Final Design Report

Project 16 – Zen and The Art of Glitter Deposition

Team Members:
Jake Varakian
Emma Marston
Helen Wang
Anthony Vieriu

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1 Abstract

In the Fall of 2021, the team set out to create a module that would efficiently and completely coat adhesive with glitter while reusing any non-adhered particles. The current design is a wedge-shaped chamber with mounting holes on either side to attach to the conveyor belt located at Integrity Industrial Inkjet Integration. The chamber makes use of a hopper and roller deposition method to deposit a dusting of glitter onto adhesive patterns entering the chamber. Then at the exit of the chamber, a blade of air causes loose glitter that would exit the chamber to tumble backwards. This tumbling motion prevents glitter from escaping while also continuing to coat the adhesive further back in the chamber. After working on this design for two semesters, the team developed a product that accomplished all the goals set out in Fall 2021 apart from preventing glitter escape from the chamber. The next steps for this project would be to continue development of the air blade attachment to create a more uniform blade of air, thus improving the clearing of the conveyor belt. Additionally, implementing an automated deposition system would greatly improve the real-world functionality of the module.

2 Problem Statement

Our client is Integrity Industrial Inkjet Integration, a company that uses inkjet technology for various applications across a wide range of industries. The function of interest for this project is the application of powders to a substrate. This is done by using inkjet printer heads to spray adhesive in a programmable pattern and sending the patterns through a continuously depositing curtain of powder across the width of a conveyor belt. The adhesive is then cured with a UV light and more layers of adhesive and powder may be added. The problem with this current method is that material use is extremely high with no recovery method to reuse the material that isn't adhered to the substrate.

The client requested proof of concept for a module that would coat a layer of adhesive with glitter and reuse any glitter that is not adhered. This module would be used in conjunction with their current Inkjet and UV curing setup to stack multiple layers of powder and adhesive while reducing material waste. A fully functional product would reduce material waste and save money on manufacturing across a plethora of industries. Additionally, due to the conveyor compatibility, the module could be used in high-speed manufacturing to continuously coat items without the need for batch coatings.

The main qualities of a successful module are to ensure the adhesive is completely coated with no deformation of the desired pattern. It should also be able to remove excess glitter and utilize it for subsequent coatings with minimal glitter escaping from the chamber. A product that performs these main functions would be considered a success.

3 Requirements

The complete list of requirements and how they are weighted by potential customers is found below. The three customers identified for this table are: Integrity, Integrity's Customers, and the conveyor technicians that would be working with the module. Each of the requirements was given a score to represent its importance to each customer. Additionally, each customer was given a different number of points to represent the weight of their opinion.

Table 1: Customer Requirements

Customers				Requirements	
Integrity	Integrity's Customers	Conveyor Technicians		Category	Requirement
10	7	-		*Functionality*	Remove excess glitter without removing adhered particles
13	**10**	**-**			**Remove excess glitter without removing any adhesive**
15	**10**	**-**			**Glitter covers the adhesive efficiently**
9	3	**10**			**Ensure minimal glitter escapes the box**
6	-	5			Box must be securely mountable to Integrity's conveyor system
5	-	-			Must not take up too much space on Integrity's conveyor
5	5	10			Operates for long durations reliably
13	**7**				**Glitter must be randomly and evenly distributed across adhesive**
8	5	**10**		*Safety*	**Box must have zero risk for particle ignition**
8	3	**10**			**A way to easily control device to stop or divert the glitter flow**
8	-	5		*Aesthetic*	Box shall have a way to clearly observe particle flow within it

The three highest scored requirements for each client have been bolded in the above table. For Integrity and their clients, the top three requirements match as their priorities are very similar. For the conveyor technician, high level requirements focus on potential hazards when operating the module and mitigating risk.

The highest-level requirement for both Integrity and their clients was, "Glitter covers the adhesive efficiently," this is a fundamental function of the module. The main purpose of the glitter module is to reduce material waste, if this is not accomplished then the main improvements over the current method have not been completed. The second high-level requirement is, "removes excess glitter without removing any adhesive," this is an especially important requirement as maintaining the image quality is crucial. If the image exiting the module is different from the one desired by the client, then the box has failed. The final high-level requirement for integrity and their clients is, "glitter must be randomly and evenly distributed across the adhesive". This requirement is important as it ensures that the entire design is coated without any bias towards a specific area of the conveyor belt. This guarantees that any design would be coated with shape not being a factor.

The three highest level requirements for the conveyor belt technician all scored the same and center around maintaining the safety of the technician. The first is "ensure minimal glitter escapes the box". This requirement is important as powder escaping into a manufacturing line could cause issues with the other machinery present resulting in a shutdown of the entire conveyor belt. Also, depending on the powder, inhalation could be dangerous as well. The second high-level requirement is that "the box must have zero risk for particle ignition." Due to the flammability of some powders, having any ignition risk combined with mixing within the chamber could be extremely dangerous. The final high-level requirement is "a way to easily control device to stop or divert glitter flow". In the case of any sort of error on the conveyor belt, it is important to have a way to stop the deposition of glitter quickly and safely. This could prevent issues on the manufacturing line from getting worse as well as prevent unnecessary material waste.

4 Work Design Concept

4.1 Functionality

This product is a proof of concept for a new method of additive manufacturing. This method of depositing and mixing powder to coat an adhesive can be applied to a wide variety of industries. Any application that requires coating, patterned coating, 3D printed build, or 3D printed gradient is possible with this process. This module accomplishes this by first depositing a dusting of particles onto an adhesive coated substrate as it enters the coating chamber. Then the air blade gently blows across the entire width of the conveyor belt to cause any loose particles that never landed on and/or aren't touching the adhesive to tumble backwards and coat the emptier areas of the adhesive. As the substrate exits the chamber, any extra glitter continues to tumble backwards remaining inside the chamber and can be used for the next coating

4.2 Coating Chamber

To accurately convey the functionality of the coating chamber, each part will be described in such a way that allows the reader to understand what each section of the part is for. First starting with the main chamber. It has two 7.5-inch openings on either side for the substrate to come into and out of the chamber on Integrity's conveyor belt system. On the top there is a clear acrylic sheet which allows the operator to see the coating process inside the chamber as it is running, and an opening for particle introduction into the chamber. Also, on each side there are two 1/4 20-inch mounting holes spaced 4.5 inches apart to mount onto Integrity's conveyor belt system. Overall, the coating chamber is designed to resemble a wedge shape. There are two main benefits to this geometry that allow the wedge to perform its job effectively. Firstly, the conveyor outlet side of the chamber is low and close to the substrate, this allows the air coming in through the air blade adapter to blow as close to the substrate as possible. Glitter can easily be blown by the air due to this small distance between the blade and the substrate, allowing the air speed to stay as close to a minimum as possible ensuring the particles don't blow too far, and out of the conveyor inlet. Secondly, the high end towards the conveyor inlet aside allows the air flow to expand and slow down as it travels down the length of the inside of the chamber, this will further prevent glitter from being blown out of the conveyor inlet. The following image, figure 1 is a computer-generated image of the full wedge assembly showcasing all the parts.

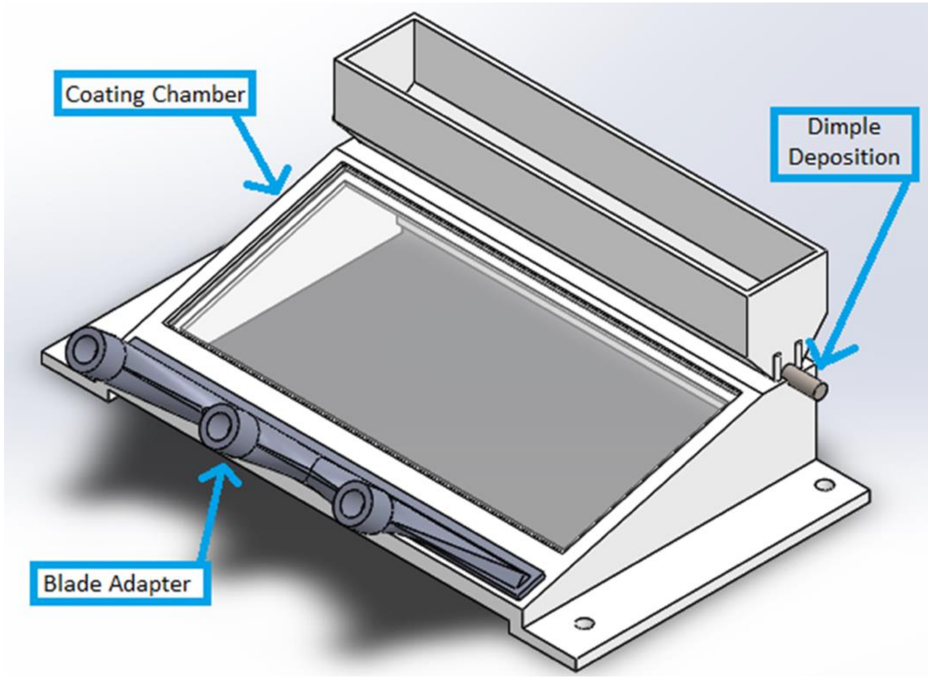


Figure 1: System Overview

4.3 Air Blade Adaptor

The air blade adaptor is a 7.5-inch-wide air control mechanism that takes in airflow from three equidistant inlets which are each connected to a tube that connects to an air compressor. The purpose of the air blade adapter is to transform the shape of the air coming in from the pump to resemble a flat 7.5-inch-wide blade. This shape of airflow will be used to gently clear glitter off the entire width of the conveyor belt. As the flow spreads across a larger area the speed of the flow is naturally reduced along the length of the adapter, allowing for more precise calibration to ensure particles aren't blowing out of the chamber. Additionally, the adaptor causes unadhered particles to tumble backwards, which assists in the coating of any remaining adhesive.

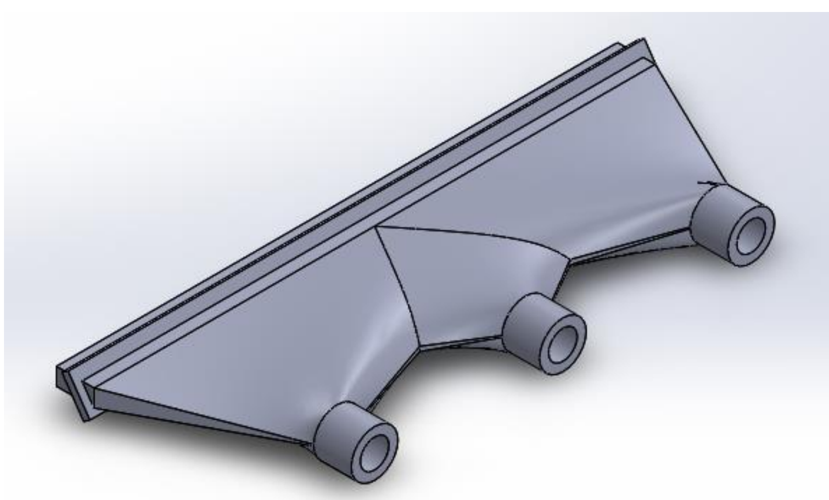


Figure 2: Air Blade Adaptor

4.4 Dimple Deposition

The dimple roller is a 7.5-inch-wide cylinder that covers the entire width of the conveyor belt. The roller is the beginning of the coating process, showering the substrate with a dusting of particles. The dimple design on the surface allows the roller to collect a controlled quantity of particles from the hopper and drop them into the chamber. The dimples also ensure that no clumping takes place with each revolution. The dusting makes coating and mixing easier because clumps of particles would be more difficult to separate from one another and may not blow through the system very well. The roller slides onto a ¼ inch metal shaft to provide rigidity and support along the length of the cylinder, securing everything in place with glue. The additional material that sticks out is used to hand-turn the roller. The team used this hand turning method for testing/controlling the deposition, but additionally would be useful for breaking jams in the hopper/roller assembly. While the hand deposition was useful in the development phase, automation of this process is a key part of the future steps for this design.

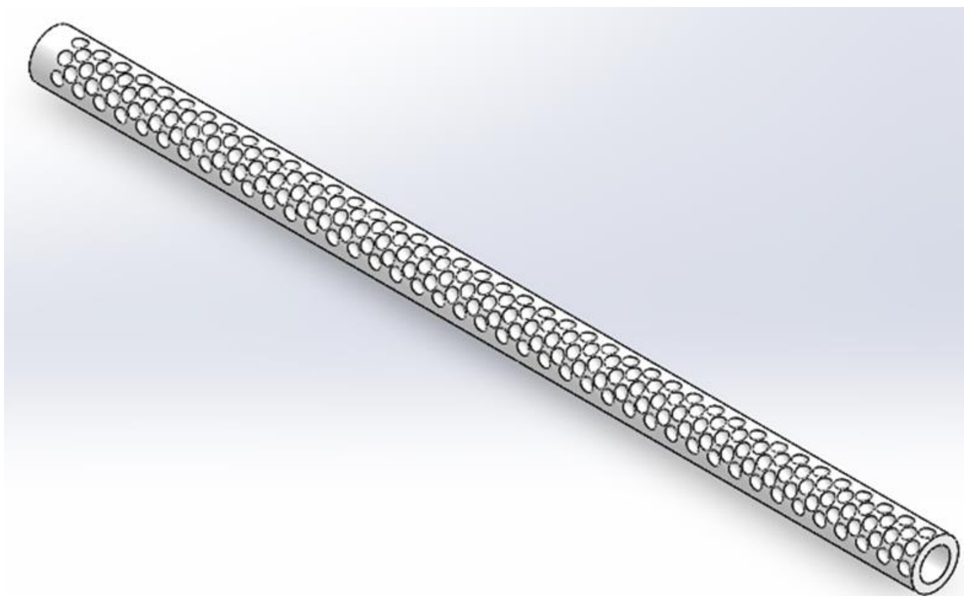


Figure 3: Dimple Deposition Roller

4.5 Hopper

The hopper subassembly is a 7.5-inch-long chamber to align with the dimensions of conveyor belt and dimple deposition and chamber assembly. The legs at the bottom of the hopper are the attachment points for connecting with the chamber. The hopper design on the top allows the glitter to be added into the product. The opening at the bottom is connected to the dimple deposition cylinder, the dimensions of the hopper opening's length and width align with the dimple roller length and diameter. The alignment with the dimple deposition is critical and was one of the challenges during the design process because of the potential of glitter escaping. Geometry tolerancing and dimensioning are a critical perspective of this design, which showed the importance of this part and the parts above.

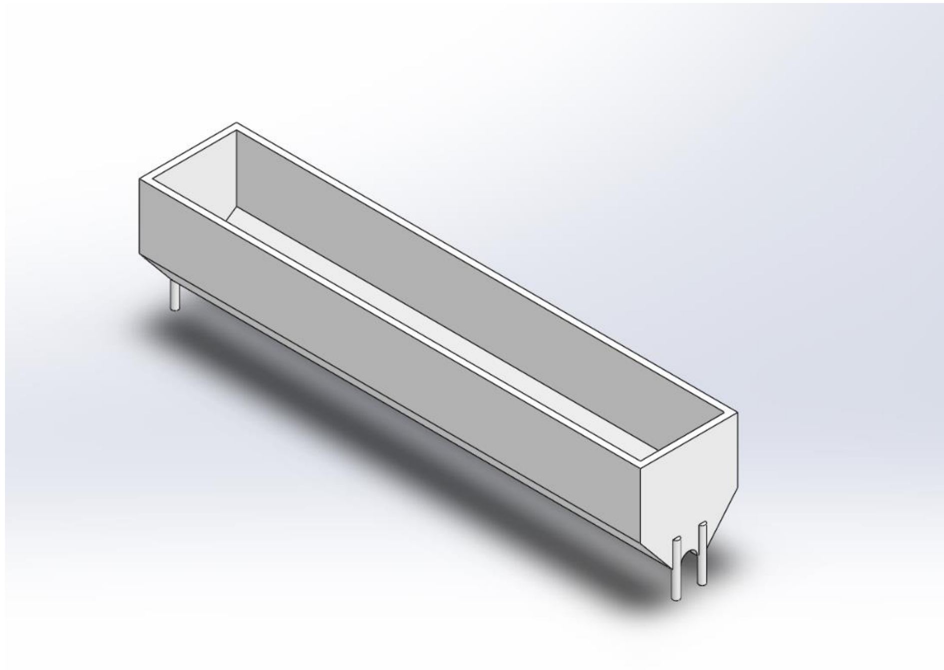


Figure 4: Hopper

4.6 Visual Scale

All the testing results are measured by the visual scale created by the team. The visual scale on the left verifies that glitter entering the system is not blown out of the module into the surrounding area. This will be done by running the system as intended and using a visual scale to score the amount of escaped glitter based on an acceptable range. The visual on the right verifies that the method for removing glitter does not also remove the glitter that has landed on the adhesive. This will be done by running the system with wet glue that has been pre-coated with glitter and comparing the number of displaced particles to the pre-determined visual scale.

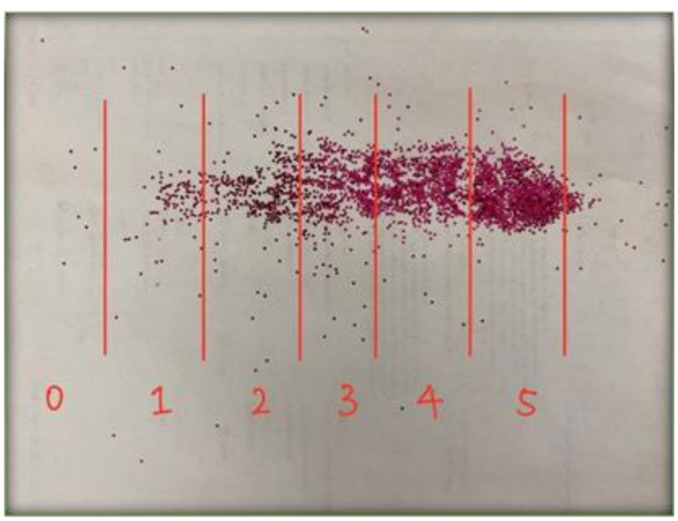


Figure 5: visual scale of glitter escaping rate

Figure6: visual scale of glitter coating rate

4.7 Design Overview

The design contains 4 subassemblies described above: air blade adaptor, dimple deposition, hopper, and the chamber. They were prototyped by 3D printing and ABS material. The design demonstrates the concept for a new method of additive manufacturing. Applications include decorative coating and 3D particle printing are possible to be applied with this design.

Figure 7: Product Prototype

Figure 8: UVM logo printed by glitter box design

5 Analyses

5.1 CFD Analysis of Two and Three Inlet Air Blade Adaptor Designs

Coming into the second semester of the SEED program, the team began experimenting with the use of an air blade adaptor to convert the pipe flow from the air source into a flat blade of air. This would make the uniform removal of glitter from the substrate much easier by spreading the airflow across the entire width of the conveyor belt. The first iteration of the air blade adaptor had a single inlet and a single outlet. While this design showed some promise for the concept of the adaptor, it failed to clear the entire width of the conveyor belt. The problem was that the flow from the pump was not expanding to fill the entire rectangular outlet. There was significantly more flow towards the center of the outlet and the edges of the conveyor belt remained uncleared. To remedy this problem, new versions of the adaptor with multiple air inlets were developed. The hope was that the multiple inlet designs would promote a more uniform blade of air by reducing the area that each stream had to expand across.

Before printing the new versions with two and three inlets, CFD was used to predict how each might perform and determine how they might be improved. ANSYS/Fluent was used to run the CFD, these programs make use of the continuity equation and the Navier-Stokes equation to solve for basic flow characteristics.

$$Continuity: \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \cdot v) = 0$$

$$Navier - Stokes: \rho \left(\frac{dV}{dt} + v \cdot \nabla v \right) = -\nabla p + \mu \nabla^2 v + f$$

The SolidWorks models of each adaptor were exported into ANSYS Workbench where a volume extraction was used to mesh the space where air would be flowing. In addition to the interior of the adaptor, space directly out of the outlet was also meshed to see how the flow spread out once leaving the adaptor. This interior mesh was generated using a sphere of influence method centered about the origin of the SolidWorks model, each element was given a size of .001 m. This method was used for both versions and resulted in a mesh of 467784 finite volumes for the 2-inlet version and 472308 finite volumes for the 3-inlet version. The default generated mesh for the solid blade adaptor was kept as there would be no flow through the solid walls. Inlet and outlet boundary conditions were specified for each version and the finished meshes were exported to Fluent where the simulations would be run.

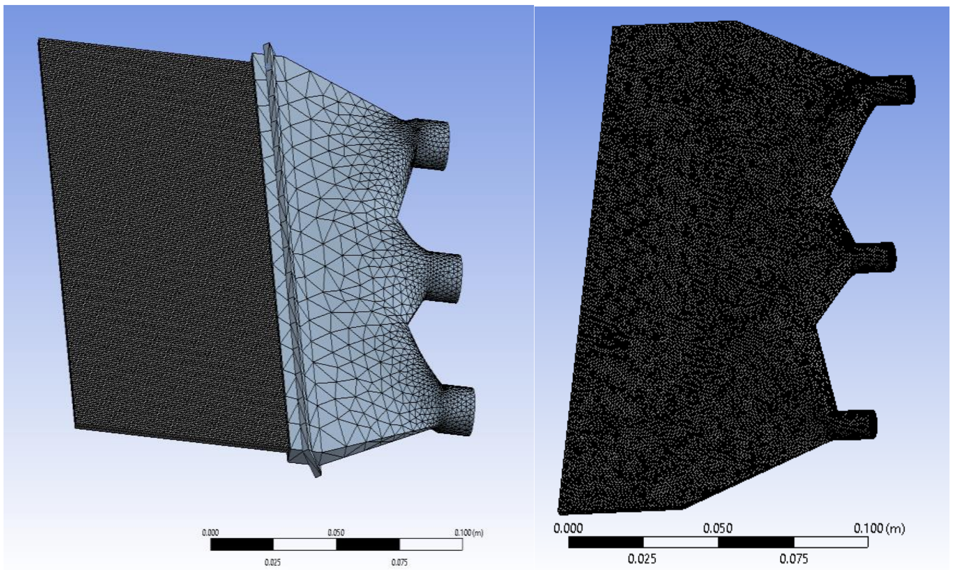
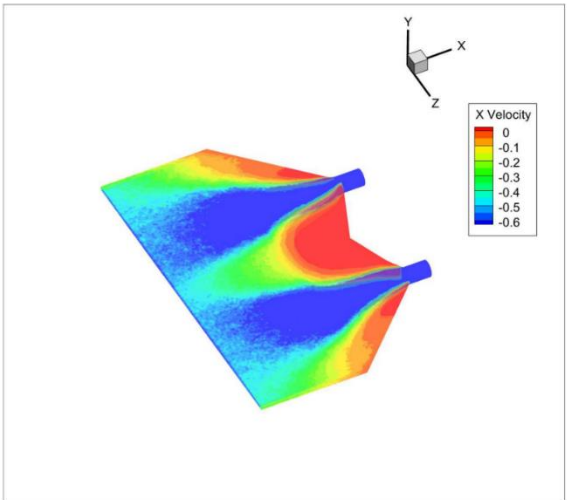


Figure 9 and 10: Interior Meshes for each version

Once in Fluent, the simulation parameters were set. A pressure-based steady-state simulation was used with air as the working fluid. The air was given the values of $\rho = 1.225 \ \frac{kg}{m^3}$ and $\mu = 1.225 \ \frac{kg}{m \cdot s}$, it was assumed that the density and viscosity of the air would remain constant. For each version, a total velocity magnitude across all inlets of $4 \ \frac{m}{s}$ normal to the boundary was used. This is to replicate the single flow being split into multiple paths. All pressure outlets were given a gauge pressure equal to atmospheric pressure, 101325 Pa.

The parameter of interest for this analysis was the x-velocity contour. Looking at the x-velocity contour would allow the group to visualize the distribution of flow exiting the blade adaptor. Ideal results would have a constant velocity across the entire exit of the adaptor indicating a uniform flow. Upon looking at the results below, there are still significant gaps in the contour for the two-inlet adaptor. While this design is still an improvement on the single-inlet adaptor, there is now a small gap at the center in addition to the small gaps along the edges. The areas that would be theoretically cleared by the two-inlet adaptor have a velocity magnitude of about $0.55 \ \frac{m}{s}$.

Upon looking at the results from the three-inlet adaptor, we see a more uniform flow across the exit. While there is some noticeable speckling of the velocity, this iteration covers more of the exit with more consistent flow. The average outlet velocity for the three-inlet adaptor is around 0.5 $\frac{m}{s}$. This lower exit velocity makes sense as the mixing of all three flows would result in some velocity losses.



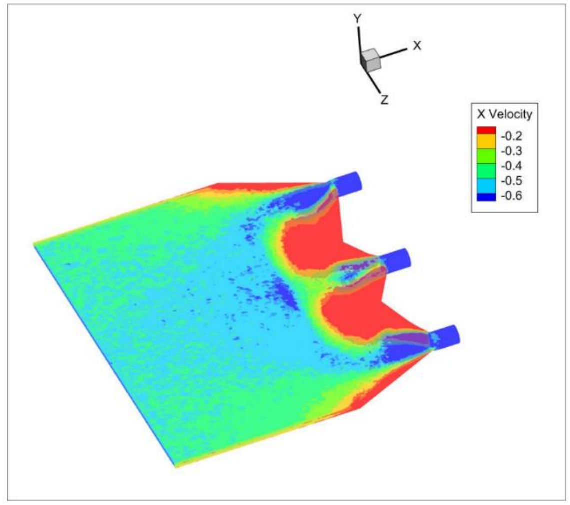


Figure 11: Two-Inlet X-Velocity Contour *Figure 12: Three-Inlet X-Velocity Contour*

When looking at these results it is important to note that, to better see the flow at the edge of the mesh, the low end of the scale was brought up. Because of this, much of the flow close to the inlet is displayed as having a velocity of 0.6 $\frac{m}{s}$ when it is actually higher. This is especially noticeable for the two-inlet version.

Using these results, the team concluded that the three-inlet design would perform the best out of the three designs. Both the two and three-inlet designs were 3D printed in a batch at the same time. Experimental tests confirmed the computational results, and the three-inlet adaptor was implemented into the final product where it greatly improved upon the single inlet design.

5.2 Mathematical analysis of Dimple Design and Glitter Deposition Volume

Dimple deposition is one of the innovative designs of the project. The roller is a long cylindrical shaft with dimples covered on ½ size of the surface area. The team was inspired by the mechanism of gumball machine at the very beginning and designed a cylindrical shaft with an extrude cut on one side of the surface. There was a problem with this design because it caused depositing in clumps and made it difficult to mix glitter. Later throughout the semester, the team was inspired by the idea of dimples on the golf ball, which would scoop smaller amount of glitter with each dimple, therefore, the design was upgraded by having dimples on the surface, and this change was designed to "dust" instead of dropping clumps. The roller covers the entire width of the conveyor belt to begin the coating process with a shower of glitter. The dimple design on the surface allows it to collect a controlled amount of glitter from the hopper and deposit a dusting with each revolution.

To analyze this dimple deposition functionality, it is important to have precise calculations of the amount of glitter deposited in one rotation so the user would have a clear idea on material quantity of product impact. By comparing the result of the dimple deposition volume with one of the engineering specifications that "the hopper shall deposit 1 tsp+/- 1/6 tsp of glitter per coating to prevent material waste", the mathematical analysis will show the deposition result of the dimple deposition design.

-Mathematics equations & calculations:

- The volume of a teaspoon: $V_t = 0.301\ in$^3
- Volume of a deposition cylinder with no openings: $V_o = 0.56\ in$^3
- Volume of a deposition cylinder with dimples: $V_d = 0.46\ in$^3
- Volume of dimples: V= Vo-Vd = 0.56 in^3 – 0.46 in^3 = 0.1 in^3
- How many teaspoon is the volume including overfill:

  (0.1in^3 / 0.301 in^3)*(1 teaspoon) = 0.332 teaspoon

  -The data of volumes above were acquired from solidworks function "mass property".

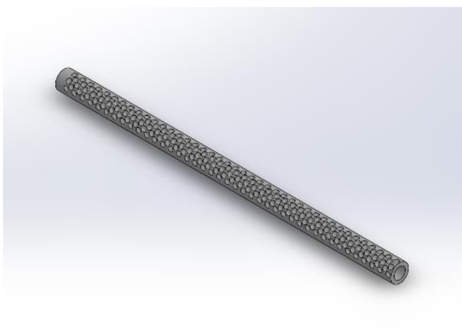


Figure 13: Dimple Deposition

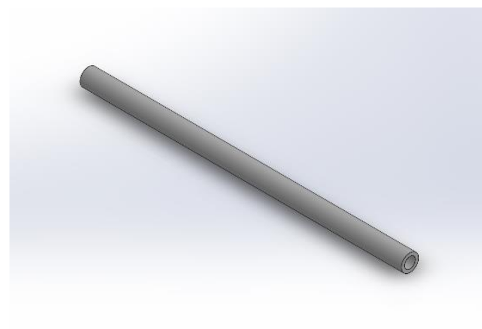


Figure 14: Cylindrical shaft without dimples

Calculations prove that the long dimple deposition takes less than one teaspoon of glitter to the system per rotation. Multiple rotations will yield the necessary amount of glitter for each individual coating assignment. Mathematical analysis proves that the goal of dimple deposition design is not only having a precise design on glitter deposition, but also proves that the design doesn't waste glitter while printing. It is significant to make sure the glitter deposition is precise because the product will be applied into inkjet industry for precise usage such as labeling on batteries or pharmaceutical printing on pills.

Glitter deposition on unique designs require different amounts of glitter while printing. Some designs have a larger adhesive area and need to add more glitter. The dimple deposition roller mechanism satisfies the client requirement for easy control, which means the deposition can come to full stop easily by pausing rotation. Calculating how many teaspoons of glitter added to the hopper can lead to the result of how many rotations needed to deposit glitter, which helps track the material use and reduce glitter waste.

5.3 Integrating bushing into roller design

A crucial feature of our design is the roller that collects and deposits the glitter from the hopper into the chamber. The roller requires some form of extension so that it can be manually rotated from the exterior of the prototype and successfully deposit the glitter. Initially, the team used a thumb screw that fit snug within the interior of the roller cylinder. It also allowed for a team member to manually twist the spade shaped head of the screw as it provided a good grip and lever. The diameter of the thumb screw was also proficient where it aligned and continued from the rod as an extension, fitting snug in between the chamber and hopper. An issue arose, though, where it required the user who was rotating it much effort to twist, resulting in a high torque. This was because of the friction occurring between the thread of the screw and the prototype. A screw has a rough surface, so the rigidity created friction and did not allow for a smooth and consistent deposition process.

The coefficient of friction between two materials in relative contact can depend on the pressure the materials impose on each other, surface roughness of the relative harder contact surface, temperature, sliding velocity, and type of lubricant such as oil. The lubricant can also represent a form of contamination or unwanted build up between the two materials. When analyzing the thumb screw, it was found that the thread creates a rough, uneven surface that would almost cut into the prototype, creating a significant amount of friction. Another variable that complicates the calculation to find the most efficient material and surface for this application is the fact that the 3D printed prototype has many tolerance issues. This ranges from the lengths being off as well as the finish, which is the primary concern for the analysis. Each of the prototypes would leave the printer with strands of excess plastic attached, as well as bumpy and rigid surfaces. The PLA material is common to have a higher surface roughness value. This along with the threaded screw provided for the most friction.

To address this issue, the team evaluated other surfaces and materials that provided a significantly less amount of friction. The team also used a file to sand down the surface in contact with the rod to create a more consistent, smooth, and even surface. After testing, it was apparent that a metal rod with a smooth finished surface would be satisfactory for this application. A plastic material rod was considered because of the lower coefficient of friction between plastic and plastic, but the surface roughness proved to be a larger factor that did not allow for a smooth process. The metal, although having a higher coefficient of friction than plastic, proved as the best solution because the surface was smooth and created less friction than the plastic on plastic. With the knowledge of a correct diameter, a round aluminum rod with an outer diameter of 0.25 inches was purchased. This correct diameter allowed for the rod to easily fit within the interior of the roller. The rod was effective, but still provided friction when rotating.

Figure 15: Aluminum Rod

Figure 16: Thumbscrew

After reviewing alternatives, it is realized that the application of a bushing would be most beneficial to the design for future modifications. The team's approach was trial and error, while this approach would include research in finding a metal with the least amount of friction as well as developing an intentional design with the bushing. Bushings, also known as sleeve bearings, are made to slide over rods to provide an extremely low-friction motion. A bearing was considered in this design but was not the correct size and could also get damaged by excess glitter entering the interior of the bearing. With multiple calculations of the tolerance of the 3D printed dimple roller, the team would know the minimum and maximum tolerance measurements needed to be considered. The next steps would include finding a bushing specific to that tolerance, ensuring it would fit within the interior of the roller. The bushing benefits this design significantly because on one end, it fits snug into the roller, and on the other, it is a specific size diameter that will exactly fit a rod for turning. With the fit, the roller can then rotate very smoothly because the bushing is a type of bearing and allows for a much better function.

After more research, a polyurethane bushing resulted as the ideal material for a bushing. They handle abrasion, impact, and most importantly can be molded. With the tolerance issue with the 3D printed dimple roller, one end of the polyurethane bushing would be molded to the interior of the roller while the other would exactly fit the rod. Purchasing a Prothane Total Kit would deliver a bushing kit with various sizes, front/rear sway bars, strut rods. These would allow for a seamless drive. With the bushing perfectly sized to the interior of the rod and can be altered to the tolerance issue of the 3D printing, then all that is concerned about is addressed because the strut rods are designed to seamlessly fit the bushing. This allows for a significant decrease in resistance, solving the issue of friction.

Figure 17 -Example of Prothane Total Kit

5.4 Optimizing wind speed calculations

Background

With this coating chamber design that the team has chosen to move forward with, it was essential to find air flow speed that would be able to push particles backwards, without pushing the particles more than 4 inches, which would be too far and out of the back of the coating chamber. The red craftsman pump shown in figure 18 would not be sufficient for this application because it only has one wind speed, blowing at approximately 5.1 m/s, constantly blowing the particles much too far.

Figure 18: Craftsman Air pump that was far too strong even with limiting modifications

After a meeting with Integrity and talking about finding a new air source, it was recommended that the team invest in an aquarium pump to try and test with. This test has proven to be very successful. The aquarium pump shown in figure xx did exactly what it was supposed to do, blowing the particles back approximately 3 inches, no further than the length of the inside of the chamber.

Figure 19: Aquarium pump used to find optimal air speed of 0.15 m/s

The next step was to find this airflow speed coming out of the aquarium pump. This was done using an air meter accurate down to hundredths decimal place when measured in meters per second. A measurement of 0.15 m/s was recorded coming out of the aquarium pump.

Assumptions

For the sake of simplification, it will be assumed that this result of 0.15 m/s is in an undisturbed environment where the aquarium pump is the only wind that is in contact with the blades of the air meter. Also, it will be assumed that the airflow coming out of the air pump at 0.15 m/s is constant and will always come out of the pump at this speed.

Equations and Calculations

The relation of cross-sectional area and air velocity to volumetric flow was needed to relate the aquarium pump flow to the speed of airflow required from the air compressor for the air blade.

Volumetric Flow: $Q_V = A * V$

This simple concept was used to perform hand calculations that provided an estimate as to what the air meter should be reading when the outlet of the air compressor is blowing at the air meter before it plugs into the air knife. The following figure 20 shows a diagram of the air knife setup, showing where the air knife speed (V_{AK}) needs to be equivalent to the aquarium pump (V_{AP}), and shows where the air speed needs to be calculated and tested (V_{AC}) with the air meter to ensure that the air knife air speed is equivalent to the aquarium pump.

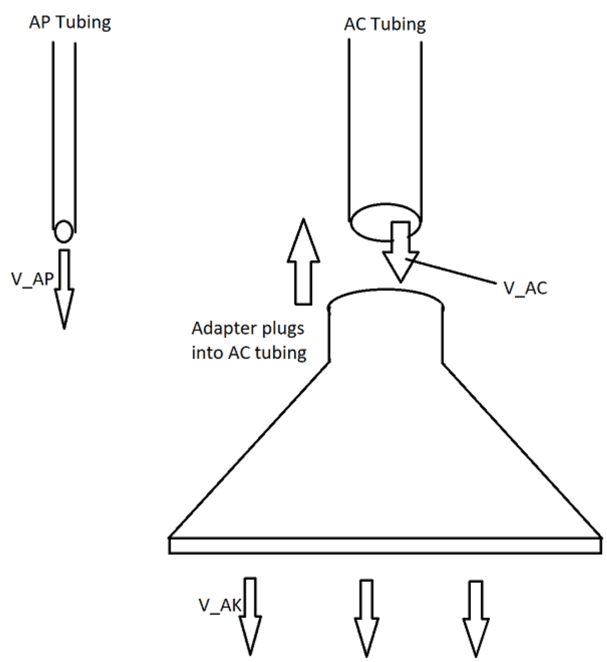


Figure 20: Diagram showing Aquarium pump tubing and Air Compressor tubing, and a simplified air knife adapter.

Organizing the calculation into three distinct parts allows for a clear understanding of the task at hand.

3) Aquarium Pump Tubing (AP)

$$Q_{V-AP} = A_{AP} * V_{AP}$$

2) Air Compressor Tubing (AC)

$$Q_{V-AC} = A_{AC} * V_{AC}$$

3) Air Knife Outlet (AK)

$$Q_{V-AK} = A_{AK} * V_{AK}$$

In the following calculations, the goal will be to find the optimal velocity of the air coming through the air compressor tubing (V_{AC}). After acquiring this value, the air compressor tubing is to be fed into the air meter and the settings are to be slowly turned up until the air meter reads this value. The settings of the compressor are then noted and saved for use in powder removal.

To find V_{AC}, the first step is to set

$$V_{AP} = V_{AK} = 0.15 \text{ m/s}$$

This is done because the air at the air knife outlet needs to be moving at the same speed as the air coming out of the aquarium pump if the glitter is to be blown in the same fashion. Next, the dimensions of the air blade are as follows:

- Air blade x Dimension (L_{BY}) = 0.002 m
- Air blade y Dimension (L_{BX}) = 0.185 m

The optimal volumetric flow of air that should be flowing through the air blade can then be solved for.

$$Q_{V\text{-}AK} = A_{AK} * V_{AP}$$

$$A_{AK} = L_{BY} * L_{BX}$$

$$Q_{V\text{-}AK} = (0.002 * 0.185) * 0.15$$

$$Q_{V\text{-}AK} = 0.0000555 \text{ m}^3\text{/s}$$

Moving on to the next step, set:

$$Q_{V\text{-}AC} = Q_{V\text{-}AK} = 0.0000555 \text{ m}^3\text{/s}$$

This is done because the volumetric flow going through the air compressor tubing will be equal to the volumetric flow coming out of the air knife outlet. Next, the dimensions of the air compressor tubing are as follows:

- Air Compressor Tubing Diameter (D_{AC}) = 0.0095 m……… (3/8 inch)

The optimal air velocity that should be flowing through the air compressor tubing can now be solved for.

$$Q_{V\text{-}AC} = A_{AC} * V_{AC}$$

$$Q_{V\text{-}AK} = A_{AC} * V_{AC}$$

Rearrange:

$$V_{AC} = Q_{V\text{-}AK} / A_{AC}$$

$$A_{AC} = \pi *(D_{AC}^2/4)$$

Solve:

$$V_{AC} = 0.0000555 / (\pi *(0.0095^2/4))$$

$$V_{AC} = 0.78 \text{ m/s}$$

What do these results mean?

To get an air velocity of 0.15 m/s at the air knife outlet, the air flow velocity to run the air through the air compressor tubing needs to be 0.78 m/s. The air speed of 0.78 m/s is to be achieved using the air compressor with the 3/8-inch (0.0095 meter) tubing provided and pointing at the air meter. The settings that achieve a result of 0.78 m/s on the air meter are marked for future use.

Moving forward

To ensure the chosen wind speed is optimal, further testing would be done and data would be required using the air compressor in figure 21 to confirm the hypothesis that V_{AC} = 0.78 m/s is the optimal wind speed for powder removal. Results may vary based on external factors such as imperfections in the blade adapter and sharp turns in the air compressor tubing.

Figures 21 & 22 – Air Compressor needed to operate the coating chamber at the correct air speeds.

6 Engineering Specifications

6.1 Overall Summary

Many of the specifications required to make this design work have each had a difficulty of their own, but SEED team 16 was able to overcome most of these issues by testing and making small incremental adjustments to the prototype until the more problematic specifications began to pass. This process is exactly what took place to make some specifications like ID20 and ID100 work at all. Some of the specifications like ID30 and ID60 would pass the verification tests on the first try because these could be deliberately designed with the correct solution to these specifications in mind. In the end, the team was able to achieve a relative pass/fail rate of 86%, only failing on one specification, ID80.

6.2 Failures

ID80 stated that “the quantity of escaped glitter is shall not exceed a 2 on the designated glitter escape visual scale.” It did not pass the specification because the glitter escape rate was not able to average below a 3 on the designated glitter escape visual scale. The glitter would continuously fly out of the back of the chamber because there was too much volume of air coming in, blowing the glitter too far. This specification was one of the most important to pass, hence the large reduction in the relative pass/fail rate.

6.3 Moving Forward

A way to potentially change the outcome of this failure would be to make the air knife blade a thinner, perhaps lowering it from a 2 mm wide blade to a 1 mm wide blade. The reason this would change the performance of the ID80 is because with a 2 mm blade, the flow field is too thick and will take more time to break up over the length of the chamber. A blade that is 1 mm thick will have the same flow speed, but a smaller flow field. Essentially, a 1 mm opening is letting in approximately half of the air volume that would come in with a 2 mm blade, allowing the flow to break up much more rapidly along the length of the chamber. This would ensure that the glitter escape rate would be at least a 2 or below by keeping the excess glitter inside the coating chamber, while still removing it from the substrate. Present integrity industrial inkjet integration with a product that met most of their specifications

6.4 Excel Table Showcasing Each Engineering Specification

Table 2: List of Engineering Specifications

Engineering Specifications					Results			
ID	**Relative Weight**	**Engineering Specification**	**Units**	**Notes**	**Verification Method**	**Verification Result**	**Verification Status (Pass/Fail/Not Verified)**	**Notes**
10	13%	The hopper shall deposit 1 tsp +/- 1/6 tsp of glitter per coating to prevent material waste	teaspoon (tsp)		Demonstration	One turn of the roller deposits < 1 tsp of glitter	**Pass**	
20	14%	The quantity of adhesive removed from the substrate shall not be below a 4 on the designated adhesive visual scale	Adhesive Visual scale (0-5)		Test	No adhesive was removed from the chamber and the image remained un distorted. The test scored a 5 on	**Pass**	
30	8%	Box shall be compatable with 1/4 20 inch mounting threaded holes on Integrity's conveyor system	inch (in)		Demonstration	Current design is compatible with 1/4 20 inch	**Pass**	
40	9%	Glitter coating process shall be haltable within 3 seconds after command is initiated	seconds (s)		Demonstration	After turning off the air source, glitter mixing halts almost immediately and takes < 3	**Pass**	
50	14%	Box shall be able to continously displace glitter for 1 minute	minute (min)		Test	Box ran continously, displacing glitter for over a minute	**Pass**	
60	4%	The chamber length shall be less than 7 inches	inch (in)		Demonstration	Design is 5.5 inches long	**Pass**	
70	8%	The box shall have at least 1 side that can be seen through to visualize glitter flow/adhesion	wall		Demonstration	1 clear acryllic sheet is present to visualize mixing from a	**Pass**	
80	14%	The quantity of escaped glitter shall not exceed a 2 on the designated glitter escape visual scale.	Glitter escape visual scale (0-5)		Test	Current design scores 4 on average on the scale.	**Fail**	Air blade with more uniform flow could remedy this in future iterations.
90	9%	Shall not have any contact between any pieces of metal or electrical wires that can create heat, sparks, or shavings.	Contact Points		Demonstration	There are currently no contact points between metal and no wires present inside of	**Pass**	If a stepper motor is implemented to automate deposition, wire placement will need to be accounted for to maintain this result.
100	8%	The quantity of adhered glitter coating the substrate shall not be below a 4 on the designated glitter coating visual scale.	Glitter coating Visual Scale		Test	The curent design scored a 4 on the scale	**Pass**	
110								
120								
130								
140								
150								
Total	**100%**					**Relative Pass**	**86%**	

7 Conclusion

7.1 Successes and Failures

The team was able to successfully complete some of the more important main qualities of the design, such as ensuring that the adhesive is completely coated with no deformation of the desired pattern. It was essential to be able to fully coat adhesive without deforming the design to create a successful product, this was the first task the team completed. Next, team focused on adhesive can be layered on top of previously dried layers of glitter to stack up multiple layers of powder, meeting the demands multilayer coating. These two tasks are among the most important fundamental functions of the design. The team managed to succeed in completing these two tasks after doing multiple rounds of research and experimentation. On the other hand, the team was not able to fully optimize the system for removing excess glitter to utilize it for subsequent coatings. Too much glitter was escaping the chamber which meant the team failed to complete one of the most important tasks presented by Integrity. This was the most difficult part of the project because the team was too focused on making sure the glitter would be correctly applied to the adhesive, rather than saving the particles and preventing a mess from happening. Rightly so, because the team could not design a system for collecting particles if there wasn't any data on what would be happening with the particles during the adhesion process. Collection and reuse of particles would have been the next focus of the project if the team had more time.

7.2 Overall Satisfaction

This was a very difficult but interesting project. Overall, the client felt the group made good progress throughout the duration of the year, rating the group for maximum performance for each sprint. Learning and forward progression took place every time a meeting was held, comparing and talking about the various technologies being implemented into the design, and endless conversations about changes to make to improve development. The client presented the group with a challenging task for which they do not yet have a solution of their own just yet, so what was most important was to make sure that the client was able to take what the group was finding and learning and attempt to use it themselves to make a working product. Unfortunately, the group did not come up with the blueprints of a design that could be taken to the manufacturing line that would work for the client as desired but did manage to present a collection of ideas and functionalities that the client can choose to integrate for further development of their own design.

7.3 Recommendations for Future Development

To further progress the development of the prototype, it is essential to break progress down into 3 different categories. Electronic automation, air knife remodeling, and particle collection/reuse. First off, the team was in the process of developing an electronic glitter deposition module that would be fully automated. This would allow for a uniform coating of glitter to be constantly fed into the chamber as the conveyor belt pulls through the substrate below. The process would consist of a time varying microcontroller code that regulates when the adhesive is coming into the box to turn on and off the introduction of glitter into the system. Secondly, the current air knife provides a surplus of air volume being introduced into the system, causing the particles to fly out of the back of the chamber. This is the reason ID80 failed the verification test. To improve upon this, as previously mentioned, the width of the air knife blade needs to be made smaller, decreasing the thickness of the air coming in. This would allow the air being introduced into the system to disperse much more rapidly across a shorter distance, potentially passing ID80 by not blowing the particles outside of the chamber. Lastly, to achieve the best results for the client, a sort of powder/glitter collection module needs to be designed to work alongside the coating chamber. This could simply be a stream of air that blows the particles into interchangeable collection chamber that would easily allow an individual to reintroduce the particles back into the hopper. With these 3 recommendations for future development in mind, the wedge design may be able to enter the production line as a functional layer by layer adhesive particle printer.

8 Impact Statement

Situation 1: To keep the testing environment clean in the lab and common area, the team had come up with an idea to purchase a storage box for testing. This idea would allow the team to contain the excess glitter inside the storage box while running testing and prevent glitter escaping to make a mess. It worked very well to contain the glitter while running tests, which guaranteed the other teams in the lab would not be bothered by excess glitter. The decision showed the team is very thoughtful as engineers and worked professionally when sharing the lab workspace.

Situation 2: To realize environmental-friendly testing procedure, the team reused the glitter from testing by recollecting the excess glitter back to the bottle so that it could be used for next testing. Even if there is still a small amount of glitter going to waste, the team would make sure to vacuum them to keep the testing area clean for the other group in lab. Glitter is microplastic and it has negative environmental impact if it travels through waterways and ends up in the ecosystems. These decisions reflect that the goals of the team as engineering students are not only to design a product for the industry, but also to retain an environmental-friendly testing procedure and source sustainably.

9 Lessons Learned

Throughout the entire year for the design, the team learned many valuable lessons such as SCRUM management, how to communicate with the clients and teammates, products testing, rapid prototyping, etc. There are two main lessons were learned from this project, which were prototyping tolerance issues and communication with client and teammates. These lessons were based on personal experiences of the team members and covered both positive and negative experiences. The lessons learned helped the team have a summary of the valuable experience and what to improve in the future.

One of the lessons learned by the team was related to prototyping tolerance issues. The mechanism design of particle deposition is mostly prototyped by 3D printing, therefore the 3D printing technology plays a significant role in the design process, while 3D printed prototype has some common defects and problems such as warping, cracking and delamination. Most of the assemblies of the design are 3D printed by fablab, there are a few times that the subassemblies did not match with each other when the parts were obtained from printer. GD&T is one of the critical lesson the team learned during the design process, especially when designing with Solidworks. However, even if the Solidworks design dimensions are precise and the parts match with each other, the 3D printed parts sometimes were not as expected. For example, when dimple roller deposition was printed, the dimple roller was supposed to rotate smoothly between the hopper and chamber, while the 3D printed roller had very rough surface with the dimples, which caused large friction when rotating between the hopper and the chamber. The team had to use sandpaper to sand down the small bumps on the rough surface. Lessons learned that prototyping methods shall be chosen flexibly according to the functionality of the part. Certain subassembly of the design may not be the best fit using 3D printing, it could be replaced by metal material like stainless steel which has less friction after it is prototyped by machine shop.

Another lesson learned by the team was related to team communication between teammates and clients. Throughout the entire duration of the project, the team was in constant contact with each other, every team member has been very communicative about planning, scheduling, assigning tasks, which helps the project keep moving forward. When there were different voices on the design directions, the team discussed what was the best plan according to the timeline and client requirements. Before finalizing the design on chamber shape, the team had rapid prototyped three other chamber designs, while the timeline has already moved onto the testing stage, some team member had new design idea but considering the timeline and compare the pros and cons of the designs, the team communicated with each other and asked for advice from mentor Professor Marshall and settled down the design onto the wedge shape box design. It was a critical moment for the team to choose which direction to go with the design. On the other hand, communicating with clients played a big role in the design process as well. The team has been communicating with clients very actively throughout the year. Weekly or bi-weekly meetings with Integrity helped the team give honest and transparent updates about what's new in the design, what are working well, what are not working well, etc. to the clients. The clients from Integrity are very responsive to give advice and update their requirements. The team has learned that it is very important to have frequent check-in and update with clients. Even by the final stage of design, stepper motor automation control on the dimple roller deposition was approved by the client, therefore the team put the assembly in the continuing development section, which help the team bettered the design and got prepared for design night. Good lesson learned that it is important to communicate with the team and the clients frequently and transparently.

10 Project Retrospective

The most impactful Kaizen for Team 16 was the ability to produce and refine many versions of a 3D printed model to directly increase the success in distributing the glitter within the chamber of the device. The initial prototype looks vastly different from the final prototype, as well as the ones along the way. Each prototype had a purpose to disperse glitter most efficiently within the chamber and coat the adhesive that would move through the module.

This Kaizen was chosen because the one requirement the team struggled most to achieve was how to maintain the air flow so that it could disperse the glitter within the chamber. The designs show much variety in geometry when compared to each other. With each prototype, lessons and concepts were learned about how to better adapt and refine the chamber of the design to enable the flow to pick the glitter up from the ground and circulate it while fully coating the adhesive.

The Kaizen shows how the team was fully involved in improving operations, continuously throughout the year. The challenge to refine the design particular to the engineering specification allowed for a pursuit to the ideal prototype.

The Kaizen of refining the design to best distribute glitter impacted our sprints in multiple ways. With each sprint review, the team is expected to show the client an 'increment'. The goal of the entire year's project is to demonstrate a design that works and functions per requirements. When the first few prototypes failed to do so, the team had to go back to the drawing board. First, it is to understand why the design is not operating as expected. Second is implementing new techniques, analyses, and adaptations to the design and test again for new results. Each sprint provided motivation and decision making. Specifically, in Sprint 5, the team made an executive decision to move on from the prototype they had been developing for four sprints and start over with multiple models. This was a large step for it may seem it is back to Day 1, but really the foundational skills and concepts learnt from the previous sprints and designs allowed for the team to work efficiently in creating and adapting the final design. After moving forward with the “Wedge” and concepts carried over from the first prototype, the process of creating, testing, and adapting was second nature and led to a successful final product.

One aspect of SCRUM that worked well for the team was the SCRUM huddles scheduled three times a week. Each team member was accountable to attend, recap work previously done, state goals for the present meeting, and what they would like to be done in the coming week or meeting time. This aspect was effective because the project was always fresh in each team member’s mind and provided a fast and steady pace for the project. With each SCRUM huddle, the SCRUM board also proved very beneficial. It kept these tasks and goals in check and on schedule, providing reference to any member that needed a reminder of what needed to be accomplished for that sprint, who was assigned to a task, and when deadlines were.

One aspect of SCRUM that did not work well overall was the demand for dedication from the students. It shows great structure, but it also created a stressful and high paced environment that is overwhelming for students who are seniors in college, taking other classes, working jobs, and dealing with other personal things. It is important to have balance as a student, but the format of this class (SCRUM) did not allow for any balance. There was constantly a demand for finishing deliverables, attending meetings with clients and mentors, testing and providing advancements in increments, etc. To modify this aspect and make it more useful is complicated, for the SCRUM method is successful but at the cost of the students’ wellbeing. A solution is possibly to have fewer deliverables or at least in less detail so the students can understand what is required without consuming most of their time.

11 Product Review

The product satisfaction levels for both the client and the development team are both very high. Based upon feedback gathered from each sprint and their final thoughts on the product, the client is very content with the results the module delivers. The product operates as required, the client is pleased with the hard work and dedication the team put into the development, and many designs were produced and implemented over the course of the year. With designs varying in foundational concepts, the clients are also able to utilize those as inspiration for more designs or further develop them. The team is also satisfied with the final product for many reasons. So much work was put into this product, making the achievement and success all more worthwhile. The obstacles presented throughout the year pushed the team to work harder and finish strong, creating a final product that reaches requirements and fully functions as hoped.

The product backlog entails the list below, sorted in order of importance from most to least:

- FDR Paper
- Final Tech Documentation
    - Solidworks schematics

  - Sketch ups of design
  - Tubing diagram
  - Testing results
  - Bill of materials
- FDR Presentation
- Automate hopper deposition with stepper motor
  - Need motor housing?
  - Gears?
  - Wiring diagram?
- Video (extra credit)

With the completion of Sprint 7, the team is now tackling the last assignments and deliverables due for the End of Semester section. The team is prioritizing the FDR Report as well as the Technical Documentation Package because they have the closest due date. The presentation is next on the list because it is due when the team is to present, which is a few days after the report and tech package are due. All of these documents will be complete and submitted by their specific due dates. The items in the backlog regarding the automated hopper deposition stepper motor will not be completed for a few reasons. This endeavor was taken upon the team in the last week of sprint 7. It was not realistic to have a finished product, but it was something that the team wanted to explore to see how the design could be advanced. The mindset was determined that it would not be complete, but the goal was to at least start exploring the mechanism and address how it could benefit the design as a whole. It was never a customer requirement; therefore it will not be prioritized to complete. As of the video, it is for extra credit and the team is looking to be able to complete all other deliverables before that is taken up.

12 Budget Review

When approaching this project, a budget of $2,500 was provided. After producing prior art research, a better understanding of what was needed to initiate the creating and testing of this product. The team took a trip to Lowe's to gather any materials that may be needed for the process. The team stayed well below budget, only purchasing what was needed. When an obstacle arose and a product was required for testing, an order was put in and delivered to continue with testing and production. In review, the team finds that they were hesitant with the funds and could have purchased more at the beginning of the year so that there would be less time waiting for products to come in and be delivered. Having the assurance that it is acceptable to purchase materials that may not be needed instantly but good to have at a moment's notice is a large takeaway and an aspect that might change to improve the success of future projects.

Below is a total detailed list of expenses, with a direct comparison of what was spent and the allotted budget.

Table 3: List of Expenses

Total Expenses	Cost
Craftsman inflator	$79.00
Glitter	$51.96
Mileage reimbursement	$106.06
Aquarium pump	$6.71
4 way pump valve	$7.99
Tubing	$7.55
Aluminum rod	$2.19
Stealth Ultra Quiet Air Compressor	$253.90
Primefit PCKIT26 Air Piping System	$84.97
Valve adaptor	$9.99
Handheld anemometer	$29.99
UVM Bookstore purchase	$34.27
Chemical Splash/Impact Goggle	$3.12
Kobalt 12-CT Comp Accessories Kit	$18.98
8 fl oz Elmer's Glue-All	$2.36
Duck tape	$2.83
66-QT Hefty Clear Storage Container	$15.18
FabLab 3D printing	$72.51
Total Spent	**$789.56**
Total Budget	**$2,500.00**
Total Leftover	**$1,710.44**