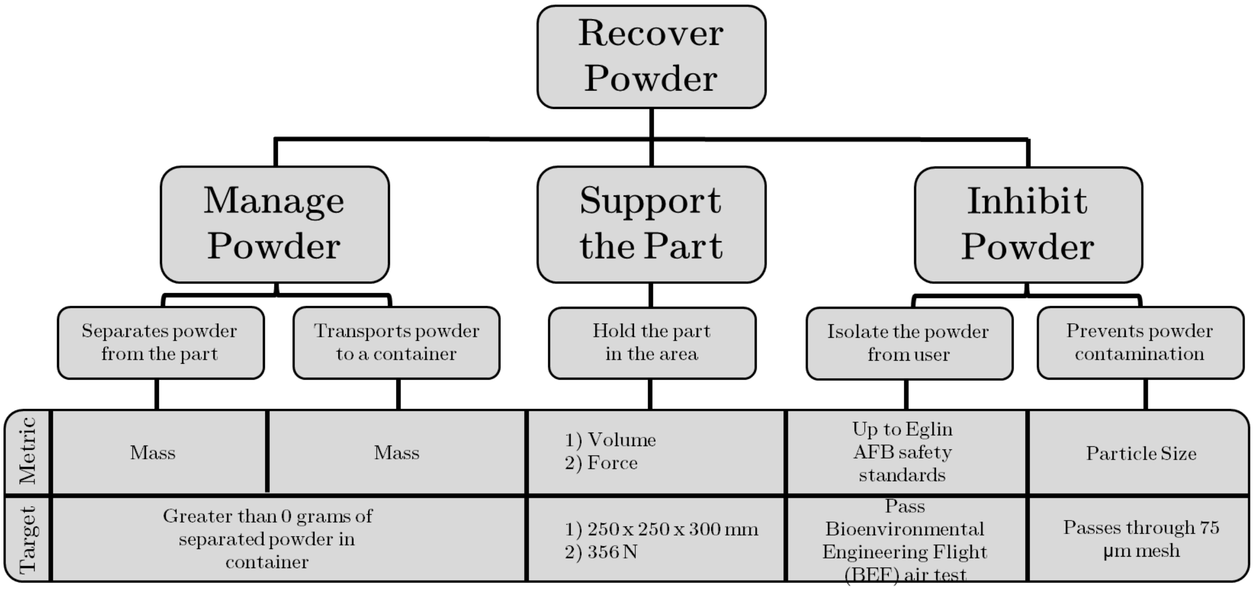
All group members are responsible for their "share" of the workload. Personal responsibilities are outlined in the "Work Breakdown" document which all group members have agreed upon. This document names every assignment in chronological order, broken down into specific sections which are named in their corresponding rubrics. Every group member has volunteered to cover an entire subsection, meaning they are responsible for not only a timely completion, but an accurate and professional final product.

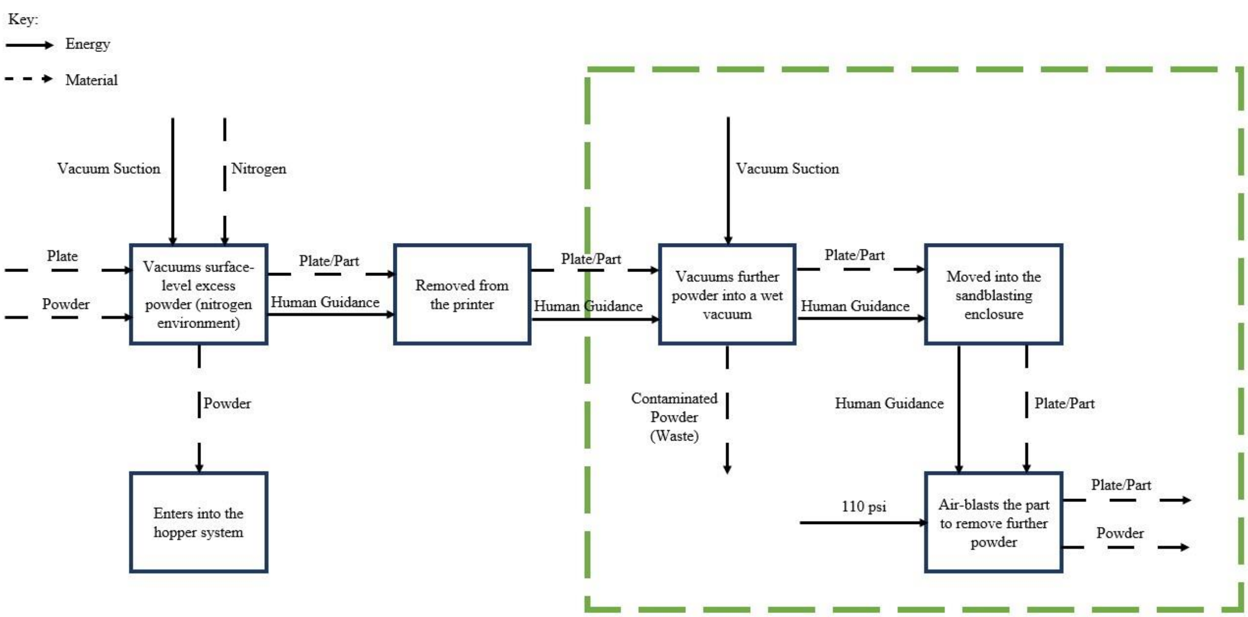
Conflict Resolution

All conflict will be documented and signed by both the project engineer and the member(s) involved. Any major decisions will be determined by majority rule. Should majority rule fail to resolve the issue, Dr. McConomy will be notified. Dr. McConomy will have the final say in any and all disagreements.

The Code of Conduct above was agreed upon and signed by all members of Team 501.

Appendix B: Functional Decomposition





Appendix C: Target Catalog

Target Catalog			
Functions	Metrics	Targets	Method of Validation
Hold the Part in the Area	Volume	250 x 250 x 300 mm	Dimensioning (via measuring device) and CAD
	Force	356 N	Physical weight, Force Calculations, and CAD
Separates Powder	**Mass of Separated Powder**	**95% recovered powder**	**Mass of separated powder compared to a baseline of previous methods**
Transports Powder to Container	**Mass of Contained Powder**	**95% transferred powder**	**Mass of contained powder compared to mass of separated powder**
Insulates User from Powder	Up to safety standards	PAPR Codes/Airtight Enclosures	Compare data to OSHA standards
Prevent Contamination of Powder	**Relative moisture**	**10% difference in recovered powder spread**	**Powder impact test to compare recovered powder to as-received powder**
Functionless	Time to operate	12 hours	Measure the time needed for the powder recovery system to operate
Functionless	Cost to operate	$95 per 100 g recovered	Cost to operate the product
Functionless	Overall Size/Footprint	Outside Enclosure: 770 x 1,350 mm footprint and 2,000 mm height	Dimensioning (via measuring device) and CAD
		Inside Enclosure: 1,210 x 730 mm footprint and 940 mm height	Dimensioning (via measuring device) and CAD

Appendix D: Operations Manual

Introduction

This device is to be used by the Air Force Research Lab to improve the amount of recovered power from objects fabricated using laser powder bed fusion. The device should only be used by trained personnel for the purpose of powder removal. As an industrial tool, those untrained in its operation should seek assistance prior to operation to avoid potential injury. For any questions, feel free to contact Team 501 from the FAMU-FSU College of Engineering located at 2525 Pottsdamer St, Tallahassee, FL 32310.

Device Operation

WARNING: Do not use this device unless you have been trained, and do not use the device for purposes other than powder recovery. Always use a powered, air-purifying respirator (PAPR) when handling the build plate, part, and powder containers. Always ensure that the sand-blasting cabinet doors are closed and secure prior to operation.

Directions

1. Open the sand blasting cabinet and slide the build plate and newly printed part upside-down, into the mounting channel, aligning the threaded holes with the screws above.

2. Fully thread the screws on top of the mounting channel into the build plate, allowing the screws to lift the build plate until it is firmly secured to the top of the channel.

3. Place an empty powder container below the funnel to collect powder and close the cabinet door.

4. Using the gloves built into the cabinet, connect the air hose to the vibrator, and power on the air compressor, increasing pressure until the in-line pressure gauge reads at least 80psi.

5. Allow the vibrator to vibrate the part until powder is no longer connected.

6. Shut down the air compressor and allow any compressed air to be released.

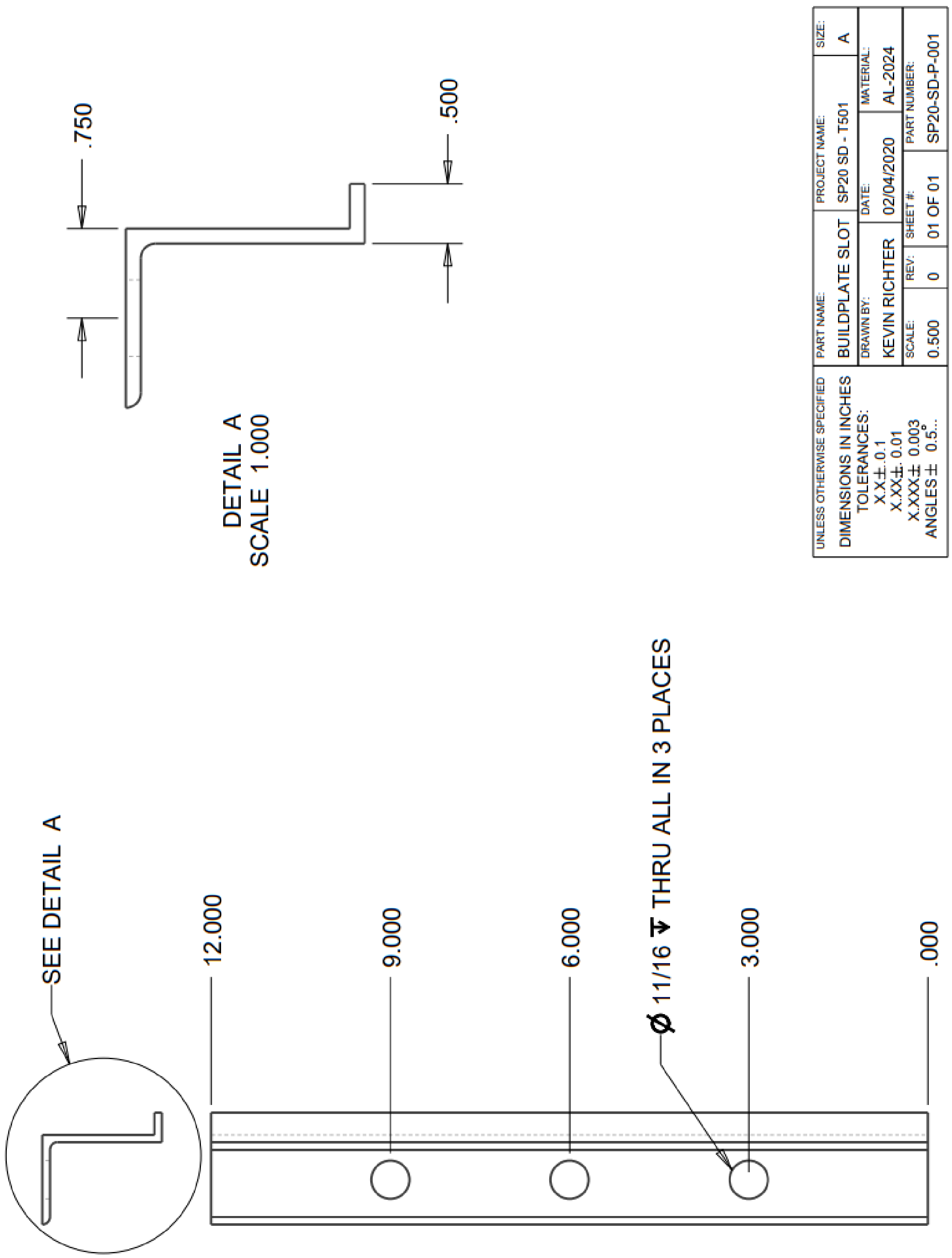
7. Using the gloves built into the cabinet, close the powder container, and disconnect the air hose from the vibrator.

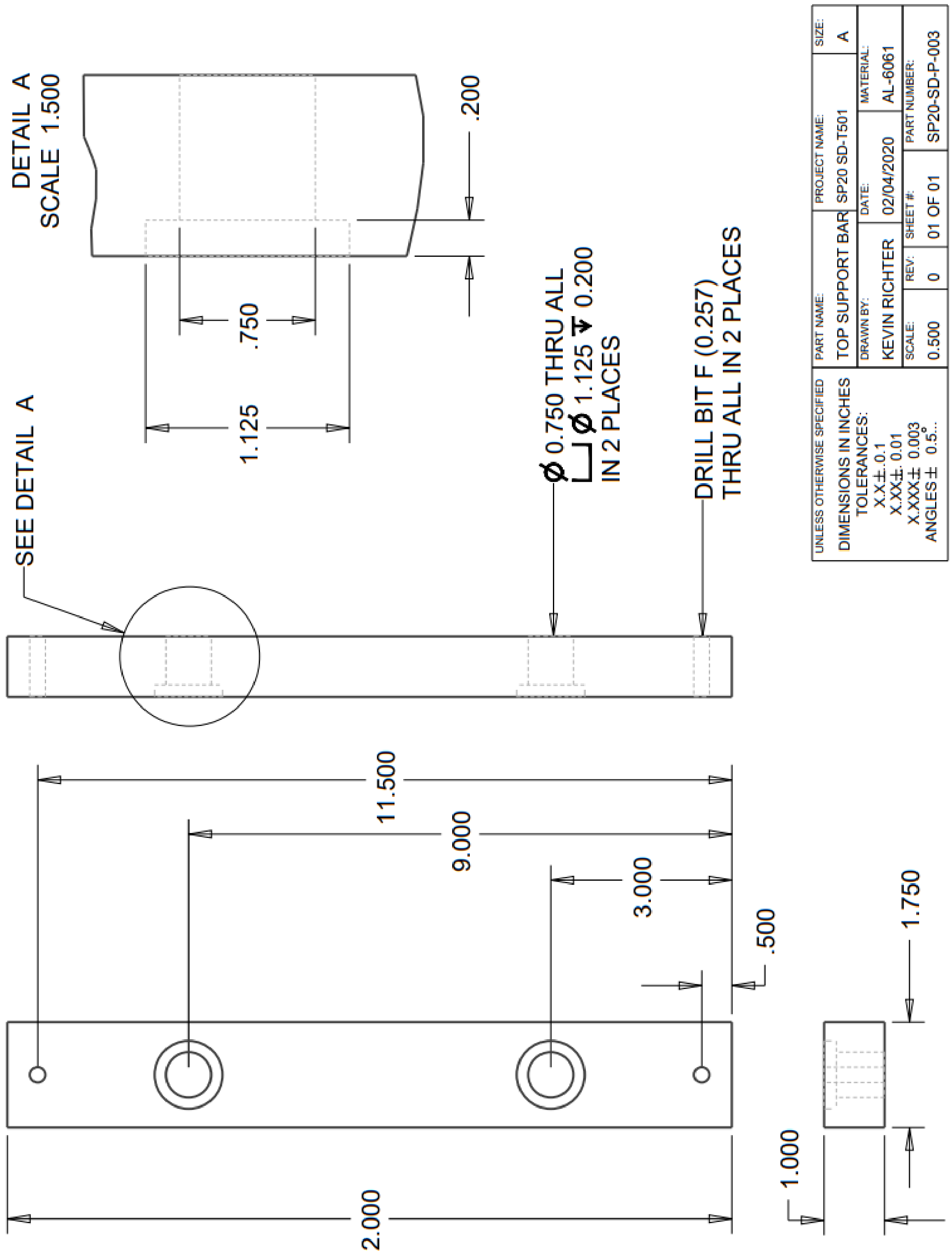
8. Open the cabinet door and remove the build plate and powder container.

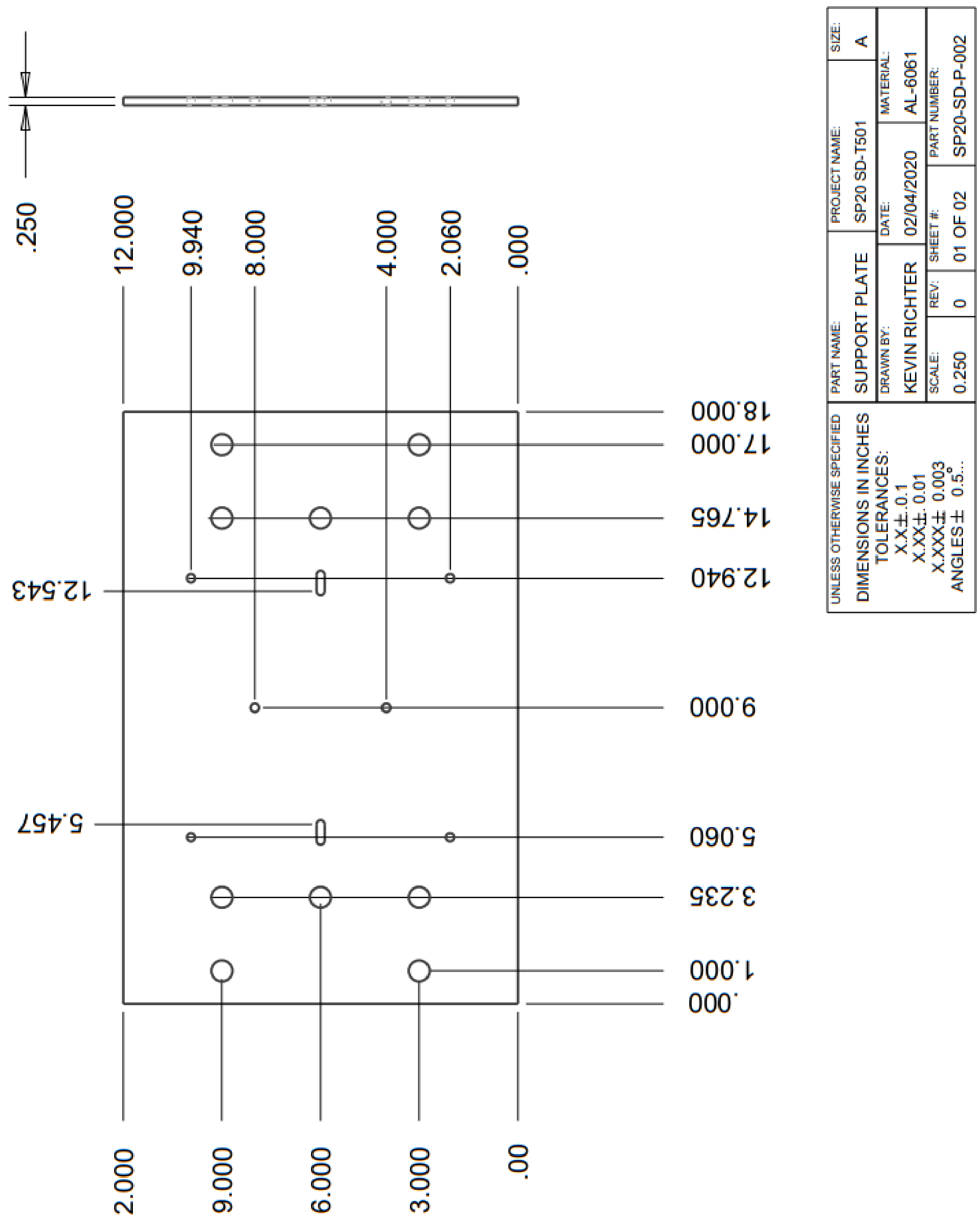
Maintenance

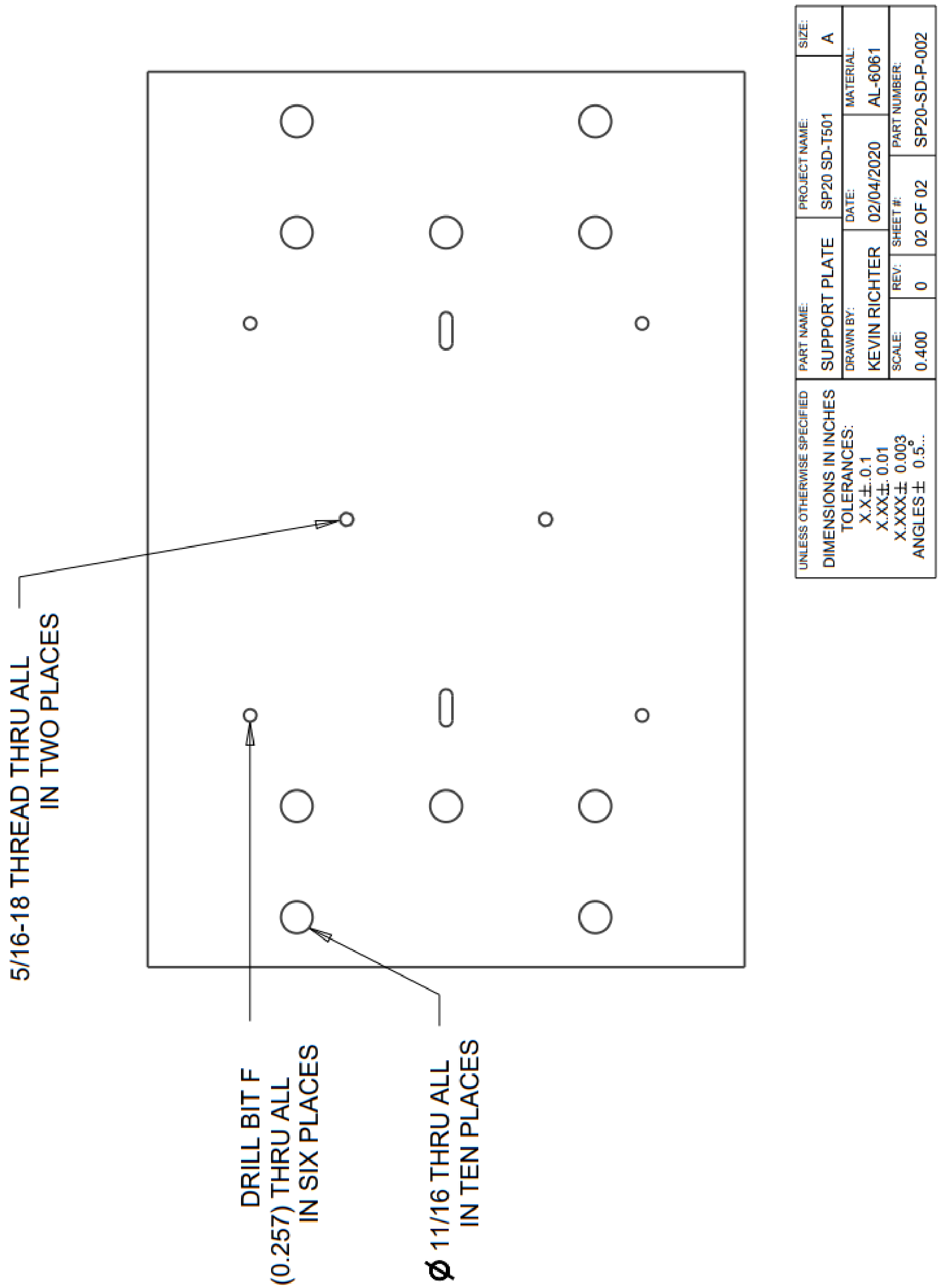
After each use, check to ensure that the system is fully operational. Replace any rubber showing signs of brittleness or cracking. Replace any spring dampers whose springs show signs of permanent deformation (relative to the other springs) or cracking. Replace any screws or nuts that have been stripped and reapply Loctite® 262 to those that have loosened. Additionally, replace the air compressor oil according to the manufacturer's user manual.

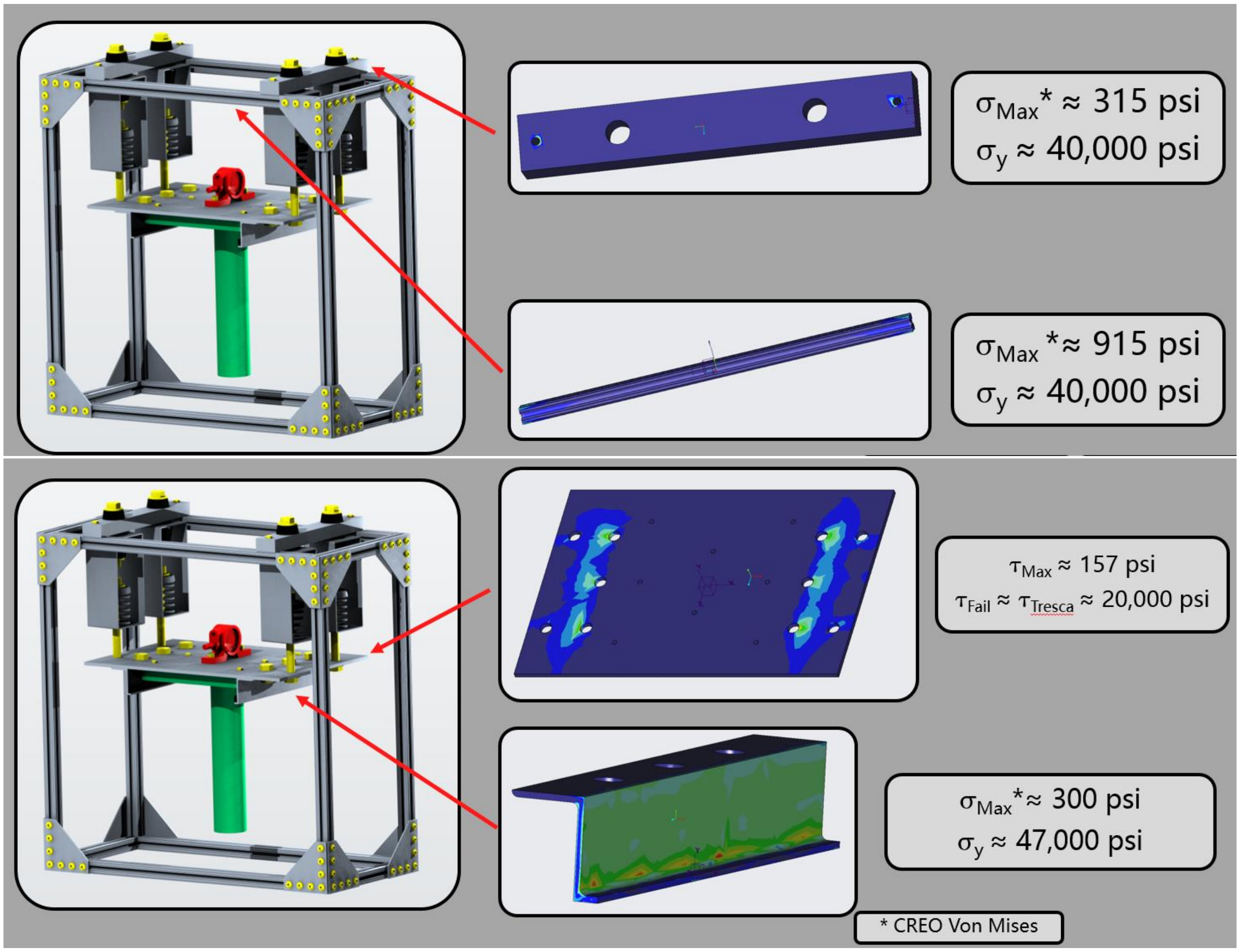
Appendix E: Engineering Drawings and Calculations




DETAIL A
SCALE 1.500
SEE DETAIL A
.200
.750
1.125
Ø 0.750 THRU ALL
⌴ Ø 1.125 ↧ 0.200
IN 2 PLACES
DRILL BIT F (0.257)
THRU ALL IN 2 PLACES
11.500
9.000
3.000
.500
1.750
1.000
12.000
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X± 0.1
X.XX± 0.01
X.XXX± 0.003
ANGLES± 0.5°
PART NAME:
TOP SUPPORT BAR
PROJECT NAME:
SP20 SD-T501
SIZE:
A
DRAWN BY:
KEVIN RICHTER
DATE:
02/04/2020
MATERIAL:
AL-6061
SCALE:
0.500
REV:
0
SHEET #:
01 OF 01
PART NUMBER:
SP20-SD-P-003


UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X ± .0.1
X.XX ± 0.01
X.XXX ± 0.003
ANGLES ± 0.5°
PART NAME:
SUPPORT PLATE
DRAWN BY:
KEVIN RICHTER
SCALE:
0.250
REV:
0
SHEET #:
01 OF 02
PROJECT NAME:
SP20 SD-T501
DATE:
02/04/2020
PART NUMBER:
SP20-SD-P-002
MATERIAL:
AL-6061
SIZE:
A
.250
12.000
9.940
8.000
4.000
2.060
.000
18.000
17.000
14.765
12.940
12.543
9.000
5.457
5.060
3.235
1.000
.000
12.000
9.000
6.000
3.000
.00


5/16-18 THREAD THRU ALL
IN TWO PLACES
DRILL BIT F
(0.257) THRU ALL
IN SIX PLACES
Ø 11/16 THRU ALL
IN TEN PLACES
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES:
X.X± 0.1
X.XX± 0.01
X.XXX± 0.003
ANGLES± 0.5°
PART NAME:
SUPPORT PLATE
PROJECT NAME:
SP20 SD-T501
SIZE:
A
DRAWN BY:
KEVIN RICHTER
DATE:
02/04/2020
MATERIAL:
AL-6061
SCALE:
0.400
REV:
0
SHEET #:
02 OF 02
PART NUMBER:
SP20-SD-P-002



Calculations done via CREO Parametric (CAD software).

Appendix F: Risk Assessment

INTRODUCTION

University laboratories are not without safety hazards. Those circumstances or conditions that might go wrong must be predicted and reasonable control methods must be determined to prevent incident and injury. The FAMU-FSU College of Engineering is committed to achieving and maintaining safety in all levels of work activities.

PROJECT HAZARD ASSESSMENT POLICY

Principal investigator (PI)/instructor are responsible and accountable for safety in the research and teaching laboratory. Prior to starting an experiment, laboratory workers must conduct a project hazard assessment (PHA) to identify health, environmental and property hazards and the proper control methods to eliminate, reduce or control those hazards. PI/instructor must review, approve, and sign the written PHA and provide the identified hazard control measures. PI/instructor continually monitor projects to ensure proper controls and safety measures are available, implemented, and followed. PI/instructor are required to reevaluate a project anytime there is a change in scope or scale of a project and at least annually after the initial review.

PROJECT HAZARD ASSESSMENT PROCEDURES

It is FAMU-FSU College of Engineering policy to implement followings:

1. Laboratory workers (i.e. graduate students, undergraduate students, postdoctoral, volunteers, etc.) performing a research in FAMU-FSU College of Engineering are required to

conduct PHA prior to commencement of an experiment or any project change in order to identify existing or potential hazards and to determine proper measures to control those hazards.

2. PI/instructor must review, approve and sign the written PHA.

3. PI/instructor must ensure all the control methods identified in PHA are available and implemented in the laboratory.

4. In the event laboratory personnel are not following the safety precautions, PI/instructor must take firm actions (e.g. stop the work, set a meeting to discuss potential hazards and consequences, ask personnel to review the safety rules, etc.) to clarify the safety expectations.

5. PI/instructor must document all the incidents/accidents happened in the laboratory along with the PHA document to ensure that PHA is reviewed/modified to prevent reoccurrence. In the event of PHA modification a revision number should be given to the PHA, so project members know the latest PHA revision they should follow.

6. PI/instructor must ensure that those findings in PHA are communicated with other students working in the same laboratory (affected users).

7. PI/instructor must ensure that approved methods and precautions are being followed by :

a. Performing periodic laboratory visits to prevent the development of unsafe practice.

b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.

c. Assigning a safety representative to assist in implementing the expectations.

d. Etc.

8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Project Hazard Assessment Worksheet				
PI/instructor:	Phone #:	Dept.:	Start Date:	Revision number:
Project:			Location(s):	
Team member(s):			Phone #:	Email:

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
Introduce powder to parts			Inhalation of Powder. Introducing powder to eyes/mouth. Contaminating environment with powder.	**EC:** PPE equipment will be used to ensure members are not contaminated. **AC:** Minimize amount of powder introduced to part. Signs will be placed on doors entering room that testing is being conducted to alert others of inhalation hazards and PPE requirements. Proper PPE will be checked by all group members or lab personnel with audible and visual confirmation.	Safety glasses, and breathing masks	Wet vac.	HAZARD:1 CONSEQ: Moderate Residual: Low Med	Safety controls are planned by both the worker and supervisor. A second worker must be in place before work can proceed (buddy system). Proceed with supervisor authorization.
Mounting vibrator to part			Accidental running of air before securely mounting. Incorrect mounting of vibrator.	**EC:** All bolts and threaded holes will be numbered so the vibrator is mounted correctly every time. **AC:** All group members will visually inspect connections and mounting point to ensure proper procedure. Area	Safety glasses, and breathing masks	Wet vac.	HAZARD:1 CONSEQ: Negligible Residual: Low	Safety controls are planned by both the worker and supervisor. Proceed with supervisor authorization.

				where compressed air controls are located will be a no go zone until all hands are outside of product and door is closed and secured.				
Mounting part to product			Incorrect mounting of part to product.	**EC:** All bolts and threaded holes will be numbered so the part is mounted correctly every time. **AC:** All group members will visually inspect connections and mounting point to ensure proper procedure.	Safety glasses, and breathing masks	Wet vac.	HAZARD:1 CONSEQ: Negligible Residual: Low	Safety controls are planned by both the worker and supervisor. Proceed with supervisor authorization.
Running air to vibrator			Improper air connections. Running product before door has been closed. Not waiting appropriate time before opening door.	**EC:** Specific air line connections on vibrator and lines so cannot be connected incorrectly. Timers with audible and visual alarms will be set to ensure proper time has passed before opening door. **AC:** All members of group and any lab personnel will confirm door is closed before running air with audible and visual confirmation.	Safety glasses, breathing masks and ear protection	Wet vac.	HAZARD:1 CONSEQ: Negligible Residual: Low	Safety controls are planned by both the worker and supervisor. Proceed with supervisor authorization.
							HAZARD: CONSEQ:	

Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

Name	**Signature**	**Date**	**Name**	**Signature**	**Date**
____________________	______________	____________	____________________	______________	______

Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures are followed.

Name	**Signature**	**Date**	**Name**	**Signature**	**Date**
____________________	______________	____________	____________________	______________	_______
____________________	______________	____________	____________________	______________	_______

DEFINITIONS:

Hazard: Any situation, object, or behavior that exists, or that can potentially cause ill health, injury, loss or property damage e.g. electricity, chemicals, biohazard materials, sharp objects, noise, wet floor, etc. OSHA defines hazards as "*any source of potential damage, harm or adverse health effects on something or someone".* A list of hazard types and examples are provided in appendix A.

Hazard control: Hazard control refers to workplace measures to eliminate/minimize adverse health effects, injury, loss, and property damage. Hazard control practices are often categorized into following three groups (priority as listed):

1. **Engineering control:** physical modifications to a process, equipment, or installation of a barrier into a system to minimize worker exposure to a hazard. Examples are ventilation (fume hood, biological safety cabinet), containment (glove box, sealed containers, barriers), substitution/elimination (consider less hazardous alternative materials), process controls (safety valves, gauges, temperature sensor, regulators, alarms, monitors, electrical grounding and bonding), etc.

2. **Administrative control:** changes in work procedures to reduce exposure and mitigate hazards. Examples are reducing scale of process (micro-scale experiments), reducing time of personal exposure to process, providing training on proper techniques, writing safety policies, supervision, requesting experts to perform the task, etc.

3. **Personal protective equipment (PPE):** equipment worn to minimize exposure to hazards. Examples are gloves, safety glasses, goggles, steel toe shoes, earplugs or muffs, hard hats, respirators, vests, full body suits, laboratory coats, etc.

Team member(s): Everyone who works on the project (i.e. grads, undergrads, postdocs, etc.). The primary contact must be listed first and provide phone number and email for contact.

Safety representative: Each laboratory is encouraged to have a safety representative, preferably a graduate student, in order to facilitate the implementation of the safety expectations in the laboratory. Duties include (but are not limited to):

- Act as a point of contact between the laboratory members and the college safety committee members.
- Ensure laboratory members are following the safety rules.
- Conduct periodic safety inspection of the laboratory.
- Schedule laboratory clean up dates with the laboratory members.
- Request for hazardous waste pick up.

Residual risk: Residual Risk Assessment Matrix are used to determine project's risk level. The hazard assessment matrix (table 1) and the residual risk assessment matrix (table2) are used to identify the residual risk category.

The instructions to use hazard assessment matrix (table 1) are listed below:

1. Define the workers familiarity level to perform the task and the complexity of the task.
2. Find the value associated with familiarity/complexity (1 – 5) and enter value next to: HAZARD on the PHA worksheet.

Table 1. Hazard assessment matrix.

		Complexity		
		Simple	Moderate	Difficult
	Very Familiar	1	2	3

Familiarity Level	Somewhat Familiar	2	3	4
	Unfamiliar	3	4	5

The instructions to use residual risk assessment matrix (table 2) are listed below:

1. Identify the row associated with the familiarity/complexity value (1 – 5).
2. Identify the consequences and enter value next to: CONSEQ on the PHA worksheet. Consequences are determined by defining what would happen in a worst case scenario if controls fail.
    a. Negligible: minor injury resulting in basic first aid treatment that can be provided on site.
    b. Minor: minor injury resulting in advanced first aid treatment administered by a physician.
    c. Moderate: injuries that require treatment above first aid but do not require hospitalization.
    d. Significant: severe injuries requiring hospitalization.
    e. Severe: death or permanent disability.
3. Find the residual risk value associated with assessed hazard/consequences: Low –Low Med – Med– Med High – High.
4. Enter value next to: RESIDUAL on the PHA worksheet.

Table 2. Residual risk assessment matrix.

Assessed Hazard Level	**Consequences**				
	Negligible	Minor	Moderate	Significant	Severe
5	Low Med	Medium	Med High	High	High
4	Low	Low Med	Medium	Med High	High
3	Low	Low Med	Medium	Med High	Med High
2	Low	Low Med	Low Med	Medium	Medium
1	Low	Low	Low Med	Low Med	Medium

Specific rules for each category of the residual risk:

Low:

- Safety controls are planned by both the worker and supervisor.
- Proceed with supervisor authorization.

Low Med:

- Safety controls are planned by both the worker and supervisor.
- A second worker must be in place before work can proceed (buddy system).
- Proceed with supervisor authorization.

Med:

- After approval by the PI, a copy must be sent to the Safety Committee.
- A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee.
- A second worker must be in place before work can proceed (buddy system).
- Limit the number of authorized workers in the hazard area.

Med High:

- After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA.
- A written Project Hazard Control is required and must be approved by the PI and the Safety Committee before proceeding.
- Two qualified workers must be in place before work can proceed.
- Limit the number of authorized workers in the hazard area.

High:

- The activity will not be performed. The activity must be redesigned to fall in a lower hazard category.

Additional Information: Hazard types and examples

Types of Hazard	**Example**
Physical hazards	Wet floors, loose electrical cables objects protruding in walkways or doorways
Ergonomic hazards	Lifting heavy objects Stretching the body Twisting the body Poor desk seating
Psychological hazards	Heights, loud sounds, tunnels, bright lights
Environmental hazards	Room temperature, ventilation contaminated air, photocopiers, some office plants acids
Hazardous substances	Alkalis solvents
Biological hazards	Hepatitis B, new strain influenza
Radiation hazards	Electric welding flashes Sunburn
Chemical hazards	Effects on central nervous system, lungs, digestive system, circulatory system, skin, reproductive system. Short term (acute) effects such as burns, rashes, irritation, feeling unwell, coma and death. Long term (chronic) effects such as mutagenic (affects cell structure), carcinogenic (cancer), teratogenic (reproductive effect), dermatitis of the skin, and occupational asthma and lung damage.
Noise	High levels of industrial noise will cause irritation in the short term, and industrial deafness in the long term.
Temperature	Personal comfort is best between temperatures of 16°C and 30°C, better between 21°C and 26°C. Working outside these temperature ranges: may lead to becoming chilled, even hypothermia (deep body cooling) in the colder temperatures, and may lead to dehydration, cramps, heat exhaustion, and hyperthermia (heat stroke) in the warmer temperatures.

Being struck by	This hazard could be a projectile, moving object or material. The health effect could be lacerations, bruising, breaks, eye injuries, and possibly death.
Crushed by	A typical example of this hazard is tractor rollover. Death is usually the result
Entangled by	Becoming entangled in machinery. Effects could be crushing, lacerations, bruising, breaks amputation and death.
High energy sources	Explosions, high pressure gases, liquids and dusts, fires, electricity and sources such as lasers can all have serious effects on the body, even death.
Vibration	Vibration can affect the human body in the hand arm with `white-finger' or Raynaud's Syndrome, and the whole body with motion sickness, giddiness, damage to bones and audits, blood pressure and nervous system problems.
Slips, trips and falls	A very common workplace hazard from tripping on floors, falling off structures or down stairs, and slipping on spills.
Radiation	Radiation can have serious health effects. Skin cancer, other cancers, sterility, birth deformities, blood changes, skin burns and eye damage are examples.
Physical	Excessive effort, poor posture and repetition can all lead to muscular pain, tendon damage and deterioration to bones and related structures
Psychological	Stress, anxiety, tiredness, poor concentration, headaches, back pain and heart disease can be the health effects
Biological	More common in the health, food and agricultural industries. Effects such as infectious disease, rashes and allergic response.