Recycled Plastic Insert Design for Beehive Top Feeder

Phase III Detailed Design Report

December 7, 2020

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Alberta Beekeepers Commission
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Subject: Recycled Beehive Top Feeder - Phase III: Detailed Design Report

Dear Connie,

SCFAX Engineering is pleased to present the Phase III: Detailed Design Report. This report contains the following:

1. Descriptions of the feeder including physical geometry, features and manufacturing components
2. Detailed analysis using calculations and experimentation
3. Compliance matrix
4. Drawing package
5. Future considerations

The final design is the Dual Feeder design. The feeder will be manufactured by injection molding processes using cleaned and recycled plastic.

Upon completion of the Phase III report, the total time invested in this project is 642.5 hours. The total design cost for Phase III is $324,427.68, and the manufacturing cost is quoted to be $23.56/feeder. The original estimated time and cost of the project were 522.5 hours and $52,453.50 respectively.

The design of the top feeder has been a long yet fulfilling project. It has been a pleasure to work alongside the Alberta Beekeepers Commission, and we look forward to any further cooperation. If there are any further questions, concerns, or comments, do not hesitate to contact our client liaison, Stephen Tokariuk (stokariu@ualberta.ca)

Sincerely,

Xusheng Yu   Stephen Tokariuk   Christopher MacDonald   Addison Tse   Fulin Song

cc.
Christopher Dennison, Faculty Advisor, University of Alberta
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Executive Summary

SCFAX Engineering was tasked with designing a beehive top feeder for the Alberta Beekeepers Commission. From Phase II, the Dual Feeder design was selected to be the final design model of the top feeder. The Dual Feeder has been improved significantly from Phase II to meet the requirements of the project in an efficient and convenient manner.

Several constraints were placed upon the design. Predominantly, the top feeder must be made from used plasticell. Some difficulties that arose when meeting this constraint were the cleanliness of the plasticell sheets and the manufacturing aspects. Regarding cleanliness, the plasticell sheets are incredibly filthy to the point where certain recycling companies have refused to work with them. Experiments on cleaning the plasticell sheets were done by the team, and it was found that soaking the sheets in Dawn dish soap and bleach for half a week will allow the grime to be removed easily using a power washer. Regarding the manufacturing aspect, it was determined that injection molding would be the most appropriate. Difficulties arose from designing the feeder so that injection molding was possible. Several consultations were made with industry workers, which helped the team design a top feeder that satisfies all injection molding requirements.

The calculations done in Phase II were originally planned to be refined for Phase III. However, due to the unique nature of the project, it was decided that prototyping would be the primary source of engineering evidence rather than calculations. There were multiple difficulties associated with prototyping. Firstly, it was difficult to find a 3D company that could manufacture a part of our size. Additionally, the cost of manufacturing one of the feeders is quite large, at around $160 for half of the total feeder. It was also difficult to find a manufacturer who could use the required material, HIPS. Secondly, a proper and logical experimental procedure needed to be devised. Due to Covid restrictions, it became difficult to have an appropriate amount of people to perform the experiment.

As of the completion of the Phase III report, a total of 642.5 hours were invested into the project. The total cost of the entire project, including salaries, manufacturing, and material costs, is $324,427.68. The original estimated time and costs were 522.5 hours and $52,453.50 respectively.

Table of Contents

Executive Summary Word Count: 378

Main Report Word Count: 2271

List of Figures

List of Tables

1 Introduction

The beekeeping industry in Alberta is among the largest in North America [1]. Alberta beekeepers manage around 25 billion bees per year [2] and more than 300,000 hives. Each hive is a stack of wooden boxes that store 9-10 wooden frames [3] used for building honeycombs. To reduce the bee's workload, beekeepers attach a plastic sheet with a honeycomb template, known as plasticell, to the frame to expedite the honeycomb building process. After use, plasticell is either burnt or landfilled.

The Alberta Beekeepers Commission (ABC) has reached out to SCFAX Engineering to design a plastic insert for beehive top feeders using recycled plasticell. The top feeders are a supplementary feeding ground for the bees during the colder seasons when they are less active. Since the feeders are placed at the top of the hive, it is essential that the feeders do not leak into the hive and drown bees, and that the bees do not drown when using the feeder. It is also essential that bees do not colonize the top feeder as the feeder itself is not part of the hive. With these considerations in mind, SCFAX Engineering has designed the Dual Feeder.

2 Dual Feeder

2.1 Overall Description of Final Design and Operation

The Dual Feeder was the most effective design from Phase II and selected as the final design. This feeder is composed of two identical plastic inserts (approximately 16.25" x 10") placed opposite one another. The feeders have angled walls that permit stackability and aid in injection molding.

A steel mesh is secured to tabs on each of the feeder halves using screws. This mesh is a surface for bees to hold on to when accessing syrup and also prevents bees from drowning in the syrup. Grooves along the feeder's inner surface guide the mesh to provide a spacing of ⅜" between the steel mesh and the inner wall. This ⅜" space prevents bees from building comb and propolis in the feeding path [4]. The entrance of the top feeder is maintained at ⅜" space as well due to the tabs between the two feeders.

A medium and shallow version of the feeder have been designed for both shallow and medium beehive box frame sizes. The Dual Feeder is shown in Figures 2.1.1 and 2.1.2.

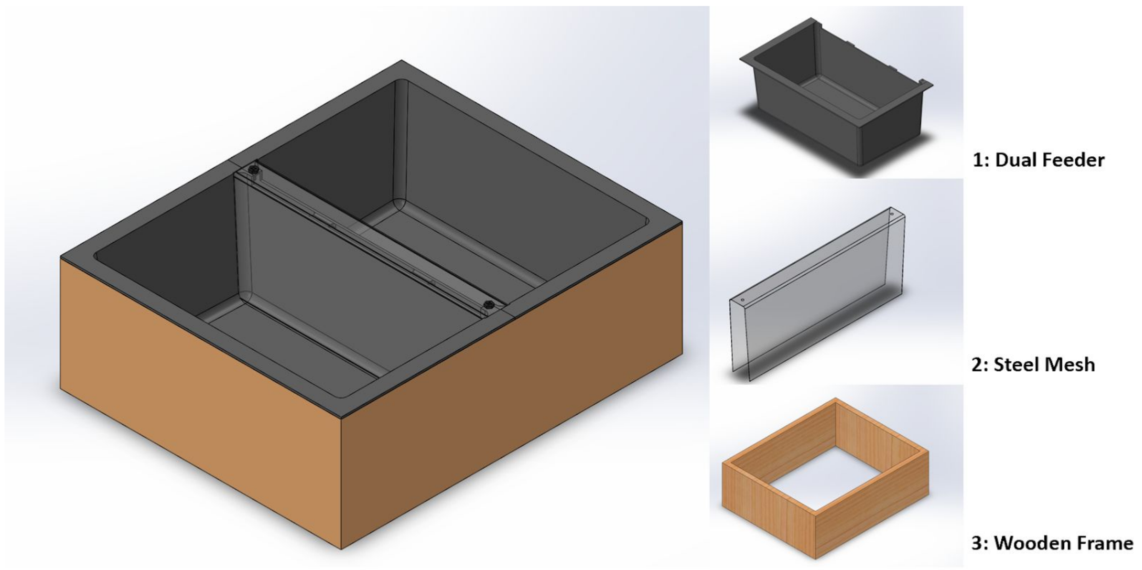

Figure 2.1.1: Full Dual Feeder Assembly

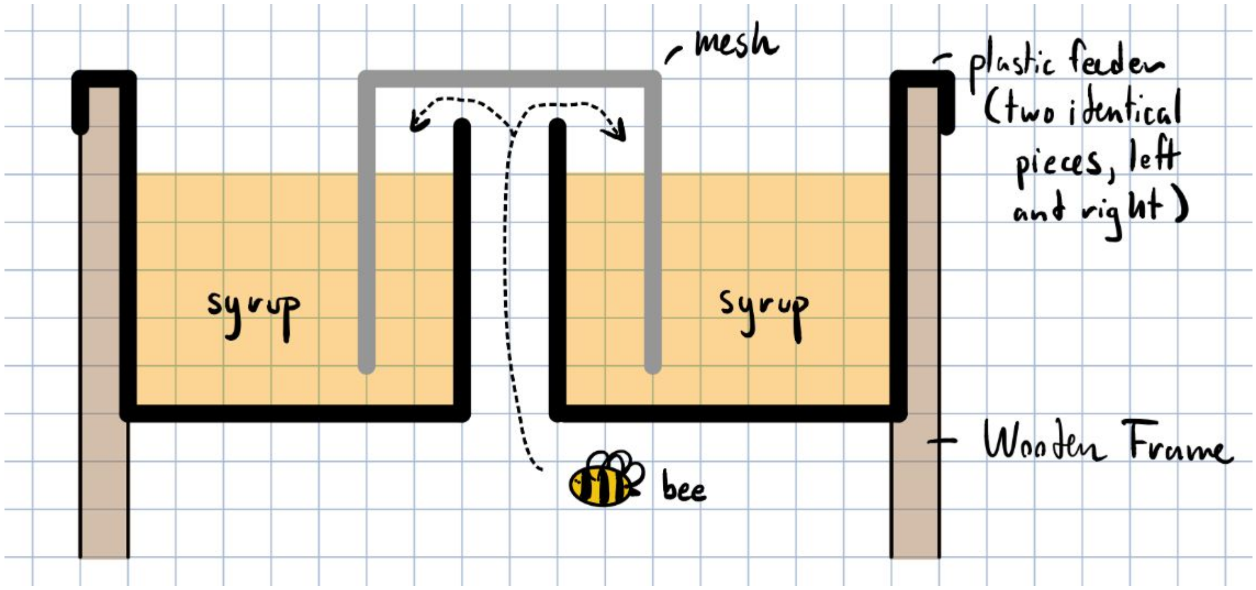

Figure 2.1.2: Descriptive Cross-Sectional Drawing of Dual Feeder

2.2 Design Features

2.2.1 Syrup Storage and Capacity

According to the Solidworks model, each feeder can hold 10.91 L of syrup. When combined, the feeder's total syrup capacity is 5.76 gallons.

2.2.2 Bee Space and Accessibility

The feeder's features (see Figure 2.2.2) ensure that a bee space of ⅜" is not exceeded. The bottom of the feeder entrance is slightly larger for manufacturing reasons but still within an acceptable range. This section will also narrow slightly when filled with syrup.

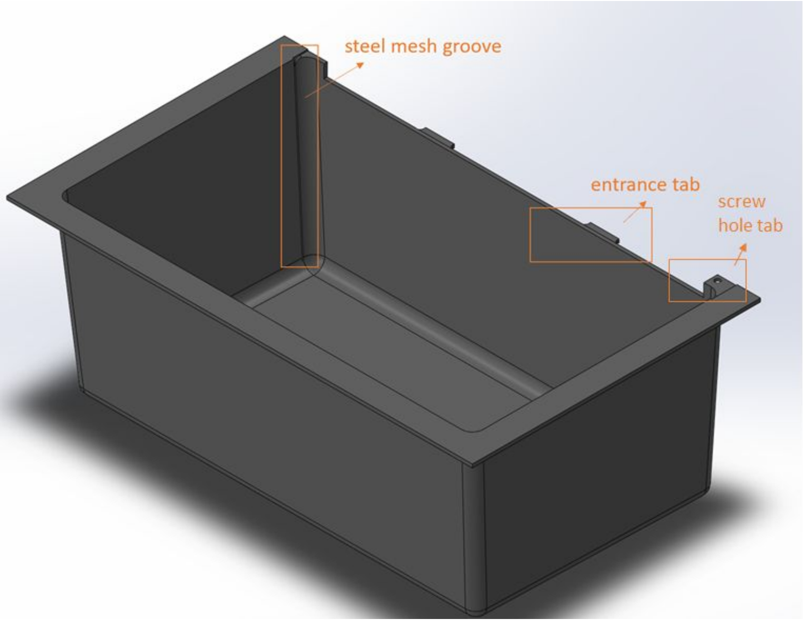

Figure 2.2.2: Locations of Bee Space Preserving Features ⅜"

2.2.3 Pouring Capabilities

Any unused content within the feeders can be easily removed by pouring. While experimenting with the prototypes it was found that the front corners of the feeder provided a more accurate pour stream than the rear corners due to the absence of the support lip (see Figure 2.2.3).

Figure 2.2.3: Pouring Capabilities of the Dual Feeder Using the Rear Corners (Left) vs the Front Corners (Right)

2.2.4 Stackability

One feature that makes this design particularly appealing is its ability to fit within itself to save room during storage and transport. Calculations in Appendix A7.1 show that stacking these feeders can yield space savings of up to 60%. Figure 2.2.4 below shows a stack of prototype feeders

Figure 2.2.4: Top Feeder Stackability

2.2.5 Ease of Assembly

The entire top feeder consists of five components: two feeders, steel mesh, and two screws. One #2 Phillips screwdriver and four easy steps (see Figure 2.2.5) is all it takes to assemble the feeder, whether it's in a hive box or not.

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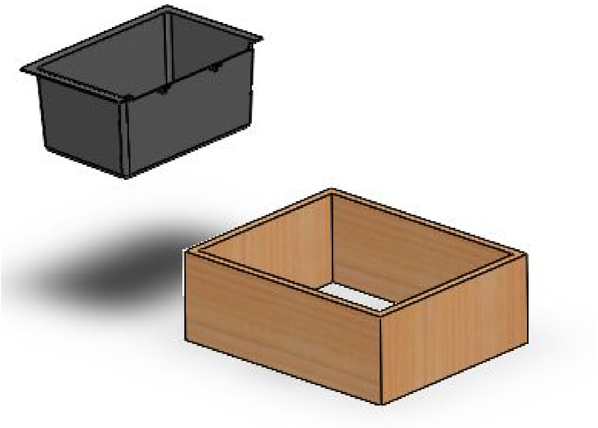
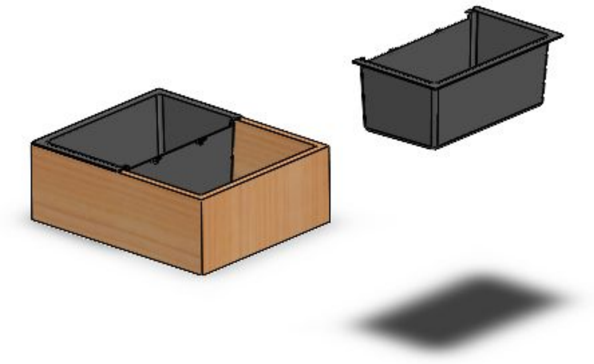
<tr><td></td><td></td></tr>
<tr><td>Step 1: Place first plastic insert inside hive box, sliding it as far back as possible</td><td>Step 2: Place the second plastic insert adjacent to first. They should meet in the center</td></tr>
</table>

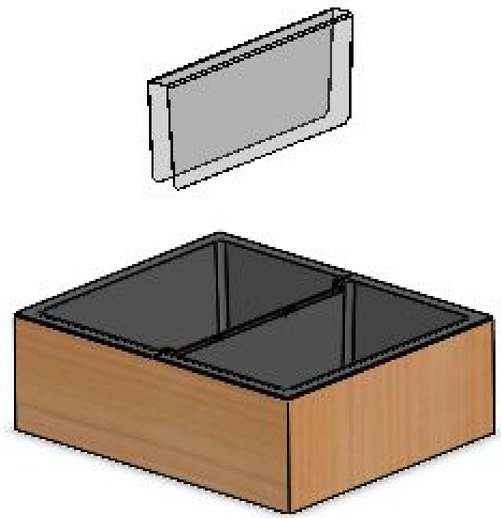
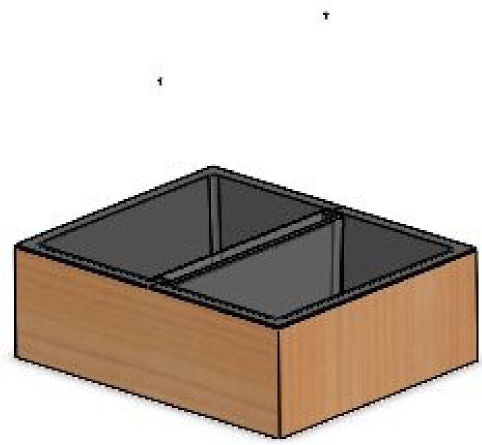
	
Step 3: Slide the mesh screen down the grooves on the side walls of both feeders	*Step 4: Use provided screws to secure the mesh to the screw holes in the plastic inserts*

Figure 2.2.5: Step by Step Assembly of Feeder in a Hive Box

2.2.7 Other Design Considerations

Beekeepers expressed interest in liquid volume measurement markings on the side of the feeder in order to gauge syrup consumption. Unfortunately, due to the fact that they could double the cost of the mold, these were left out of the design. An alternative solution could be to print the markings on a sticker that beekeepers could apply to the inside of the feeders. This would have to be offered as a separate entity as it too would increase the cost of the design.

2.3 Manufacturing and Parts

The most important feature of this design is the plastic inserts which have been decided to be injection molded using either recycled high impact polystyrene (HIPS) or high density polyethylene (HDPE), depending on available plasticell types. The mesh screen will be custom fabricated (8 cuts and two bends) from 10 to 16-mesh 304 stainless steel. Lastly, the screws used to secure the mesh to the plastic insert will be #6, ⅜", pan head, 18-8 stainless steel, #2 phillips, sheet metal screws.

3 Key Analysis and Calculations Performed

SCFAX Engineering performed a static load analysis, abrasion analysis, and impact (drop test) analysis using experimental results, some FEA analysis, and hand calculations and theory for verification. Stackability and pouring were also tested on the model.

3.1 Load Analysis

The main potential failure mode for this feeder is cracking under the weight of the syrup. As per the client's request, the final design will hold up to 5.76 gallons of syrup to eliminate the need for frequent refilling. Hand calculations (shown in Appendix A1.1) proved to be less reliable than in the second phase since the new sloped walls of the feeder create complications when trying to simplify to 1D. FEA simulations (see Appendix A1.2), however, show a maximum deflection, strain, and stress of 1.26 mm, 0.00107 mm/mm, and 2.3 MPa respectively. This stress is significantly less than the yield stress of both HIPS and HDPE, making the team confident that the design will not fail when statically loaded. The maximum deflection in the front wall was also noted to be around 0.1 mm, which will not compromise the ⅜" bee space. A mesh dependency test on the FEA simulations is included in Table A1.2.3.

3.2 Abrasion Analysis

The primary focus of the abrasion analysis was to see how the cleaning process may damage the feeder. HIPS has a material hardness of 75 to 80 M-scale [5], meaning that soft plastic tools made of materials such as PTFE (60 scale [6]) will wear themselves down instead of the feeder. When physical models were scratched with tools of varying hardness (see Appendix C3), it was observed that less abrasion occured on the HIPS prototype than a store bought top feeder.

3.3 Impact Analysis

The handling and transportation of feeders presents the risk of failure due to being dropped. To decrease the chances of the feeder breaking on impact, the geometry and mass of the feeder have been adjusted from phase II. By simply decreasing from 1.72 kg to 0.87 kg, the kinetic energy of the feeder on impact, when dropped from 1 meter, decreased from 16.88 J to 8.53 J and the force due to the impact decreased from 5.07 kN to 2.57 kN. HIPS has a low density (0.80 - 1.04 g/cc) and sufficient impact strength (70 - 100 J/m) [7] , which makes it a good candidate for the top feeder material. Note that an increase in material thickness could assist with impact resistance, but would ultimately lead to complications in manufacturing.

Drop tests were conducted on both the store-bought feeder and the HIPS prototype (Appendix C4). Unfortunately, due to the nature of 3D printing, the prototype experienced issues falling from heights greater than 0.5 m. These issues are not foreseen to be a problem with injection molding however, since seams between layers will not be present.

3.4 Heat Transfer Analysis

In the Phase II report, detailed heat transfer calculations were performed to demonstrate that the feeder is sufficiently warm and that the syrup does not freeze. However, it was decided that these calculations were unneeded and therefore discontinued in Phase III. Firstly, the feeders, while used in colder seasons, are not used during winter temperatures as bees will die at temperatures below 5 degrees [8]. During the winter, the bees hibernate and become more inactive. There will be no reasonable scenario for beekeepers to use the top feeders at the risk of the livelihood of their bees. Secondly, the beekeepers have not deemed the freezing of syrup to be an issue. They do not use the feeders during temperatures that could freeze syrup. One of the client's top feeders features the feeding area at the outside edges, which is the coldest location in the feeder, yet it functions well. The designed feeder features the feeding area at the center of the feeder, which is the warmest location. Furthermore, the top feeder is placed inside a wooden box and covered with a lid and, occasionally, a tarp. The thermal calculations from Phase II are still provided in Appendix A4.1. Clarity modifications were made.

3.5 Cost and Manufacturing Analysis

A comprehensive and detailed cost analysis was completed (see Appendix A5) to judge the economic feasibility of manufacturing large quantities of the product. The costs can be broken down into three main categories: recycling, manufacturing, and engineering overhead.

Recycling involves collecting, sorting, washing, and transporting used plasticell to a professional local plastics recycler. Assuming the worst case scenario where all cleaning and sorting has to be done by the ABC and all equipment must be purchased new, the cost of recycling each plasticell sheet comes out to $0.68. Note that recycling of these sheets can be done whether or not the feeder is put into production.

Manufacturing is where the bulk of the cost comes from. Injection molding using a single cavity mold for 20,000 inserts (10,000 feeders) is quoted to cost $4.69/insert ($9.38/feeder) with raw material included. For the mesh screen, the raw material was quoted at $3.26/screen and the fabrication cost (including raw material) was $11.25/screen. The screws are to be simply bought off the shelf at a retail price of $0.04/screw making the total manufacturing cost per feeder $20.71. Note that this price includes the use of recycled plastic, but not beehive plastic. If the cost of recycling enough plasticell to produce the inserts is considered, the cost of the feeder increases $2.85 per unit, totalling $23.56. All the quotes mentioned above, as well as other quotes that may be more expensive or less feasible, can be found in Appendix A5

Lastly, though not of concern to the ABC, the engineering overhead was determined by recording all time spent working on this design and multiplying it by standard engineering rates.

The final overhead cost was $59,334.25 which includes a prototyping budget of $969.25. For the goal of 10,000 feeders, the engineering overhead works out to $5.39/feeder

In summation the total cost per unit of engineering and manufacturing 10,000 feeders from recycled foundation plastic is $29.49. It should be noted that the conservative estimates made throughout the analysis will likely be negated by freight charges which were not included yet due to the fact that too many variables are still unknown at this point.

SCFAX is confident that the feeders designed for the ABC will meet their goal of being competitive in the market. However, if cheaper or more viable options can be found for recycling and manufacturing, there could be more room to cover any costs that were overlooked, more profits for the ABC, and/or more incentive for beekeepers to use locally recycled products.

4 Design Compliance Matrix

To ensure that the final design satisfies the clients expectations, the design specification matrix (see Appendix D1) was reviewed with the client one final time. In light of newly available information, slight changes were made to the matrix (marked in red) before the final design was evaluated against each of individual criterion. Table 4 below shows which items in the matrix were deemed compliant along with a short justification as to why or why not.

Table 4: Design Compliance Matrix

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5 Project Management

SCFAX Engineering allocated 253 team hours for Phase III of this project. In reality, 369 hours were spent by the team and 5 were spent by the advisor. In total, the engineering cost of Phase III works out to $33,960.00. The updated work hours for each group member is attached in Table 5.1. All timesheets can be seen in Appendix D4.

Instead of focusing on FEA and hand calculations in this phase, the team decided to 3D print prototypes and perform experimental analysis. This, along with the unplanned inclusion of manufacturing analysis in Phase III contributed to the larger accumulated hours than anticipated. A detailed GANTT Chart of Phase III activities is seen in Appendix B2.

As per the Cost Analysis in Section 3.5, the cost of recycling and manufacturing 10,000 units is approximately $235,600.00. Therefore, the total cost of the project is $324,427.68. Table 5.2 displays the updated total cost estimate.

Table 5.1: Actual Hours Spent on Project in Phase III

Member	Number of Actual Hours Spent (# of Hours)						Total Cost ($90/h for team, $150/h for advisor)
	Research	Meetings	Report Writing	Design	Analysis / Calcs	Total	
Xusheng (Team)	10	49.5	48	4	19	130.5	$11,745
Christopher (Team)	18	36	51.5	12	11	128.5	$11,565
Stephen (Team)	23	37.5	69	21	18	168.5	$15,165
Addison (Team)	5.5	36	38	4.5	15.5	99.5	$8,955
Fulin (Team)	13	32.5	17	4.5	39.5	106.5	$9,585
Prof. Dennison (Advisor)	0	9	0	0	0	9	$1,350
Total (Team)	69.5	191.5	223.5	46	103	**633.5**	**$57,015.00**
Total (Team and Advisor)	69.5	200.5	223.5	46	103	**642.5**	**$58,365**

Table 5.2: Final Design Costs

Project Design Cost						
	# of Hours			Cost ($)		
	Phase I Estimate	Phase II Estimate	Actual Hours	Phase I Estimate	Phase II Estimate	Actual Cost
Phase I (Team): $90/hour	94.5	90	**90**	$8,505.00	$8,100.00	**$8,100.00**
Phase II (Team): $90/hour	176	174.5	**174.5**	$15,840.00	$15,705.00	**$15,705.00**
Phase III (Team): $90/hour	241	253	**369**	$21,690.00	$22,770.00	**$33,210.00**
Senior Engineer (Advisor): $150/hour	11	11	**9**	$1,650.00	$1,650.00	**$1,350.00**
Total	522.5	528.5	**642.5**	$47,685.00	$48,225.00	**$58,365.00**
Prototyping				N/A	N/A	**$969.25**
Recycling and Manufacturing Cost (10 000 Inserts)				N/A	$20,000.00	**$235,600.00**
10% Contingency				$4,768.50	$11,645.00	**$35,329.93**
Total				$52,453.50	$75,047.50	**$324,427.68**

6 Limitations and Future Considerations

SCFAX Engineering has identified future considerations in this project that are beyond the scope of the team's technical ability and time constraint. This is presented in Table 6.1.

Table 6.1: Future Considerations

Action	Description
Determine alternative method to decrease mesh screen cost	The cost of the SCFAX Engineering recycled feeder is already estimated to be lower than other feeders on the market. However, as per the cost analysis in Section 3.5, the cost to fabricate the steel mesh was quoted to be more expensive than the plastic feeder itself. Therefore, SCFAX Engineering recommends looking for a sheet metal fabrication shop that can cut and shape the steel mesh at a more reasonable cost. Otherwise, in-house fabrication methods of the steel mesh can be considered to save money.
Determine accurate plastic properties for recycling	Jianbo Lu and his team at the Government of Alberta performed a series of experiments to determine the material and basic material properties of used plasticell sheets. However, recycling facilities require accurate plastic material properties to effectively recycle the material. This information is protected intellectual property of plastic manufacturers. Therefore, plastic manufacturers must be contacted and a sample must be sent to recycling facilities to be tested for recyclability.
Fabricate mesh screen prototype for experimentation	SCFAX Engineering performed extensive experimentation on the 3D printed plastic inserts and is confident that the design meets or exceeds all requirements set out by the client. SCFAX Engineering proposes that a steel mesh screen be fabricated and fitted onto the plastic prototypes for more complete and realistic experimentation.
Produce plastic prototype using other manufacturing methods	As noted in the experiment analysis, the 3D printed prototype did not perform identically as an injection molded model, even though they are both made of HIPS. Recall that the layers of plastic created by 3D printing did not adhere property, causing cracks and warping, which affected experimental results. Therefore, another test model should be created using other manufacturing methods to achieve more accurate experimental results closer to the performance of an injection molded component.

Perform field tests and gather beekeeper feedback	Jeremy and Landon, beekeepers under the Alberta Beekeeping Commission, provided invaluable feedback throughout this project. Therefore, test models should be given to beekeepers for field testing, and beekeeper feedback should be collected and reviewed. This would ensure that end users are satisfied with the product before proceeding to production and distribution.

7 Conclusion

The final top feeder design follows similarly to the dual feeder in phase II with the addition of key features such as bee entrance gap spacing tabs, a screw hole tab, mesh guide channels, and sloped walls. The plastic insert is to be injection molded using either recycled high impact polystyrene or high density polyethylene. The mesh screen will be custom fabricated from 10 to 16-mesh 304 stainless steel and will be secured using two #6, ⅜” sheet metal screws. The design costs $23.56/feeder to manufacture using recycled plasticell sheets which is competitive in the current market. FEA analysis and physical experimentation with full scale prototypes show that the feeder will not fail under the weight of a full syrup load (5.76 gallons), will survive impact forces from small drops, and will resist reasonable abrasion. The design allows the feeder to be stacked inside of one other to save space and features an easy-to-clean contour. The size of the feeder allows it to fit into any standard 16 ¼” x 19 ¾” hive box and even comes in two different depths (shallow and medium) The client is satisfied with the design and is interested in looking further into the possibilities presented.

References

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Appendices

Appendix A: Key Analyses and Calculations

Appendix A1: Load Analysis

Appendix A1.1: Hand Calculations for Verification

As in the Phase II report, rough hand calculations were performed to determine the maximum bending stress experienced by the base of the feeder due to the weight of the syrup. Free body, shear force, and bending moment diagrams were created for the new feeder design and are shown below along with supporting calculations (Note: a syrup density of $1150\ kg/m^3$ [9] was used)

Known Properties:

Syrup Density: $\rho\_syrup := 1150\ \frac{kg}{m^3}$

Young's Modulus: $E := 3.35\ GPa$

Material Thickness and Width: (From Solidworks Model) $t := 3\ mm$ $w := 227.0125\ mm$

Calculations

Volume of Each Section:

$V\_sloped := 392.07\ cm^3 = 0.0004\ m^3$

$V\_flat := 10125.86\ cm^3 = 0.0101\ m^3$

$V\_total := (V\_sloped \cdot 2) + V\_flat = 0.0109\ m^3$

Mass of Feeder in Each Section: (From Solidworks Model)

$m\_sloped := 0.1284\ kg$

$m\_flat := 0.2322\ kg$

Mass of Syrup in Each Section:

$m\_syrup\_sloped := V\_sloped \cdot \rho\_syrup = 0.4509\ kg$

$m\_syrup\_flat := V\_flat \cdot \rho\_syrup = 11.6447\ kg$

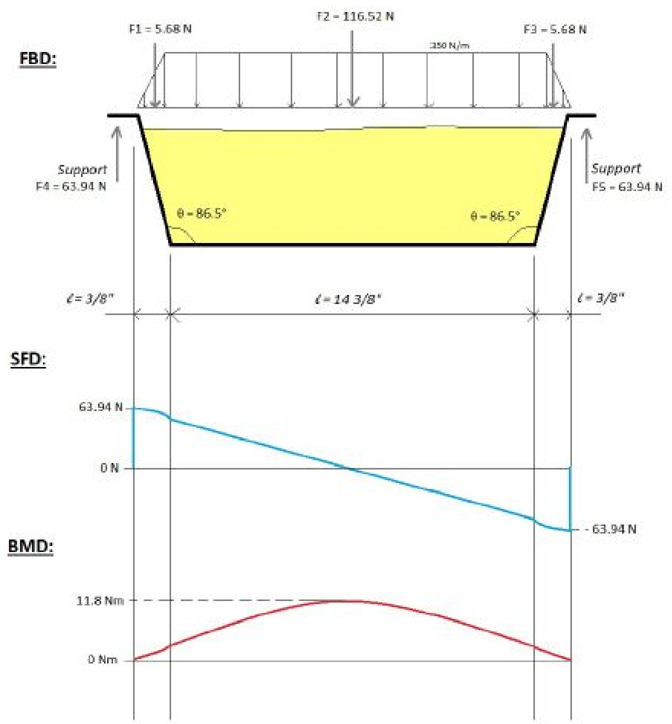
Gravitational Forces:

$$F\_sloped := (m\_syrup\_sloped + m\_sloped)\cdot 9.81\,\frac{m}{s^2} = 5.6827\ N$$

$$F\_flat := (m\_syrup\_flat + m\_flat)\cdot 9.81\,\frac{m}{s^2} = 116.5128\ N$$

$$F\_total := (F\_sloped\cdot 2) + F\_flat = 127.8783\ N$$

Free Body, Shear Force, and Bending Moment Diagrams:



Max Bending Moment:

$$M := 11.8\ N\,m$$

Max Bending Stress:

$$\sigma := \left(\frac{M\cdot\left(\frac{t}{2}\right)}{\left(\left(\frac{w\cdot t^3}{12}\right)\right)}\right) = 3.47\cdot 10^{7}\ Pa$$

Strain:

$$\varepsilon := \frac{\sigma}{E} = 0.0103$$

It can be seen that the maximum bending stress exceeds the tensile yield strength of the material slightly. This is likely due to the fact that 1-dimensional hand calculations are not comprehensive enough to account for the complex 3-dimensional geometry of the feeder. The FEA analysis and the experimental results will provide a more accurate idea of the stresses within the product.

Appendix A1.2: ANSYS Workbench Load and Deflection Analysis

To verify that the deflection in the feeder would not cause the bee space to be obstructed significantly and to ensure the yield strength is not exceeded, a static structural analysis was performed on ANSYS Workbench.

As the feeder may be plastic injection molded using either recycled HIPS or HDPE, the analysis considered both materials. Material properties for the recycled HIPS were obtained from research done by Jianbo Lu's research team at the Bio Processing Innovation Centre (BPIC) in the Government of Alberta's Agriculture and Forestry Department. Some HIPS material properties needed for the analysis could not be obtained from Jianbo's team, so values were incorporated from online sources. Furthermore, Jianbo's team could not provide material properties for HDPE, so default ANSYS polyethylene material properties were assumed. Material properties inputted into ANSYS are listed in Table A1.2.1 and Table A1.2.2 for HIPS and polyethylene, respectively.

The ANSYS Workbench analysis was performed as a static structural problem. Then, the properties for HIPS and polyethylene were inputted into the Engineering Data. The geometry was imported from Solidworks into DesignModeller and subsequently meshed. Then, boundary conditions were applied. The outer edges of the feeder were set at fixed support because that would be one of the supports of the feeder on the wooden box frame, assuming an infinitesimally thin box frame. The two tabs were set as frictionless supports which were constrained in the normal direction. That is because they would be in contact with the other feeder on the other side of the frame, but would not be constrained to move perpendicular to the other feeder. Gravitational acceleration was also applied to the feeder. Finally, hydrostatic pressure was applied to the inner walls of the feeder where the syrup would be contacting the feeder. An annotated image of the boundary conditions and forces is presented in Figure A1.2.1.

Subsequently, the analysis was performed. A mesh dependency analysis was completed for the HIPS case (Tables A1.2.3 and A1.2.4, as well as Figures A1.2.2 to A1.2.5) and polyethylene case (Tables A1.2.5 and A1.2.6, as well as Figures A1.2.6 to A1.2.9).

Table A1.2.1: ANSYS Workbench Material Properties for Recycled HIPS

Material Property	Value	Comments
Density (kg/m^3)	800	Data was not available from Jianbo's team. Densities for HIPS range from 800 - 1040 kg/m^3 [10] so the lowest value was used for a conservative estimate.
Young's Modulus (MPa)	2190	Young's modulus for plastic can be estimated to be equal to its flexural modulus, which Jianbo's team obtained to be 2190 MPa.
Poisson's Ratio (unitless)	0.41	Data was not available from Jianbo's team. Poisson's Ratio obtained from an online source [11].
Bulk Modulus (MPa)	4056	Calculated automatically by ANSYS from Young's Modulus and Poisson's Ratio.
Shear Modulus (MPa)	777	Calculated automatically by ANSYS from Young's Modulus and Poisson's Ratio.
Tensile Yield Strength (MPa)	31	Obtained from Jianbo's team as "tensile strength" [12] .
Compressive Yield Strength (MPa)	N/A	Not used in analysis.
Tensile Ultimate Strength (MPa)	31	Obtained from Jianbo's team as "tensile strength".
Compressive Ultimate Strength (MPa)	N/A	Not used in analysis.

Table A1.2.2: ANSYS Workbench Material Properties for Polyethylene

Material Property	Value	Comments
Density (kg/m^3)	950	Default ANSYS Engineering Data Material Properties.
Young's Modulus (MPa)	1100	Default ANSYS Engineering Data Material Properties.
Poisson's Ratio (unitless)	0.42	Default ANSYS Engineering Data Material Properties.

Bulk Modulus (MPa)	2292	Default ANSYS Engineering Data Material Properties.
Shear Modulus (MPa)	387	Default ANSYS Engineering Data Material Properties.
Tensile Yield Strength (MPa)	25	Default ANSYS Engineering Data Material Properties.
Compressive Yield Strength (MPa)	N/A	Default ANSYS Engineering Data Material Properties.
Tensile Ultimate Strength (MPa)	33	Default ANSYS Engineering Data Material Properties.
Compressive Ultimate Strength (MPa)	N/A	Default ANSYS Engineering Data Material Properties.

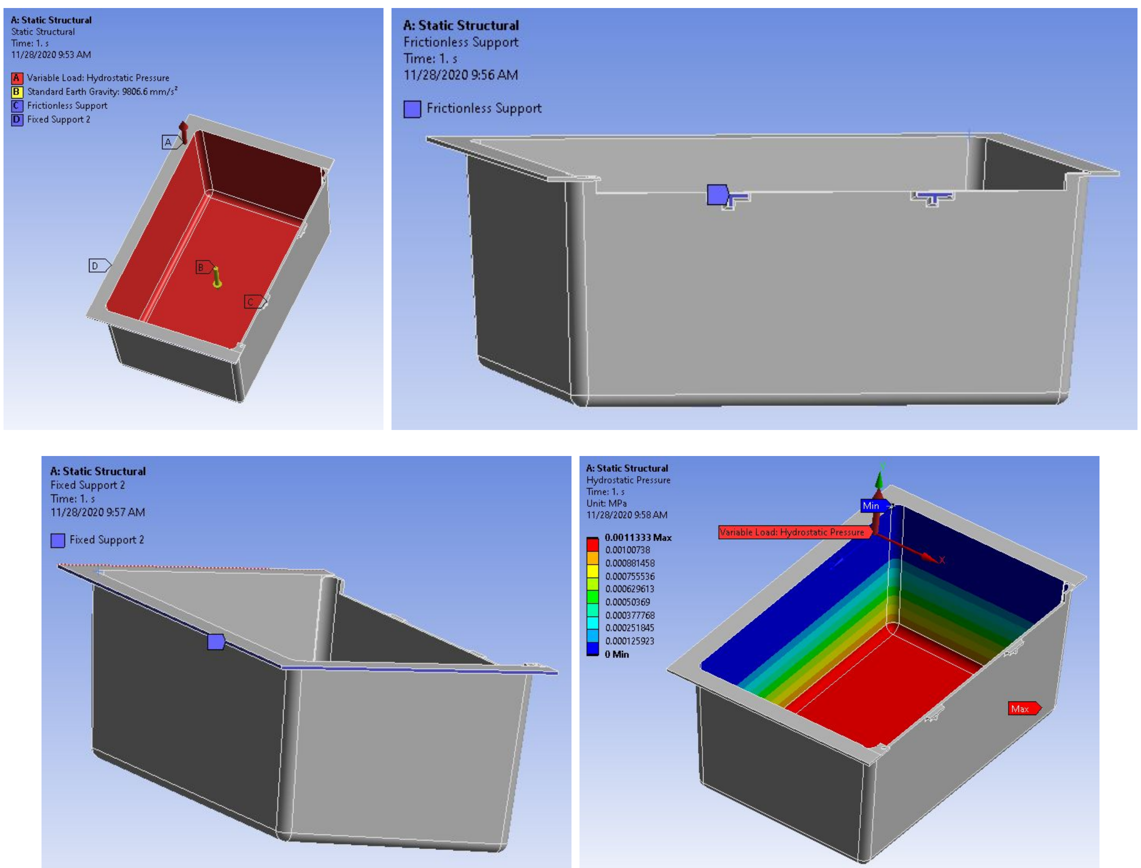


Figure A1.2.1: Boundary Conditions and Forces Applied to Model on ANSYS Workbench

Table A1.2.3: Mesh Dependency Table for Static Structural Analysis using HIPS Properties with Total DOF

					Maximum		
Run #	**Mesh Size (mm)**	**Total Nodes**	**DOF**	**Total DOF**	**Deformation (mm)**	**Strain (mm/mm)**	**Stress (MPa)**
1	10	15780	3	47340	0.97534	0.00058525	1.2537
2	7.5	26111	3	78333	1.19260	0.00082971	1.8115
3	5	53998	3	161994	1.24410	0.00085972	1.7483
4	4	78843	3	236529	1.25500	0.00098000	2.1242
5	3	137829	3	413487	1.26110	0.00106160	2.3089
6	2.5	200123	3	600369	1.26490	0.00106850	2.3049

Table A1.2.4: Mesh Dependency Table for Static Structural Analysis using HIPS Properties with Relative Errors

Maximum			Errors		
Deformation (mm)	**Strain (mm/mm)**	**Stress (MPa)**	**Deformation Relative Error**	**Strain Relative Error**	**Stress Relative Error**
0.97534	0.00058525	1.2537	-	-	-
1.19260	0.00082971	1.8115	22.28%	41.77%	44.49%
1.24410	0.00085972	1.7483	4.32%	3.62%	3.49%
1.25500	0.00098000	2.1242	0.88%	13.99%	21.50%
1.26110	0.00106160	2.3089	0.49%	8.33%	8.70%
1.26490	0.00106850	2.3049	0.30%	0.65%	0.17%

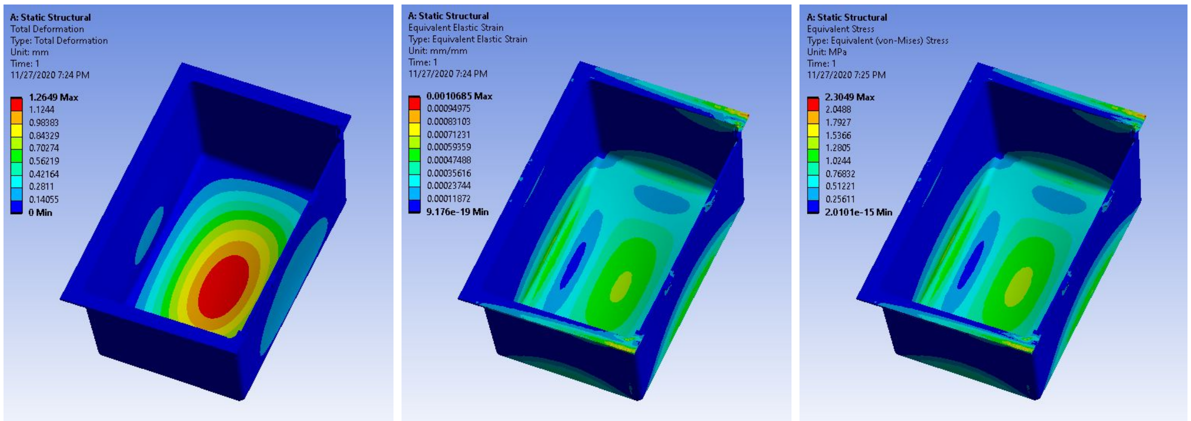


Figure A1.2.2: ANSYS Workbench Outputs for Total Deformation (left), Equivalent Elastic Strain (center), and Equivalent Stress (right) using HIPS Material Properties

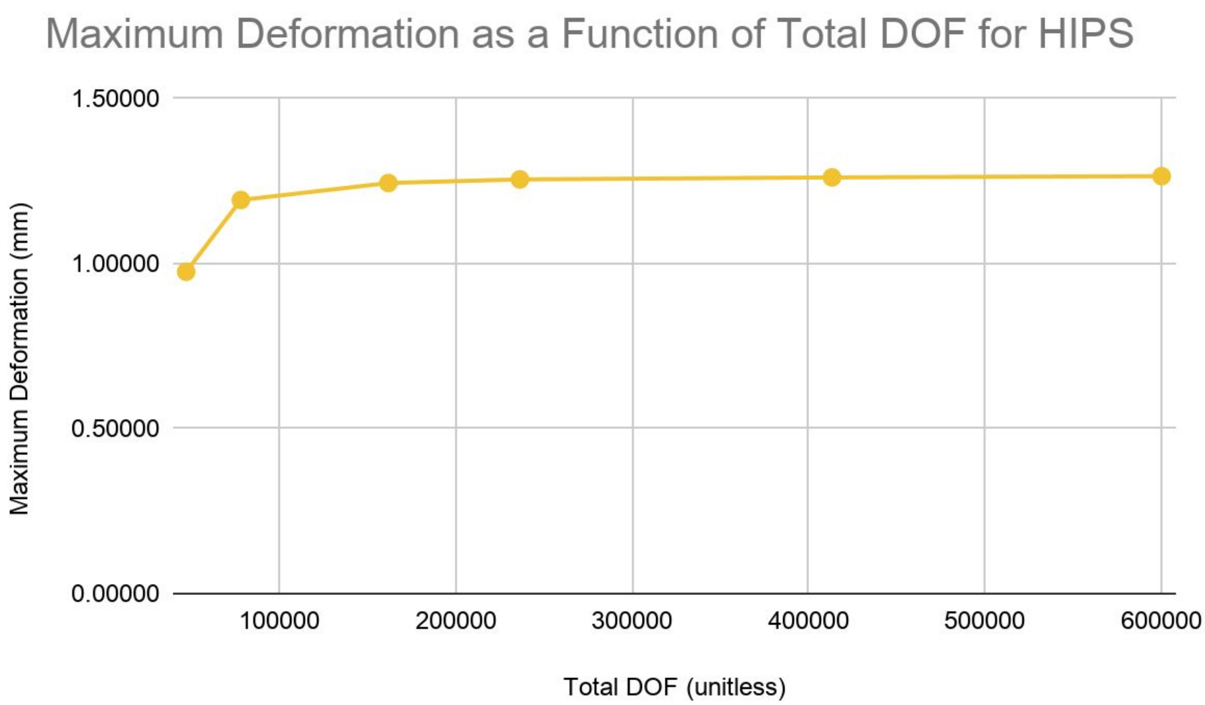


Figure A1.2.3: Maximum Deformation per Total DOF using HIPS Material Properties

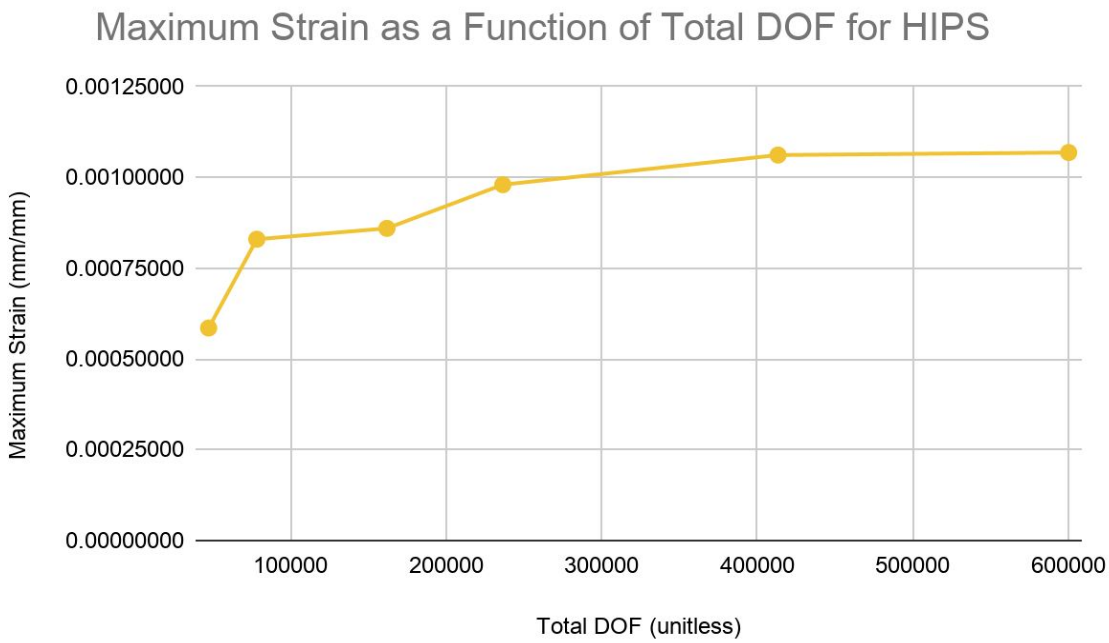


Figure A1.2.4: Maximum Strain per Total DOF using HIPS Material Properties

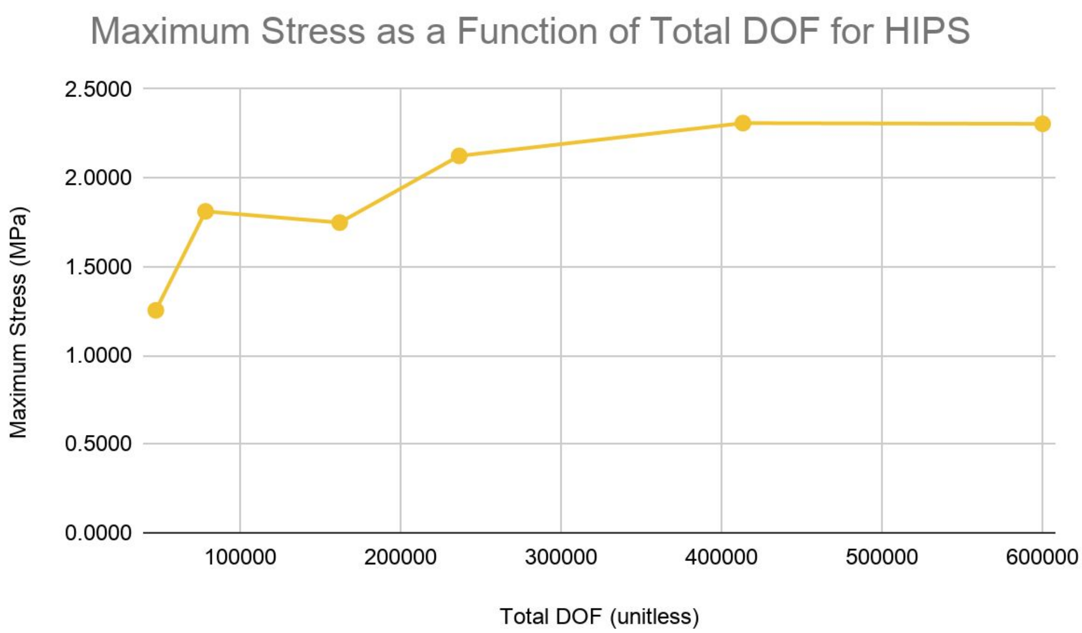


Figure A1.2.5: Maximum Stress per Total DOF using HIPS Material Properties

Table A1.2.5: Mesh Dependency Table for Static Structural Analysis using Polyethylene Properties with Total DOF

					Maximum		
Run #	Mesh Size (mm)	Total Nodes	DOF	Total DOF	Deformation (mm)	Strain (mm/mm)	Stress (MPa)
1	10	15780	3	47340	1.9203	0.0011563	1.2599
2	7.5	26111	3	78333	2.3576	0.0016335	1.7916
3	5	53998	3	161994	2.4623	0.0016986	1.7439
4	4	78843	3	236529	2.4845	0.0019526	2.1246
5	3	137829	3	413487	2.4969	0.0021218	2.3166
6	2.5	200123	3	600369	2.5047	0.0021261	2.3017

Table A1.2.6: Mesh Dependency Table for Static Structural Analysis using Polyethylene Properties with Relative Errors

Maximum			Errors		
Deformation (mm)	Strain (mm/mm)	Stress (MPa)	Stress Relative Error	Strain Relative Error	Deflection Relative Error
1.9203	0.0011563	1.2599	-	-	-
2.3576	0.0016335	1.7916	22.77%	41.27%	42.20%
2.4623	0.0016986	1.7439	4.44%	3.99%	2.66%
2.4845	0.0019526	2.1246	0.90%	14.95%	21.83%
2.4969	0.0021218	2.3166	0.50%	8.67%	9.04%
2.5047	0.0021261	2.3017	0.31%	0.20%	0.64%

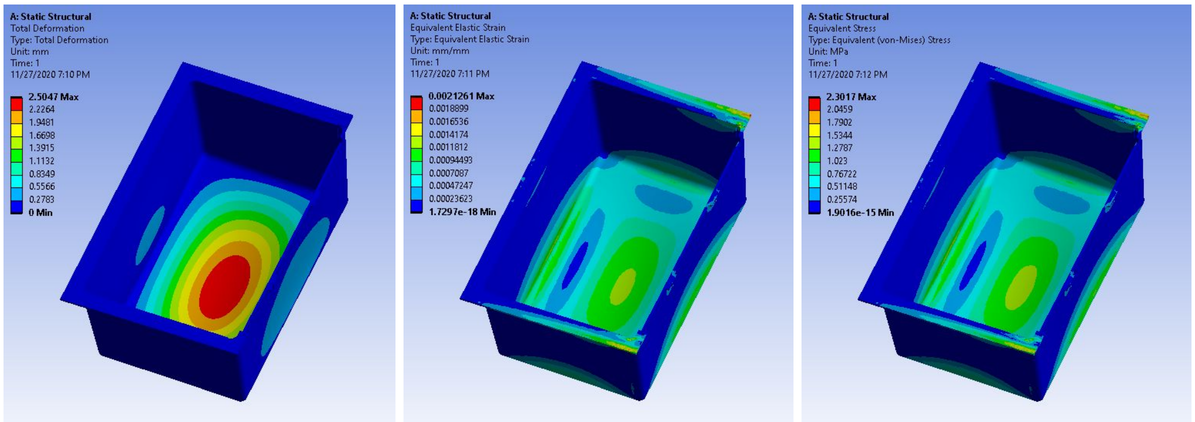


Figure A1.2.6: ANSYS Workbench Outputs for Total Deformation (left), Equivalent Elastic Strain (center), and Equivalent Stress (right) using Polyethylene Material Properties

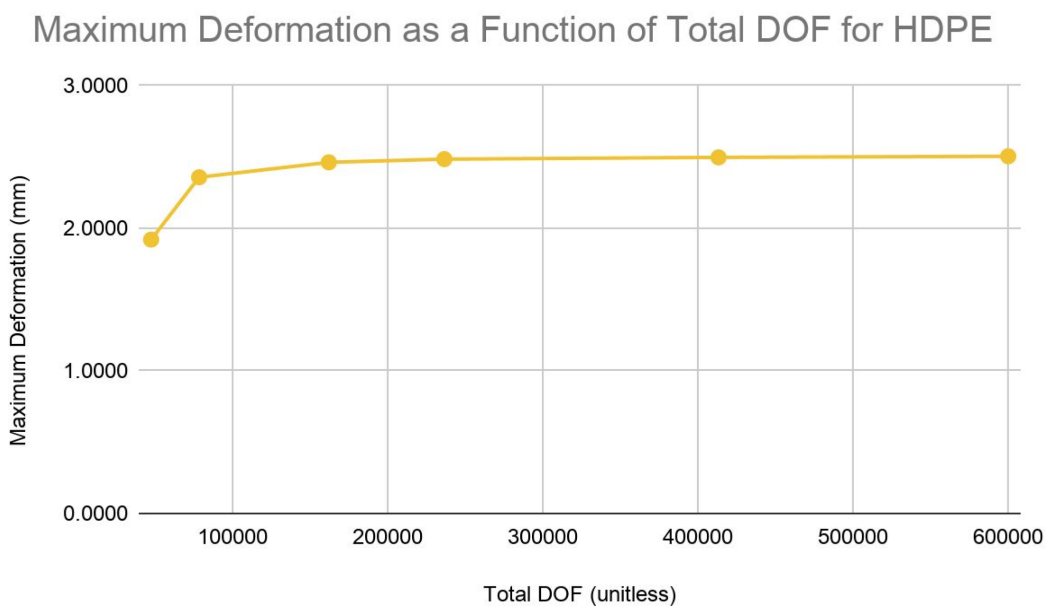


Figure A1.2.7: Maximum Deformation per Total DOF using Polyethylene Material Properties

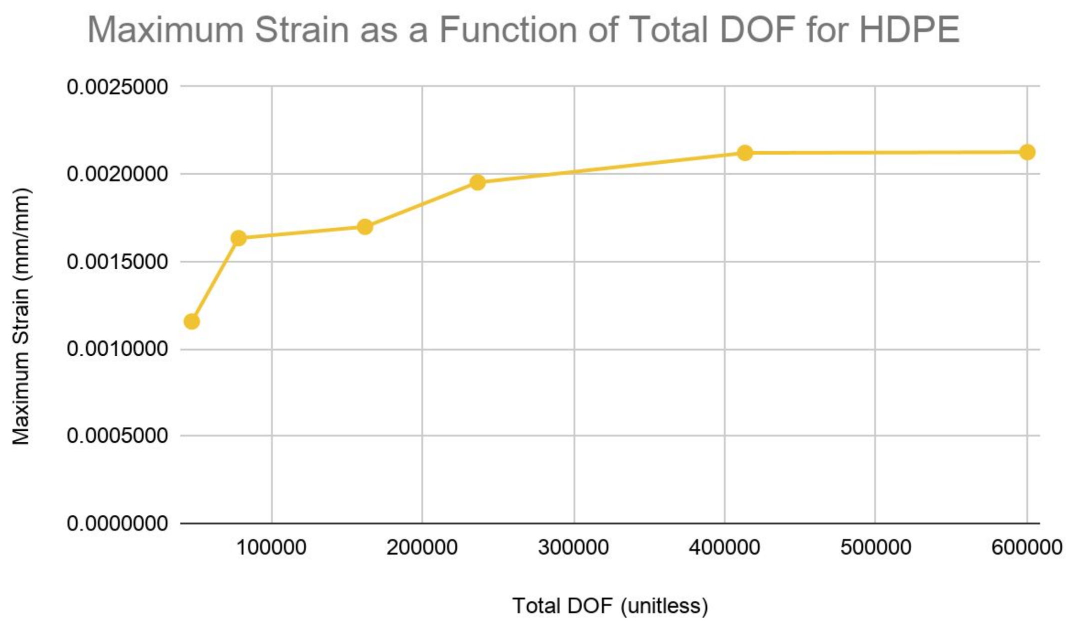


Figure A1.2.8: Maximum Strain per Total DOF using Polyethylene Material Properties

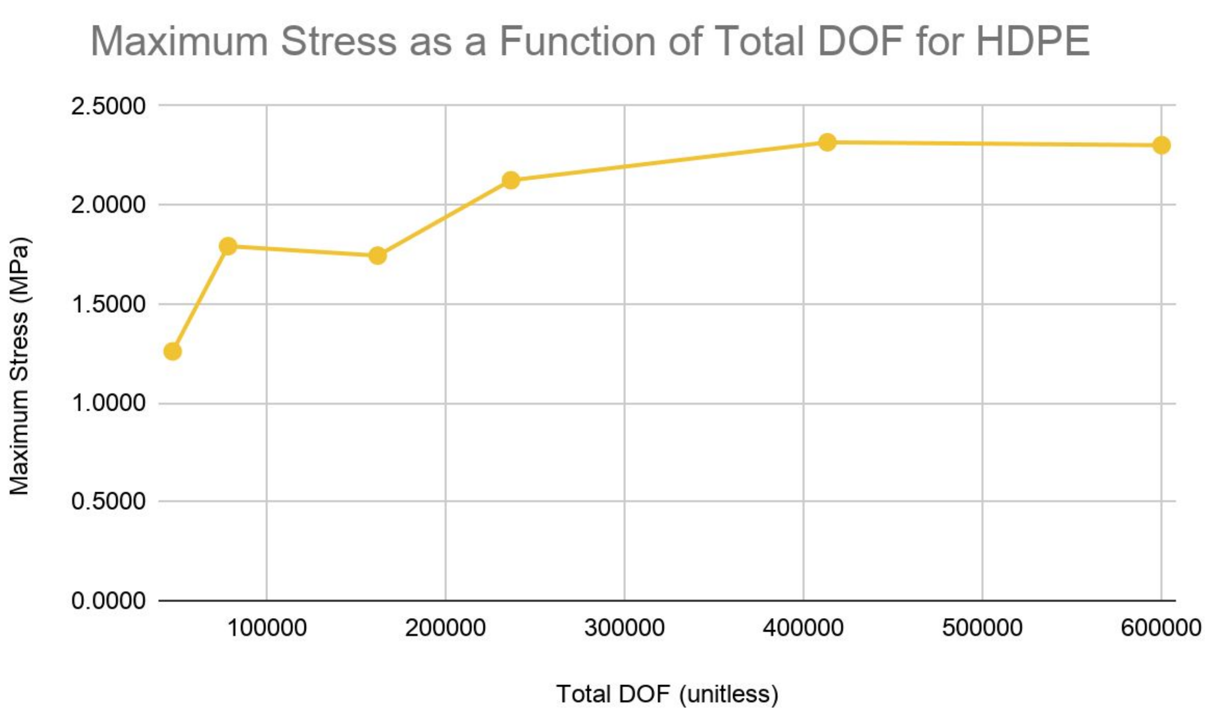


Figure A1.2.9: Maximum Stress per Total DOF using Polyethylene Material Properties

The results of the analysis show that for HIPS, the maximum deflection is approximately 1.26 mm, the maximum strain is approximately 0.00107 mm/mm, and the maximum stress is approximately 2.3 MPa. Furthermore, for polyethylene, the maximum deflection is approximately 2.5 mm, the maximum strain is approximately 0.00213 mm/mm, and the maximum stress is approximately 2.3 MPa.

These values are significantly small compared to the maximum yield strength of HIPS and HDPE, which are 31 MPa and 25 MPa, respectively. Therefore, it can be confidently concluded that the feeder will not yield with syrup in the feeder.

Furthermore, deformation on the wall of the feeder at the bee access area has deflected only approximately 0.1 mm for both the HIPS and HDPE models. This is significantly small compared to the ⅜ in bee space (9.525 mm) required for optimal bee access (~1% of total bee space) and therefore does not significantly impact the bee space and bee access.

Appendix A2: Abrasion Analysis

Analysing the effects of abrasion on the feeder using FEA was considered in this report. However, a discussion with someone more experienced in FEA [13] revealed that accurate analyses of abrasion is extremely difficult to model and has much potential for completely inaccurate results. Fortunately, the physical HIPS prototype was available, and an experiment was conducted to compare the abrasion resistance of the new feeder to a store-bought feeder. The results from this experiment can be found in Appendix C3.

Appendix A3: Impact Analysis

By changing the geometry of the preliminary Dual Feeder (removing back tab, adding draft angles for injection molding, reducing the thickness to 3 mm and making it consistent throughout the design so that it can be manufactured via injection molding) the volume of plastic decreased. This decrease in volume lowered the mass of the feeder from 1.72 kg to 0.87 kg. This decreases the kinetic energy of the feeder at the point of impact, and the force of impact of the feeder when dropped.

Impact Force Analysis

$g := 9.81 \frac{m}{s^2}$ $h := 1\ m$ $t_{pulse} := 0.003\ s$

Velocity at time of impact:

$v := \sqrt{2 \cdot g \cdot h} = 4.4294 \frac{m}{s}$

Acceleration due to impact:

$a := \frac{2 \cdot \sqrt{2 \cdot g \cdot h}}{t_{pulse}} = 2952.9646 \frac{m}{s^2}$

Kinetic Energy of feeder at time of impact:

$KE(m) := \frac{1}{2} \cdot m \cdot v^2$

Impact Force:

$F(m) := m \cdot a$

Preliminary Dual Feeder Half:

$m_{dual'} := 1.72\ kg$

$KE_{dual'} := KE(m_{dual'}) = 16.8732\ J$

$F_{dual'} := F(m_{dual'}) = 5079.0991\ N$

New Dual Feeder Half:

$m_{dual} := 0.87\ kg$

$KE_{dual} := KE(m_{dual}) = 8.5347\ J$

$F_{dual} := F(m_{dual}) = 2569.0792\ N$

Analysing the effects of impact on the feeder's structural integrity using FEA was also considered in this report. However, experimentation done in this report can obtain much more accurate results than FEA, since an FEA analysis would be dynamic and therefore involve many more variables and assumptions that may result in an inaccurate solution. Therefore, for the time constraint and scope of this project, an FEA impact simulation was not pursued.

Appendix A4: Heat Transfer Analysis

The following calculations are the same thermal analysis performed in Phase II with minor quality changes. While the recommendations from Phase II have been read and acknowledged, the calculations have remained unchanged as thermal calculations were not pursued in Phase III for reasons mentioned.

Thermal analysis for beehive feeders.

Section 1: Preliminary Knowledge

The thermal resistance due to conduction is R.cond = L/kA
The thermal resistance due to convection is R.conv = 1/hA.s
The thermal resistance due to radiation is R.rad = 1/h.radA.s, where h.rad=εσ(T.s^2-T.surr^2)(Ts+Tsurr)

The three feeder designs all comprise of five elements with thermal resistances: wood, plastic, syrup, steel and air.
The thermal conductivity of wood varies between 0.12-0.04. (http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/thrcn.html)

$k_w := 0.04\ \frac{W}{m\ K}$

The film coefficient of outside air is 500 W/m^2k (https://www.sciencedirect.com/topics/engineering/convection-heat-transfer-coefficient. The conduction coefficient for air is between 0.02-0.025 W/mk (https://www.engineeringtoolbox.com/air-properties-viscosity-conductivity-heat-capacity-d_1509.html?vA=-15&degree=C&pressure=1bar#)

$h_a := 500\ \frac{W}{m^2\ K}$

$k_a := 0.025\ \frac{W}{m\ K}$

The thermal conductivity of polystyrene varies between 0.03-0.04 (https://www.nuclear-power.net/nuclear-engineering/heat-transfer/heat-losses/insulation-materials/thermal-conductivity-of-expanded-polystyrene/#:~:text=Typical%20thermal%20conductivity%20values%20for,low%20thermal%20conductivity%20of%20gases.) but the thermal conductivity of expanded polysytrene is 0.03 while the thermal conductivity of HDPE is between 0.42-0.51.

$k_p := 0.04\ \frac{W}{m\ K}$

The syrup that the beekeepers use is either cane syrup or sugar beet syrup. These values are difficult to obtain and vary depending on the supplier. For the sake of the phase II, a value between 0.26-0.46 W/mK will be assumed based off https://www.sciencedirect.com/science/article/abs/pii/S0960308519308946

$k_s := 0.46\ \frac{W}{m\ K}$

Since the mesh has many gaps in it and is very thin, it's thermal resistance effects will be neglected.

For radiation calculations, an emissivity of 0.9 will be assumed. (https://www.engineeringtoolbox.com/emissivity-coefficients-d_447.html). The Stefan-Boltzmann constant σ is also required,

$\varepsilon := 0.9$ $\sigma := 5.67 \cdot 10^{-8}\ \frac{W}{m^2\ K^4}$

$T_s := 228.15\ K$ $T_{surr} := 228.15\ K$ $T_1 := 233.15\ K$ $Q := -5\ W$

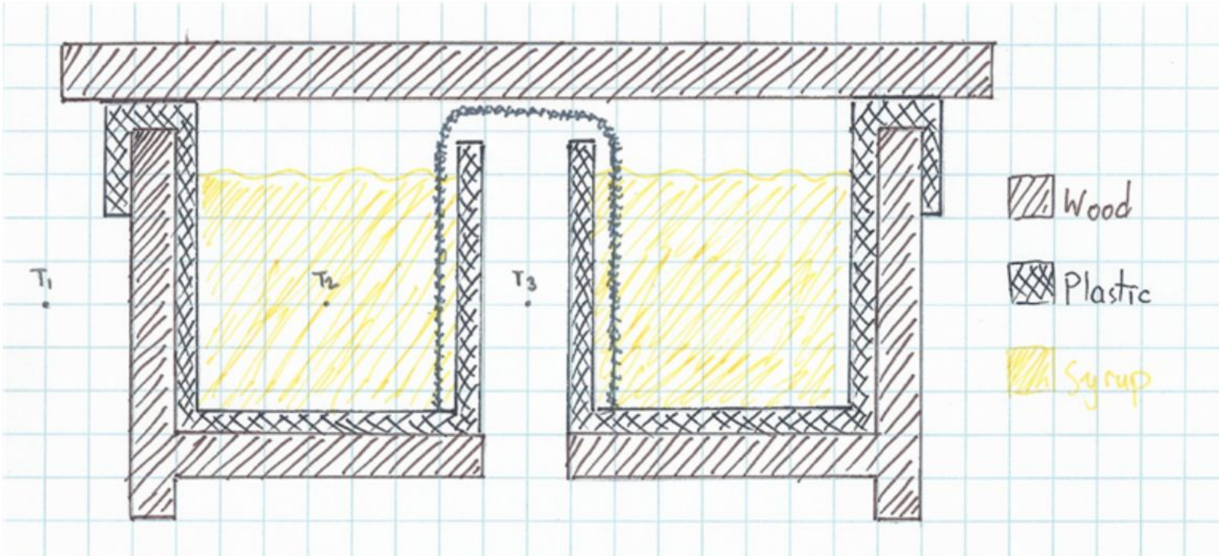
$$h_r := \varepsilon \cdot \sigma \cdot \left(T_s^{\ 2} + T_{surr}^{\ 2}\right) \cdot \left(T_s + T_{surr}\right) = 2.4241\ \frac{kg}{K\ s^3}$$

The areas will change depending on which section is being calculated. Area will be calculated in the equations. The geometries need to be defined however. The dimensions of the box are 16 1/4" x 19 3/4". Converting to metric gives the box dimensions 0.41275m x 0.50165m.

$t_w := 0.03\ m$ $w_b := 0.50165\ m$ $L_b := 0.41275\ m$ $h_b := 0.243\ m$

$t_p := 0.003\ m$

Section 2: Dual Feeder Analysis



Assumptions :

1. The thermal resistance of the steel/plastic mesh is negligible.

2. Fluid inside the feeder will mostly remain stationary. Convection effects of the internal syrup and air may be neglected.

3. The wooden box will be the same for all three feeders. The air underneath the plastic feeder is neglected.

4. The syrup level inside the feeder changes with time as the bees feed. Since the rate of syrup decrease is unknown, the thermal resistances of the air that would occupy the syrup space as it decreases is forced to be neglected.

5. The air above the syrup in the diagram is neglected. In reality, the syrup would be filled up to a level where the air presence is negligible until the syrup levels begin to decline.

6. The thermal resistance due to the brink is neglected. It is a very tiny portion of the entire feeder and would contribute minimal difference in the total thermal resistance due to the thinness of the plastic.

For the dual feeder, a length L.s1 is defined as the width of the syrup space.

$L_{s1} := 0.21\ \mathrm{m}$

Using standard thermal resistane procedure, the total thermal resistance in the dual feeder can be calculated as:

$A_{syrup} := \left(w_b - 2 \cdot t_w\right) \cdot \left(h_b\right) = 0.1073\ \mathrm{m}^2$ R_eq11 is resistance up to the center of the syrup and R_eq12 is resistance up to the center of the feeder

$$R_{eq11} := \frac{1}{A_{syrup} \cdot \left(h_r + h_a\right)} + \frac{t_w}{k_w \cdot A_{syrup}} + \frac{t_p}{k_p \cdot A_{syrup}} + \frac{\frac{1}{2} \cdot L_{s1}}{k_s \cdot A_{syrup}} = 9.8327\ \frac{\mathrm{K\ S}}{\mathrm{A}^2}$$

$$R_{eq12} := \frac{1}{A_{syrup} \cdot \left(h_r + h_a\right)} + \frac{t_w}{k_w \cdot A_{syrup}} + \frac{t_p}{k_p \cdot A_{syrup}} + \frac{L_{s1}}{k_s \cdot A_{syrup}} + \frac{t_p}{k_p \cdot A_{syrup}} = 12.6584\ \frac{\mathrm{K\ S}}{\mathrm{A}^2}$$

The temperatures at location T.2 and T.3 can be dertermined using the following equation (Q is required):

$T_{12} := T_1 - R_{eq11} \cdot Q = 282.3133\ \mathrm{K}$

$T_{13} := T_1 - R_{eq12} \cdot Q = 296.442\ \mathrm{K}$

Appendix A5: Manufacturing Analysis

The client specified that the material for the plastic insert must be the plastic used in plasticell foundation, which is in the form of plastic pellets. Therefore, SCFAX Engineering identified that manufacturing processes are fundamentally limited to the following material addition processes: injection molding, extrusion, blow molding, and rotational molding. Due to the high production number, CNC machining was not considered due to cost and time intensiveness. Additionally vacuum forming was not considered since the plastic will be provided in pellet form and it would not be efficient to form the pellets into sheets and then to vacuum form them.

From research and consultation with industry experts and senior engineers [14], injection molding was deemed most feasible for our applications. Extrusion was ruled out as a manufacturing process since it is only suitable for products with continuous profiles, such as window frames. Blow molding was also eventually ruled out since it is most suitable for hollow plastic parts, like bottles. Rotational molding was deemed unfit for this project since it is ideal for larger hollow parts, and is less popular. Because injection molding is the most widely used process for mass manufacturing plastic parts (above 5000), this meets our production and cost requirements.

In a conversation with Lorry Dickson from L-D Tool, it was found that an injection molding machine with a tonnage of 800 tons would be sufficient for this project. The tonnage can be roughly determined by multiplying the top surface area of the feeder by three. The length and width of the feeder is approximately 17” and 10”, respectively. A safety factor of 1.1 can be applied.

$$17'' \times 10'' = 170\ sq.in.$$

$$170\ sq.\ in. \times 3\ ton/sq.\ in. \times 1.1 = 561\ ton$$

Therefore, a 600 ton machine could produce the desired plastic insert.

In industry, the maximum amount of recycled (or regrinded) plastic is usually 20%, since material properties degrade after each recycling process. Provided below in Figures A5.1.1 to A5.1.6 are quotes that were received from various companies who were approached to assist in this project. Not all of the quotes were used in the analysis, but they all provided insight.

Appendix A5.1: Manufacturer Quotes/Bills

ACCURATE SCREEN & GRATING

Accurate Screen Ltd.
7571 57th Street SE
Calgary AB T2C 5M2
Canada

Quote
#QT75815
11/19/2020

Ship To	Bill To	Customer Shipping Specifications
Stephen Cash Sale Calgary **ALBERTA CUSTOMERS ONLY** AB Canada	Stephen Cash Sales Calgary Calgary AB Canada	

Expires	Exp. Close	Fulfillment Location	Sales Rep	Shipping Method
12/19/2020	11/19/2020	Calgary	Matthew Lydon	Pickup

Item	Qty	UOM	Weight	Rate	Amount
WOW-Stainless-304-Roll-Bare-16-0.018"-48"x100' Woven Wire 14-16 week Lead Time For Stock Replenishment Stainless 304 Material 0.045" Opening 0.018" Wire Diameter. FOB Our Shop.	26,800	Sq Ft	9,380	$2.43	$65,124.00

Currency CAN

	Subtotal	$65,124.00
	PST / QST	$0.00
1) Thank you for this opportunity. Please do not hesitate to contact us should there be any additional questions or concerns in this matter. 2) Check out our website WWW.ACCURATESCREEN.CA	**GST / HST**	$3,256.20
Total Order Weight 9,380 LBS	**Total**	$68,380.20

Figure A5.1.1: Accurate Screens Quote for Mesh Screen Raw Material (~20,000 units)

Mark Gagnier Wed, Nov 25, 1:11 PM (11 days ago)
to me

Hi Stephen
Did a quote for a 150 units. This would be the best to start off with to ensure what we are making would work for you.
Supply and form 150 only u-channel screen made from 10 mesh .025 wire T304 (.075"/1.91mm opg) 149mm x 39mm x 149mm x 371mm long @ 61.00 each.

We would then look at the large qty's once the design is confirm.

Hope this will work for you. Any concerns please contact me.

Figure A5.1.2 : Metal Fabricators and Welding Ltd. Quote for Mesh Screen Custom Fabrication

Quotes
to me

Fri, Nov 27, 7:58 AM (9 days ago)

Good Morning Stephen,

The cost to supply these using #10 – 304 s.s. mesh with .025 wire will be $11.25 each. Pricing is based on an order of 10,000 pieces. We would need to do a sample prior to proceeding with the order.

Thanks

Pat Morrow
President

MIDWEST FABRICATORS LTD
16310 – 121A Avenue
Edmonton, AB T5V 1J9
Tel. 780-447-0747
Fax. 780-447-0774

Please send all new **quote** requests to:
quotes@midwestfabricators.ca
Please send all new **orders** and **jobs** to:
orderdesk@midwestfabricators.ca

Figure A5.1.3: Midwest Fabricators Quote for Mesh Screen Custom Fabrication

Darin LaBonte <d_labonte@hrctool.com>
to me

Good afternoon Steve,
Since there are still some unknowns for material type and whether you/your client will be supplying, let us proceed by excluding their cost for now.

We are able to offer the following:
Option 1
1 single cavity mold $46,000.
Producing batches of 10,000 units within 2-3 weeks of receiving a purchase order and raw material at a unit cost of $2 each.

Option 2
1 double cavity mold $97,000.
Producing batches of 10,000 units within 7 days of receiving a purchase order and raw material at a unit cost of $0.90 each.

We understand that the design may change slightly but trust that these figures are close enough for you to work through the decision processes.
Please let me know if you have any questions and keep me up to date on any developments.
Thank you.

Darin LaBonte
General Manager

HRC TOOL & DIE MFG. LTD.
3804 – 93 Street NW, Edmonton, AB T6E 5K8
Ph: 780.450.3222
Fx: 780.439.3618
Toll Free: 1.888.450.3472
d_labonte@hrctool.com
www.hrctool.com

Figure A5.1.4: HRC Tool Quote for Plastic Insert Injection Molding

L-D Tool & Die

Division of MADIX Engineering Inc.

Quotation

Customer:	University of Alberta		Prepared by:	A.SCHEEL
Attn:	Xusheng Yu		Quote number:	AS23112020
Contact #:	xusheng@ualberta.ca		Date:	NOV-23-2020

PRODUCT QUOTE

Item #	Part Description	Material	Colour	MOQ / 2500
TBD	BEEHIVE TOP FEEDER	**CUSTOMER SUPPLIED**	YELLOW	**$4.200**
TBD	BEEHIVE TOP FEEDER	ABS	YELLOW	**$8.420**

MOULD QUOTE

Mould #	Part Description	Cavities	Mould Leadtime	Mould Cost
TBD	BEEHIVE TOP FEEDER	1	5-6 Weeks	$31,000.00

PARTS

1. Part pricing is based on todays material cost.
2. **Terms of payment**: Net 30, subject to applicable taxes
3. Shipping: EXW Ottawa
4. L-D Tool & Die labour cost guaranteed for one year
5. This quotation is based on information given to us at this time.
6. Pricing may be subject to change anytime.

N.B All Part prices are in CDN funds

Approved:
Date:
11-23-2020

MOULDS

1. Mould cost includes trial and 15 shots.
2. Delivery of first off samples: 6-7 weeks after receipt of PO, acceptable electronic files & down payment.
3. Shipping by sea approximately 6 weeks after samples are approved.
4. Air shipment (10 Days) is optional .
5. Shipping is Not included.
6. **Terms of payment**:

60% down with PO.
Balance, plus all taxes, due prior to shipping moulds.
As long as the mould is in the care of L-D it will be maintained, for the life of the project, at no charge to Univerersity of Alberta.
Upon final payment the mould will become sole property of University of Alberta.

N.B All Mould prices are in USD funds.

Figure A5.1.5: L-D Tool Quote for Plastic Insert Injection Molding

Union 3D Printing — INVOICE #D188

Complete your purchase

Complete your purchase — or Visit our store

Order summary

Custom 3D Print Beehive Top Feeder × 1	$180.00
Shipping- Edmonton × 1	$5.00
Subtotal	**$185.00**
Shipping	**$0.00**
Taxes	**$9.25**
Total	**$194.25 CAD**

Figure A5.1.6: Union 3D Prototyping Bill

Appendix A6: Cost Analysis

Step 1: Collecting/Recycling Raw Material

Ideally, clean and pre-sorted plasticell sheets would be delivered to the Alberta Beekeeping Commission by the beekeepers themselves. However, in the case that the sheets are delivered too dirty or not sorted, a cost may be associated with bringing them up to a recyclable standard.

An experiment was performed (see Appendix C1) to determine the most efficient way to clean used foundation sheets. The cost of performing the cleaning is broken down in the calculations below:

Materials: (All should be locally available across Alberta)

Containers (Must be at least 43 cm long): ($98.97 + 5% GST)/6 units = $17.32/unit
https://www.walmart.ca/en/ip/sterilite-831-latch-tote-blue-6pk/...
...6000199678400?rrid=richrelevance

Per sheet:

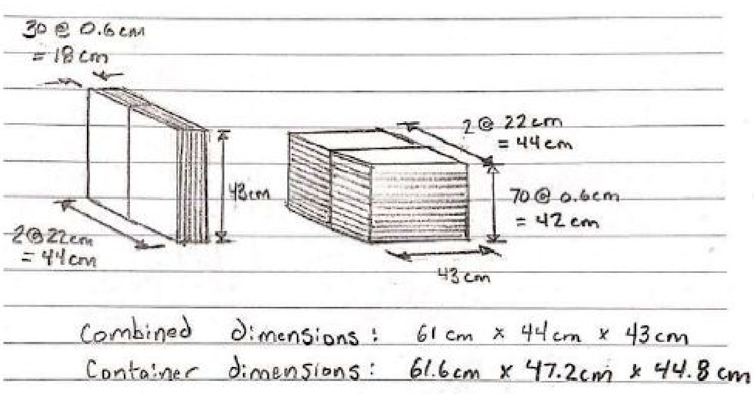
Container Dimensions:

Length: 0.616 m
Width: 0.472 m
Height: 0.448 m

Plasticell Sheet Dimensions:

Length: 0.43 m
Width: 0.006 m
Height: 0.22 m

If sheets are stacked as seen in the diagram below, these containers could hypothetically hold 200 sheets though, in order to soak each surface thoroughly, the sheets should not be packed that tight. Also, to account for abnormalities in the sheets as well as the special geometries of the containers we will assume that an average of 125 sheets fit per container (37.5% safety margin)



Therefore the cost per sheet can be calculated to be as:

($17.32/unit) / (125 sheets/unit) = $0.14/sheet

NOTE: THIS COST IS WORST CASE SCENARIO, CONTAINERS SHOULD BE REUSED IN MULTIPLE BATCHES TO REDUCE WASTE AND COST (OVERHEAD COST, NOT VARIABLE)

12% Chlorine Liquid Bleach: ($36.99 + 5% GST)/20L $1.94/L
https://www.homehardware.ca/en/20l-12-chlorine-liquid-bleach/p/4510572

Dawn Dish Soap: ($9.97 + 5% GST)/2.66L $3.94/L
https://www.wholesaleclub.ca/Cleaning-%26-Supplies/Dishwashing/plp/RCWC002003002000

Solution: 6:2:1 water to bleach to soap ratio

Volume required to fill remaining space in containers:

Container volume = 83 L
Individual sheet volume: 43 cm * 22 cm * 0.6 cm * (3/4) = 425.7 cm^3 = 0.426 L
NOTE: this volume assumes that, due to the pockets in the sheets, the material only accounts for 2/3 of the total volume

Available liquid volume = 83 L - (125 sheets * 0.426 L) = 29.75 L

Assume 25 L of solution will be used so that there is still some free space
this solution will require roughly 17 L water, 5.5 L bleach, and 3 L soap

{(5.5L / 125 sheets) * $1.94/L} + {(3L / 125 sheets) * $3.94/L)} = $0.18/sheet

2,000+ PSI Pressure Washer: ($148.00 + 5% GST) = $155.40/unit
https://www.homedepot.ca/product/sun-joe-pressure-joe-2-030-psi-1-76-...
...gpm-14-5-amp-electric-pressure-washer/1000659881

Lifetime?

If the washer is to hypothetically wash 100,000 sheets in its lifetime and each sheet takes 30 seconds to wash thoroughly (generous), the washer must operate for a runtime as follows:

(100,000 sheets * 30 seconds/sheet) / (3,600 seconds/hour) = 834 hrs

If the pressure washer operator runs the machine roughly 20 out of 40 hrs each work week, it will take approximately 42 work weeks to wash all 100,000 sheets. This is just shy of a year, but the warranty on this specific unit extends 2 years, so as long as it is not defective, it should have no problem accomplishing this.

Therefore a conservative guess for the cost per sheet of purchasing a brand new pressure washer is as follows:

($155.40/unit) / (100,000 sheets/unit) = $0.002/sheet (NEGLIGBLE!)

But to be even safer, we will assume that since utilities such as water and electricity are required to run this particular unit, the cost to wash each sheet is closer to:

Assume utility bill of {$200/month * (12 months/year)} / (100,000 sheets/year)

Cost of running pressure washer: $0.024/sheet + $0.02/sheet = ~$0.04/sheet

Used Plasticell Sheets: $0.00/sheet

(These are expected to be returned free of charge)

Cost of Labour:

Manpower required to soak the sheets, prepare the work area, and operate the pressure washer should be included in the recycling cost calculation

Hourly wage for a labourer = ~$21.00/hr
https://www.glassdoor.ca/Salaries/edmonton-labourer-salary-...
...SRCH_IL.0,8_IM969_KO9,17.htm

Time required to wash 100,000 sheets assuming washer is running 50% of the time = 42 work weeks.

Assuming no overtime/holiday pay, the labour cost for each foundation sheet is as follows:

(42 weeks / 100,000 sheets) * 40 hours/week * $21.00/hour = $0.35/sheet

Professional Recycling Facility Cost:

The final cost associated with recycling the material is having the cleaned sheets processed by a professional plastic recycler. Based on discussions with a representative from Merlin Plastics (Calgary), the cost of recycling High Density Polyethylene is as follows:

Reward for plastic provided: $85 / metric ton

Purchase price for fully recycled and pelletized plastic: $0.23/lb
NOTE: THIS PRICE IS BASED OFF A PURCHASE OF 40,000 LBS AND GREATER

Mass per sheet = {(425.7 cm^3/sheet) / (1,000,000 cm^3/m^3)} * (950 kg/m^3)

Number of sheets / metric ton = (1000 kg/t)/(0.404 kg/sheet) = 2473 sheets/t

HDPE density source:
https://www.plasticseurope.org/en/about-plastics/what-are-plastics/...
...large-family/polyolefins#:~:text=The%20density%20of%20HDPE%20can,...
...and%20tensile%20strength%20than%20LDPE.

Monetary reward per sheet: ($85/t) / (2473 sheets/t) = $0.03/sheet

IN SUMMARY:
NOTE: These costs are conservative and can potentially be reduced, but freight charges for transporting materials have not been included since too many variables are unknown

Washing Container: $0.14/sheet
Washing Solution: $0.18/sheet
Pressure Washer (+ Utilities): $0.04/sheet

Used Plasticell Sheets: $0.00/sheet
Washing Labour: $0.35/sheet
Return Reward: -$0.03/sheet

NET COST OF RECYCLING PLASTIC FOUNDATION SHEETS = $0.68/sheet

Step 2: Manufacturing Feeder

Recycled Material:

The amount of recyled material needed to be purchased to produce each feeder is calculated below:

Volume of plastic required per plastic insert: 801.83 cm^3 (as per Solidworks)

Mass of material required = {(801.83 cm^3/insert)/(1,000,000 cm^3/m^3)}*(950 kg/m^3)

= 0.762 kg * (2.2046 lb/kg) = 1.68 lb/insert

Material Cost: (1.68 lb/insert) * ($0.23/lb) = $0.39/insert

Manufacturing:

Through discussion/consultation with a representative from a local injection molding company, a quote was issued outlining two possible options for manufacture based on quantity. The image below is an excerpt from an email conversation with the representative:

Option 1

1 single cavity mold $46,000.

Producing batches of 10,000 units within 2-3 weeks of receiving a purchase order and raw material at a unit cost of $2 each.

Option 2

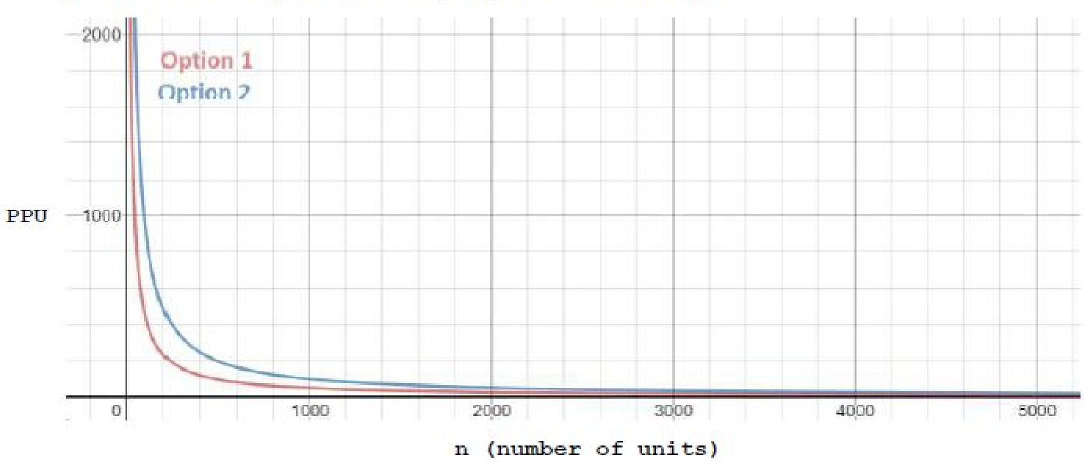
1 double cavity mold $97,000.

Producing batches of 10,000 units within 7 days of receiving a purchase order and raw material at a unit cost of $0.90 each.

Based on these figures, a simple analysis can be conducted to see for which quantities are each option is most valid:

Let n be the number of units desired for production:

Option 1: Price per unit = ($46,000 + $2.00*n)/n
Option 2: Price per unit = ($97,000 + $0.90*n)/n



As seen in the above graph, Option 1 is definiely the cheaper option for lower quantities of production. For Option 2 to become more feasible, production must be greater than:

$$\text{Option 1} > \text{Option 2}$$
$$\$46,000 + \$2.00*n > \$97,000 + \$0.90*n$$
$$\$1.1*n > \$51,000$$
$$n > 46364 \text{ units}$$

For our goal of 10,000 feeders (20,000 plastic inserts), option 1 is definitely the most feasible and would have a price per unit of:

{$46000 + ($2.00/unit * 20,000 inserts)} / 20,000 insert = $4.30/insert

Including raw material costs: $4.30/insert + $0.39/insert = $4.39/insert

Mesh Screen:

Costs associated with the mesh screen include both raw materials and fabrication. Through discussions with a local mesh supplier as well as a local custom fabricator, the following estimate was able to be put together: for stainless steel 10 to 16-mesh:

Raw Material Cost = $65,124.00 / 20,000 units = $3.26/unit
(as quoted by Accurate Screens based out of Calgary)

$11.25/unit

Fabrication + Raw Material Costs = $112,500 / 10,000 units =
(as quoted byy Midwest Fabricators out of Edmonton)

By extrapolating from these two quotes, it can be assumed that a majority of this parts cost comes from fabrication/material mark up. To further minimize costs, if would be worth looking into in-house fabrication solutions: the nature of this material allows it to be cut and bent fairly easy.

Screws:

The chosen type of screw to be used in this design is a #6, 3/8", pan head, 18-8 stainless steel, sheet metal screw though, other screws may work in a pinch. These can simply be purchased off the shelf in bulk at almost any hardware store. The cost per unit on these is calculated below:

Retail Price: $3.63/100 screws = $0.04/screw
https://www.grainger.ca/en/product/Metal-Screw%2CPan%2C%236%2C3-8-In-...
...L%2C100-PK/p/EBP1VE50

Hive Box:

These are expected to be owned by the beekeepers prior to the purchase of this product. Therefore the price is: $0.00/box

IN SUMMARY:

NOTE: These costs are not as conservative as before but can still be reduced if certain measures are taken. Freight charges have again been neglected in this analysis since too many variables are unknown at this time.

Plastic Insert (x2): $9.38/feeder
Mesh Screen (x1): $11.25/feeder
Screws (x2): $0.08/feeder

NET COST OF MANUFACTURING TOP FEEDER = $20.71/Feeder

Added Price of Using Recycled Plasticell:

Number of sheets per feeder: (Assume that 10% of the sheets volume is lost during the recycling process)

(801.83 cm^3/insert) / {(425.7 cm^3/sheet)*90%} = 2.09 sheets/insert

Cost per Insert: (2.09 sheets/insert) * ($0.68/sheet) = $1.42/insert

Total Added Cost: ($1.42/insert) * (2 inserts/feeder)= $2.85/feeder

Revised Feeder Cost: ($20.71/feeer) + ($2.85/feeder)

COST OF MANUFACTURING TOP FEEDER FROM PLASTICELL = $23.56/Feeder

Step 3: Engineering Overhead

As far as the Alberta Beekeepers Commission is concerened, the costs associated with the engineering of the design are not of any concern. However, for the purpose of a complete and comprehensive cost analysis, this fee cannot be overlooked. Based on a standard junior and senior engineering rate of $90/hr and $150/hr respectively, the following labour calculation was made:

Junior Engineering Hours Spent During Each Phase:

Phase 1: 90 hrs	= $8,100.00
Phase 2: 174.5 hrs	= $15,705.00
Phase 3: 369 hrs	= $33,210.00
Total Hours: 633.5 hrs	= $57,015.00

Senior Egineering Hours: 9 hrs = $1,350.00

Total Engineering Labour Cost: = $58,365.00

Prototyping costs should also be included here since they were part of the process and cost a significant amount of money. It should be noted that these are one time costs and they are slightly inflated due to the fact that 2 out of the 4 feeders purchased were unnecessary, but free to the team. The estimated costs of these prototypes were derived from speaking to Roger Marchand, the shop Technical Services Supervisor. They will still be included in the cost analysis even though they were never actually incurred

HIPS and PLA Prototype (from Union 3D): $194.25

ASA and Nylon Prototype (for U of A): $775.00
(estimated to be $350.00 and $425.00 respectively)

Total Prototyping Costs: $194.25 + $775.00 = $969.25

Total Engineering Overhead: $58,365.00 + $969.25 = $59,334.25

Assuming that this overhead cost will be distributed across our goal of 10,0000 units, the price per feeder for engineering overhead is as follows:

$59,334.25 / 10,000 feeders = $5.93/feeder

TOTAL COMPREHENSIVE UNIT COST OF PRODUCING 10,000 FEEDERS: $29.49/Feeder

Note that if 100,000 units are produced, the engineering overhead is only $0.59/feeder, which is significantly cheaper

Appendix A7: Other Calculations and Analysis

Appendix A7.1: Stackability Ratio

To calculate a "stackability ratio" the stacked vertical height was simply divided by the accumulated height of each individual feeder in the stack. The bottom feeder in a stack does not inherently save any space and therefore acts as an overhead value that is overcome by increasing numbers of units. Based on the measurements shown in the stacked assembly drawing (see page 3 of the drawing package) it is known that a single feeder is roughly 160 mm tall and each stacked feeder adds an additional 63 mm to the total height. Using *n* as the number of feeders being stacked, the equation (and corresponding graph in Figure A7.1.1) below shows how the stackability ratio function:

<u>Stackability Calcs:</u>

$$SR := \left(1 - \left(\frac{160\ \text{mm} + \left((n-1) \cdot 63\ \text{mm}\right)}{n \cdot 160\ \text{mm}}\right)\right) \cdot 100\ \%$$

As n approches infinity:

$$SR := 1 - \left(\frac{1}{n} - \frac{63}{160 \cdot n} + \frac{63}{160}\right) = 1 - 0 + 0 + 0.4 = 0.6 = 60\%$$

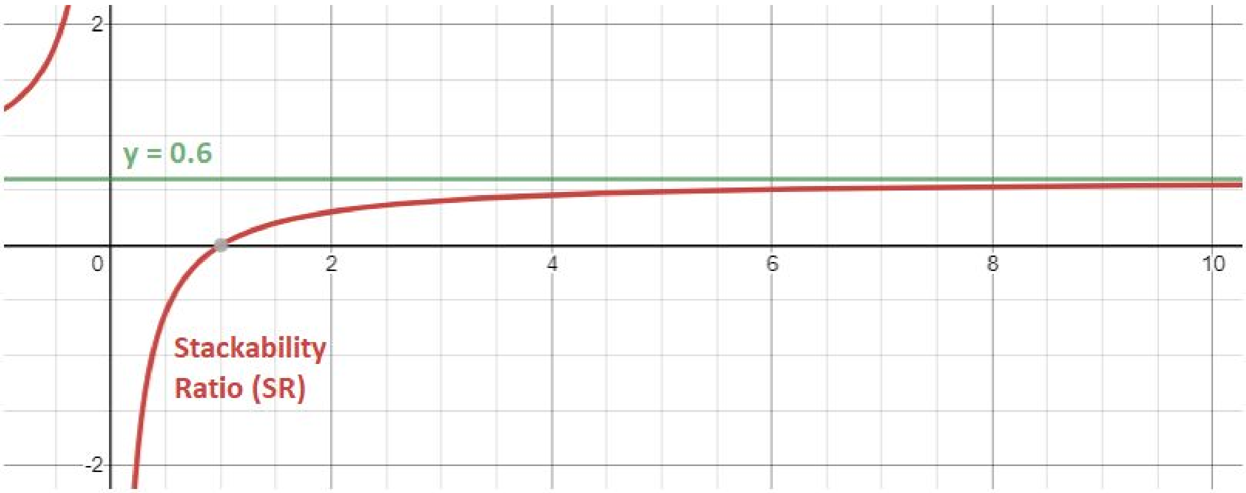


Figure A7.1.1: Stackability Ratio Function

Note that by looking at the graph above, it can be seen that 1 unit has a stackability ratio of 0% (no space savings) but 10 units is already quickly approaching 60%. 0.60 was determined to be the maximum by taking the limit of the function as the number of feeders approaches infinity (see above).

Appendix A7.2: Injection Mold Solidworks Analysis

A draft analysis of the Dual Feeder model was conducted using Solidworks. The direction of pull is set to be perpendicular to a plane that passes through the bottom edge of the back overhang and the top of the tab at the tab centerline (seen in Figure A7.2.1). The minimum draft angle is set to be 2.00° [15] which is recommended for the injection molding process. From Figure A7.2.2 it can be seen that the Dual Feeder design meets the draft angle requirements for injection molding.

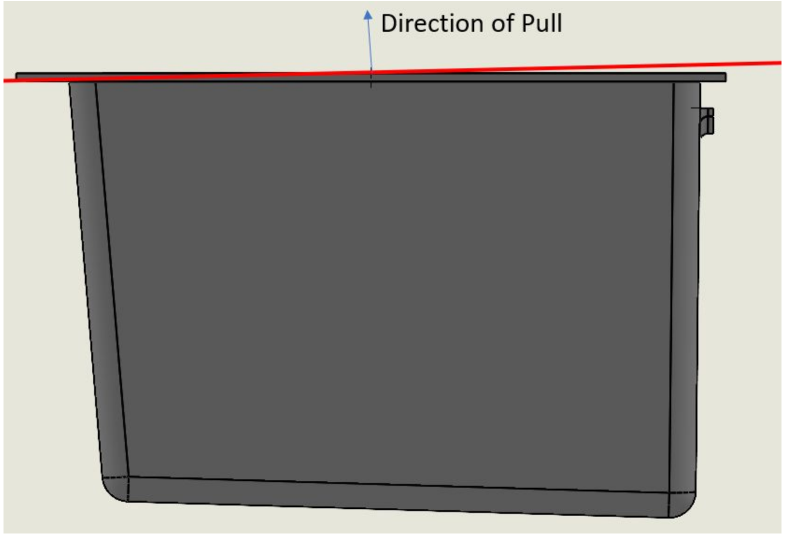


Figure A7.2.1: Draft Analysis of Dual Feeder

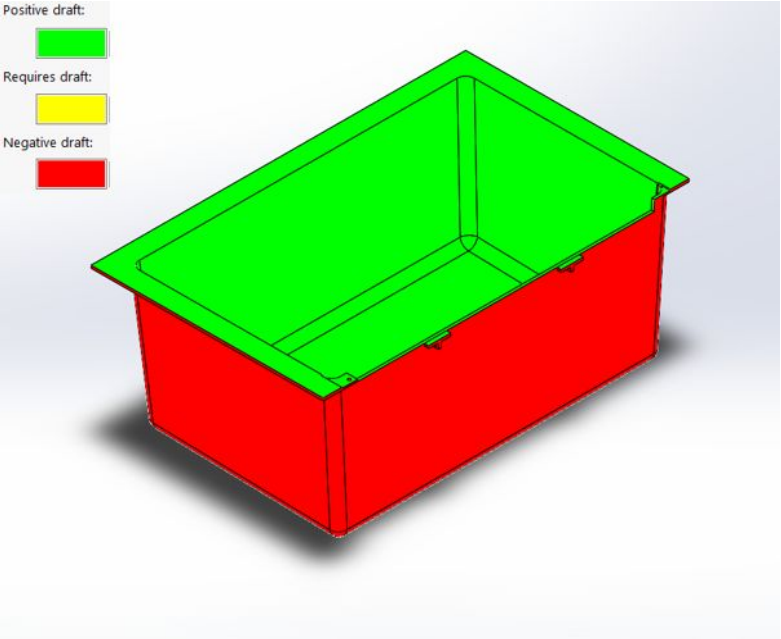


Figure A7.2.2: Draft Analysis of Dual Feeder

An injection mold simulation was run using Solidworks. This calculates certain parameters that show the overall ability of the design to be manufactured using injection molding. The injection location was placed at the midpoint of the bottom of the feeder which ensures that any weld lines resulting from the plastic injection process will not be located at the bottom surface or walls of the feeder, as failures in these regions could result in leaks that would be detrimental to the hive. From the simulation results, weld lines are unlikely to occur during the injection molding process for the Dual Feeder design. Weld lines have a small chance of occurring in the center tabs and the overhangs (near the outer edge) which can afford to be slightly weaker as they are the areas that are under the least stress.

The conditions of the injection mold simulation are:

Control Type: Ejection Temperature

Model:

- Volume = 801.83 cm
- Mass = 842.48 g
- Size:
  X: 255.44 mm
  Y: 159.87 mm
  Z: 412.75 mm

Material:

- Material Name: “Generic material of HIPS”
- Melt Temperature = 230.00 °C
- Transition Temperature = 100.00 °C
- Thermal Conductivity = 1.200*10^4 erg/(cm-s-°C)
- Young's Modulus = 1900.00 MPa
- Poisson’s Ratio = 0.38

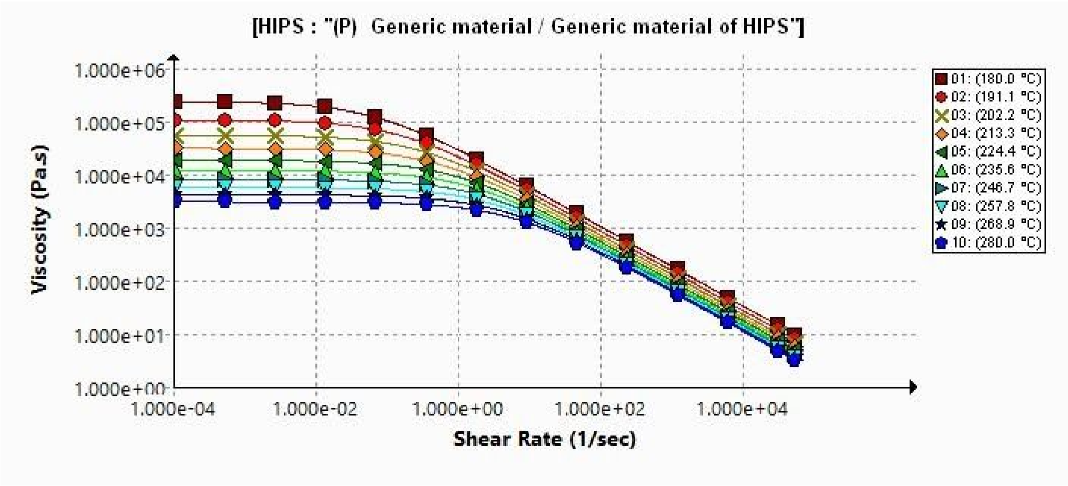


Figure A7.2.3: HIPS Viscosity vs. Shear Rate at Different Temperatures

Process:

Flow:

- Expected Filling Time = 3.67 s
- Mold Temperature = 50.00 °C
- Injection Pressure Limit = 100 MPa

Cool:

- Min. Coolant Temperature = 25.00 °C
- Ejection Temperature = 90.00 °C
- Ambient Air Temperature = 30 °C
- Mold Open Time = 5 s
- Average Coolant Flow Rate = 150 cc/s

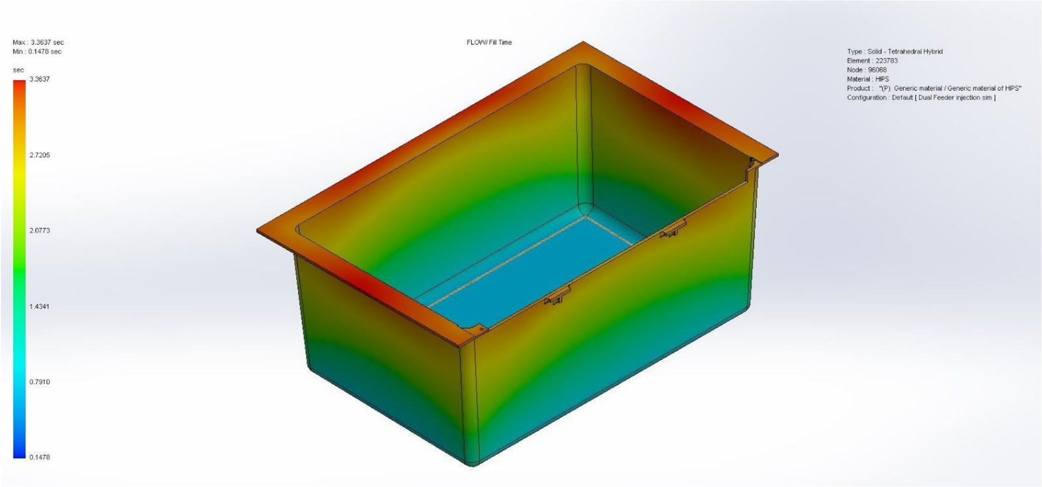


Figure A7.2.4: Injection Mold Simulation Fill Time

From Figure A7.2.4, it can be seen that the injection is able to be completed in 3.3637 s. By choosing the center of the bottom of the feeder it can be seen that the plastic has relatively even flow paths up the walls of the feeder profile in the mold cavity (reducing the likelihood of the racetrack effect and therefore, reducing the possibility of weld lines).

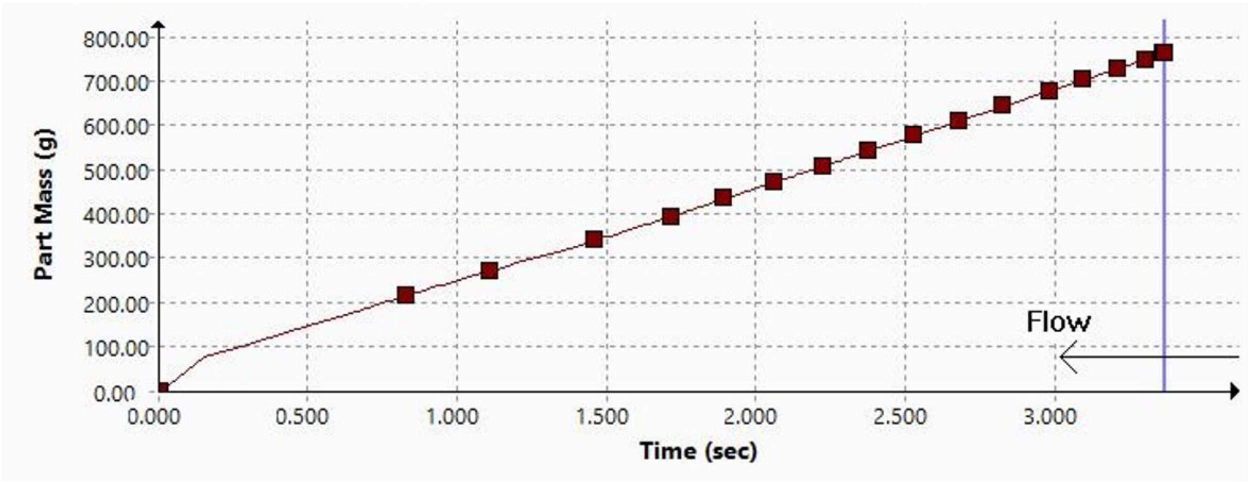


Figure A7.2.5: Mass of Feeder over Time

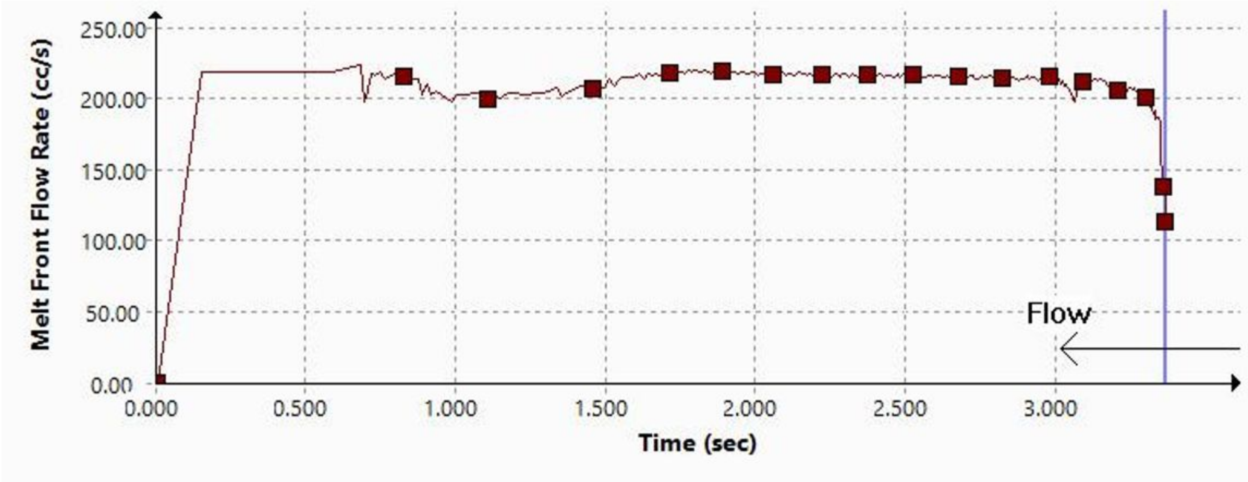


Figure A7.2.6: Melt Front Flow Rate over Time

As can be seen in Figure A7.2.5, the mass of the feeder increases linearly with time, indicating that the volume is being filled at close to constant rate. This is consistent with Figure A7.2.6 which shows that the melt front flow rate is roughly 220 cc/s throughout the plastic injection process.

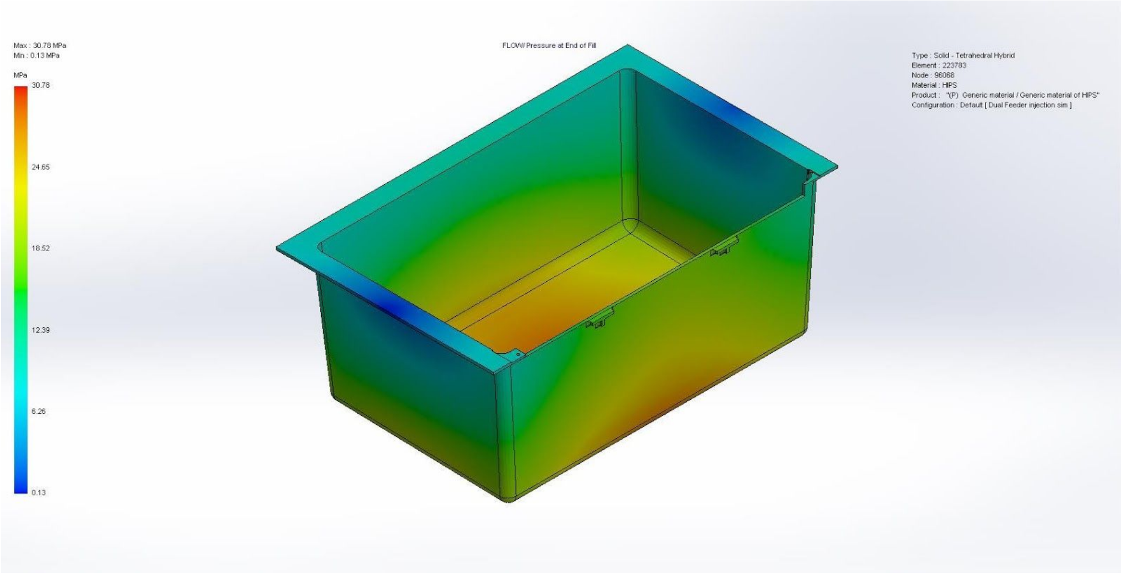


Figure A7.2.6: Pressure at End of Fill

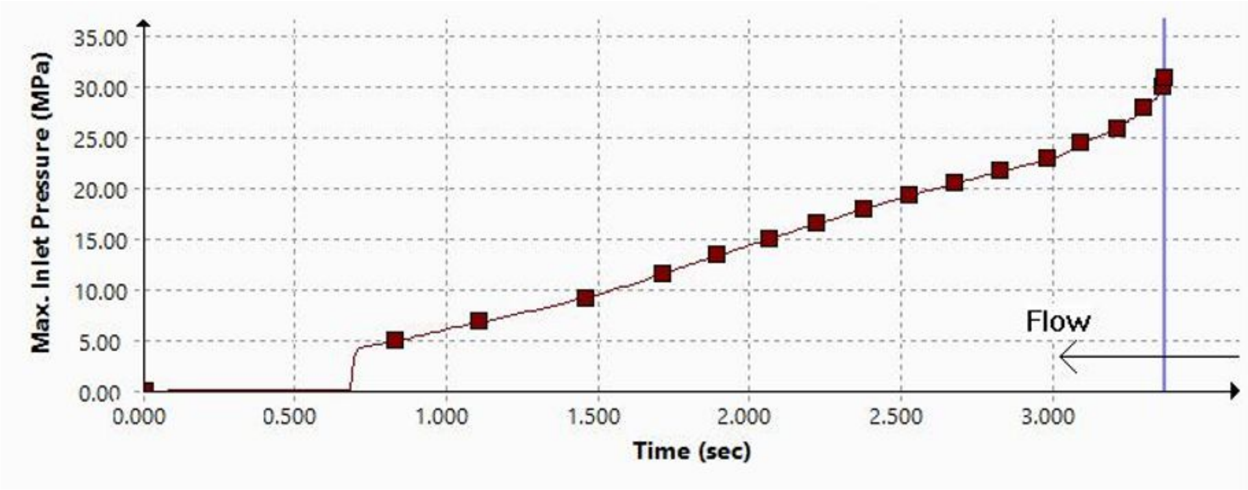


Figure A7.2.7: Maximum Inlet Pressure over Time

From Figures A7.2.6 and A7.2.7, it can be seen that the maximum injection pressure required to fill is 30.78 MPa which is less than 66% of the maximum injection pressure limit specified for the analysis.

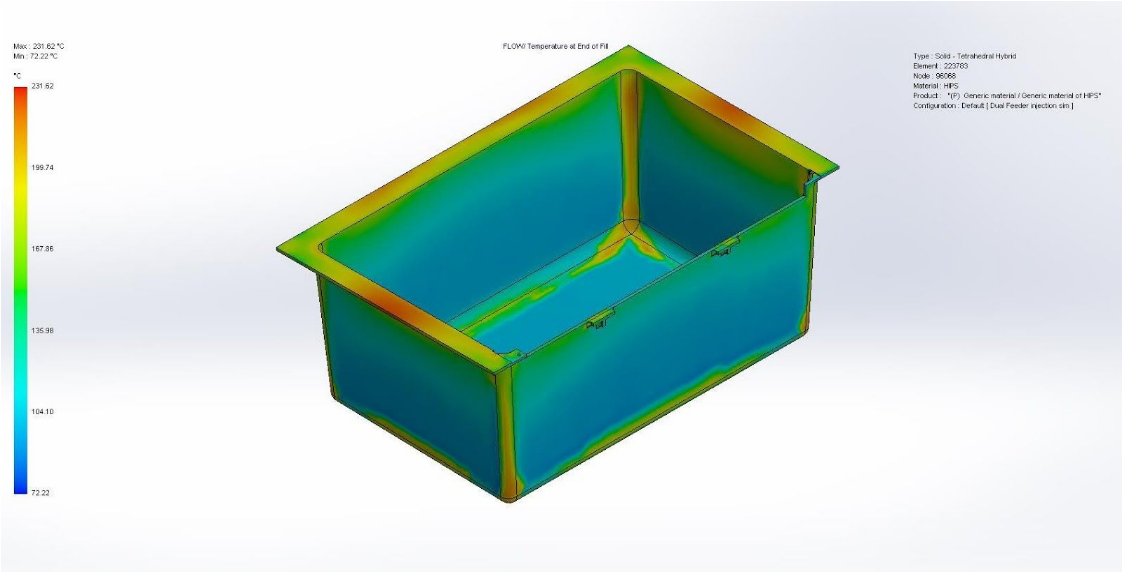


Figure A7.2.8: Temperature at End of Fill

From Figure A7.2.8, it can be seen that the maximum temperature at the end of fill is 231.62 °C which is within 10 °C of the starting melt temperature (230.00 °C) therefore, there is little to no risk of material degradation. The flow front melt temperature is also within the acceptable range of 10 °C from the starting melt temperature. This promotes good mold filling and packing, minimizes injection pressure requirements, helps achieve good weld line integrity.

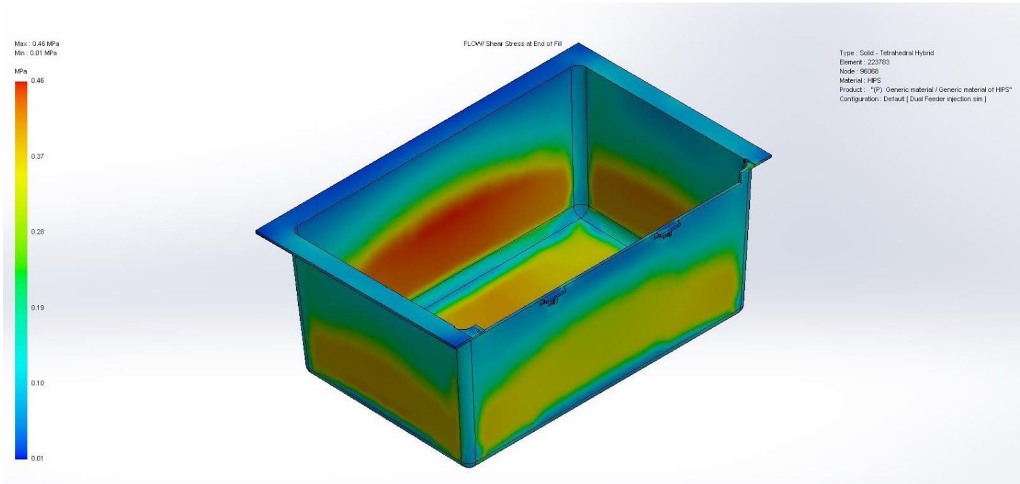


Figure A7.2.9: Shear Stress at End of Fill

From Figure A7.2.7, it can be seen that the maximum shear stress is 0.46 MPa.

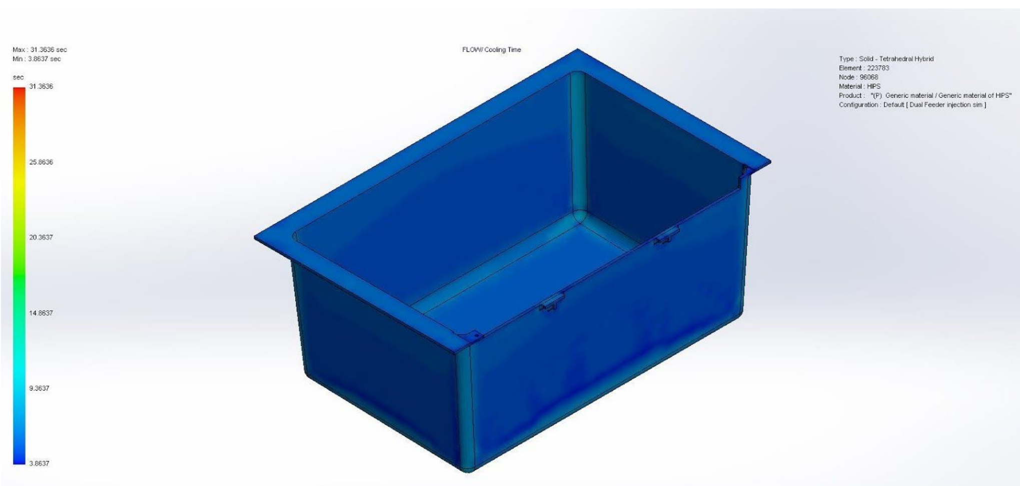


Figure A7.2.10: Injection Molding Cooling Time

From Figure A7.2.8, it can be seen that the maximum cooling time is 31.3636 s, though most of the feeder cools in less than 10.0 s. The cooling time is typically 70% of the total cycle time.

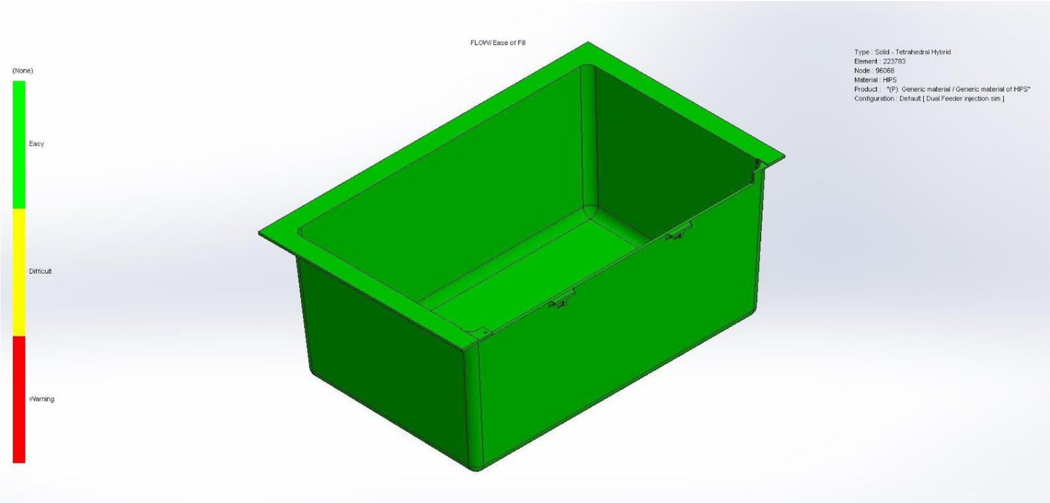


Figure A7.2.11: Ease of Injection Mold Fill

From the Solidworks injection mold simulation the ease of fill is determined to be “easy” (Table A7.2.9). From the simulation data as well as conversations with professionals in the injection mold industry, it can be seen that the part can be successfully injection molded.

Appendix A7.3: Plastic Selection

Table A7.3.1: Material Properties of HIPS and HDPE

Material Property	**High Impact Polystyrene (HIPS)**	**High Density Polyethylene (HDPE)**
Density (g/cc)	0.80 – 1.04[16]	0.94 – 0.97
Tensile Strength (MPa)	11 – 45 (31)[17]	18 – 30
Elongation at Break (%)	10 – 100 (15.97)	20 – 500
Flexural Modulus (GPa)	0.60 – 3.00 (2.19)	0.80 – 1.25
Impact Strength, Notched (J/m)	70 – 100	50 – 100
Surface Hardness (Shore D) [18]	SD60 – SD75	SD60 – SD70

Based on preliminary research done by the Bio Processing Innovation Centre (BPIC), Alberta Agriculture and Forestry for the Alberta Beekeepers Commission, high impact polystyrene (HIPS) and high density polyethylene (HDPE) were identified as common plastics found in the plasticell sheets. Based on the material properties of these materials it was determined that HIPS was the best option to be used in the Dual Feeders. Both materials have comparable densities with HIPS having a slightly lower mid range value of 0.92 g/cc while HDPE has a mid range value of 0.955 g/cc. This means the HIPS would result in a feeder that is slightly less heavy which increases the ease of transportation and installation, as well as reduces the kinetic energy from potential drops. The HIPS has a higher tensile strength than HDPE which is beneficial as the top feeder will be under tensile stresses when loaded statically with the syrup. The HIPS also has a higher flexural modulus than the HDPE which is advantageous since minimizing deflection to maintain ‘bee space’ is a design goal. HIPS has higher mid range values than HDPE for both impact strength and surface hardness meaning it is the material that would better endure scraping and potential falls.

Appendix A8: References

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[17] Jianbo Lu, Zhixiong Zhang, and Norman Zhang, Plastics beehive foundation recycling - From shredded to recycled pellets, Bio Processing Innovation Centre (BPIC), Alberta Agriculture and Forestry, 2020

[18] "Hardness Shore D." Shore D Hardness Test (Durometer Scale) - Hardness of Plastic Materials, omnexus.specialchem.com/polymer-properties/properties/hardness-shore-d

Appendix B: Drawing Package and CAD

Appendix B1: Drawing Tree

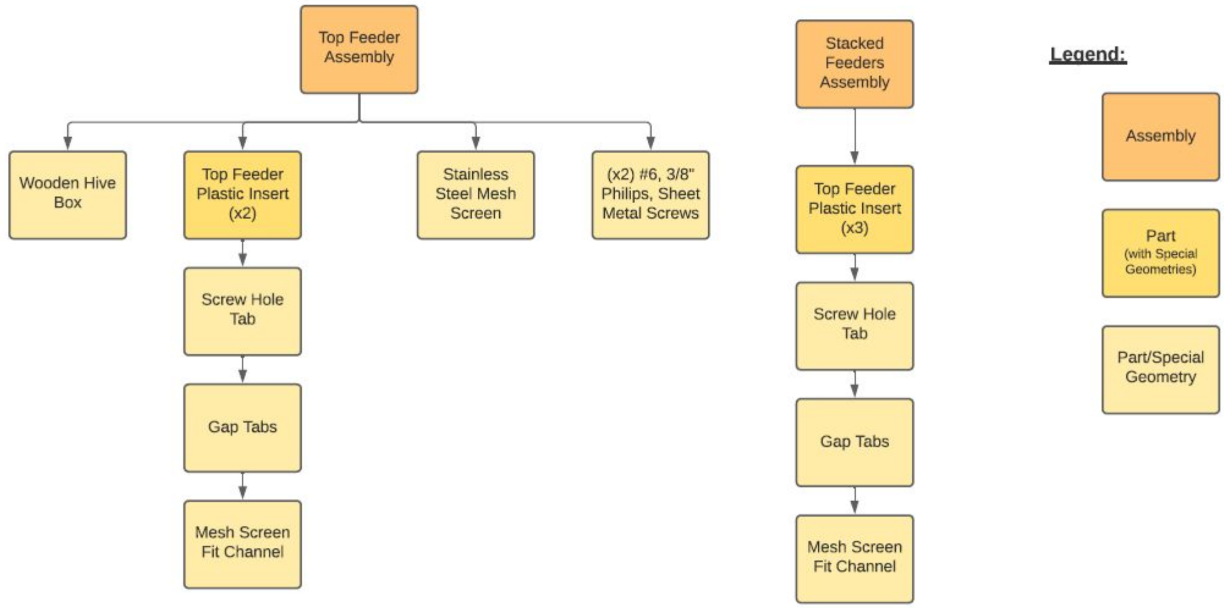

Figure B.1: Top Feeder Drawing Tree

Appendix B2: Drawing Package

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Appendix C: Experiment Results

Appendix C1: Foundation Cleaning Study

PHASE I

In order to determine the most effective way to clean the used Plasticell sheets, 7 different solutions were made to soak sample sheets for 24 hrs. Once soaked, the sheets were removed and analyzed to see if anything had come off on its own. Lastly, a firm wire brush was used to scrub the sheets for 5 minutes. The sheets were analyzed a third time and notes were taken on how well each solution cleaned the sheet. The best solution(s) will then be taken into Phase II which will attempt to further refine the cleaning process. Provided below are the notes along with pictures from each stage of each test:

Notes:

** The pictures below may not fully display the extent of cleanliness for each sheet since the depth of wax in each pocket is difficult to visualize **

<u>Vinegar</u> – Decently effective, cheap, and safe

<u>Paint Thinner</u> – Marginally better than vinegar but is more expensive, harsher on the environment, and releases harmful fumes (dangerous to work with)

<u>Acetone</u> – Harmful/dangerous chemical, melted/deteriorated plastic such that it could not be scrubbed/cleaned. Definite disqualification.

<u>Coca Cola</u> – Not very effective. Overall, not very practical either

<u>Lemon Juice</u> – Not effective at all. Do not recommend

<u>Bleach/Dish Soap</u> – Highly Effective. A great deal came off just from soaking 24 hrs. May not be the most environmentally friendly/cheapest method but by far the most effective

<u>Cold</u> – Surprisingly mildly effective. Cold temperatures must make the wax more brittle and easier to break off. Not nearly as effective as the bleach and soap solution though

1) Vinegar (5% Acetic Acid)

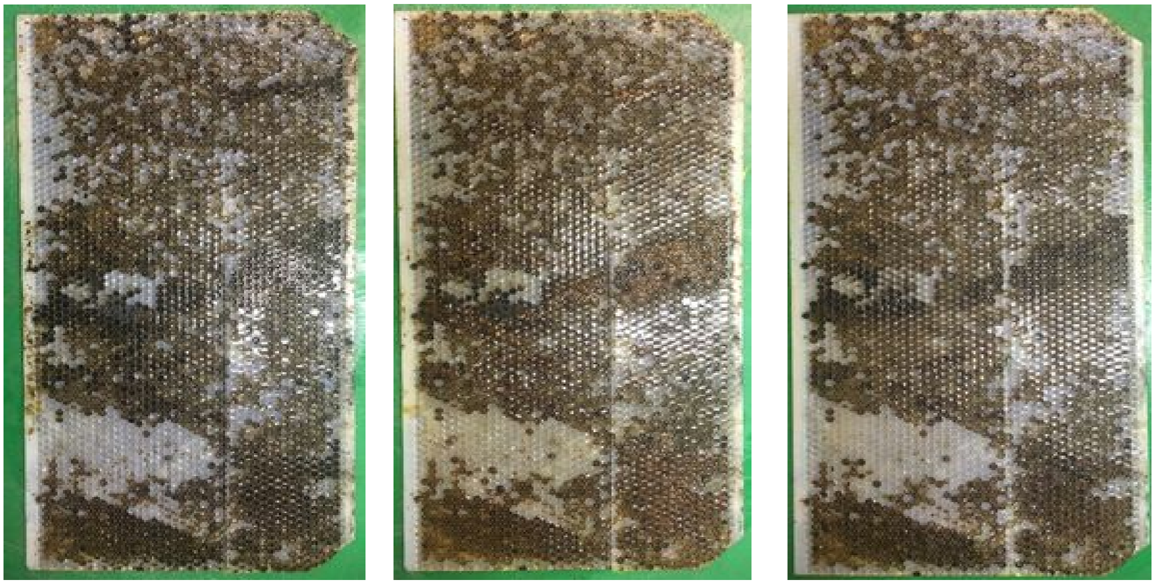

Figure C1.1: Used Plasticell Sheets Before Soaking in Vinegar (Left), After Soaking (Center), and After Scrubbing (Right)

2) Paint Thinner

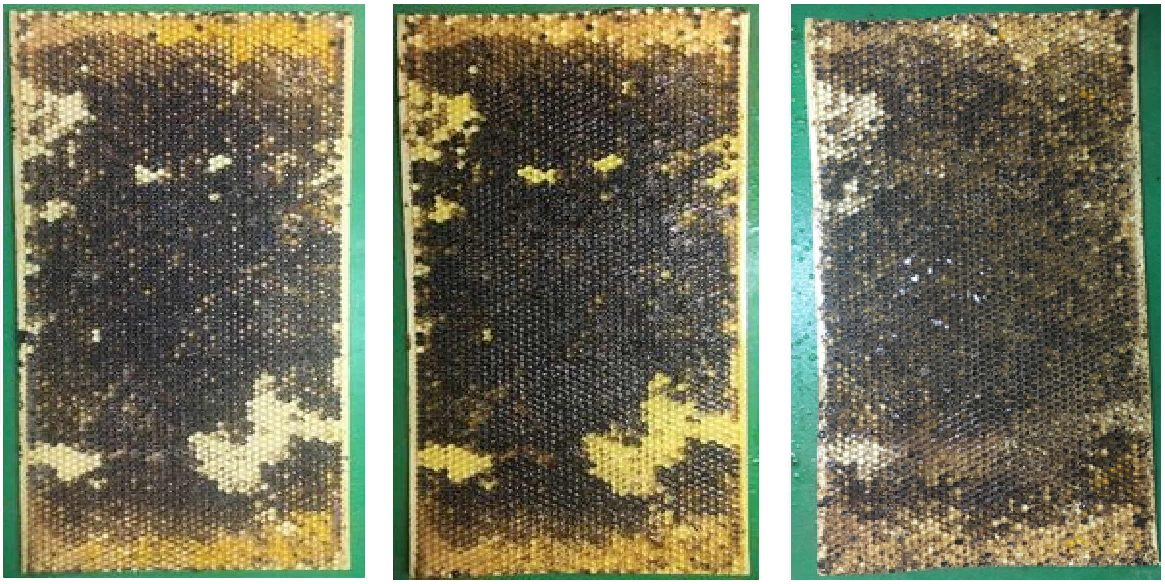

Figure C1.2: Used Plasticell Sheets Before Soaking in Paint Thinner (Left), After Soaking (Center), and After Scrubbing (Right)

3) Acetone

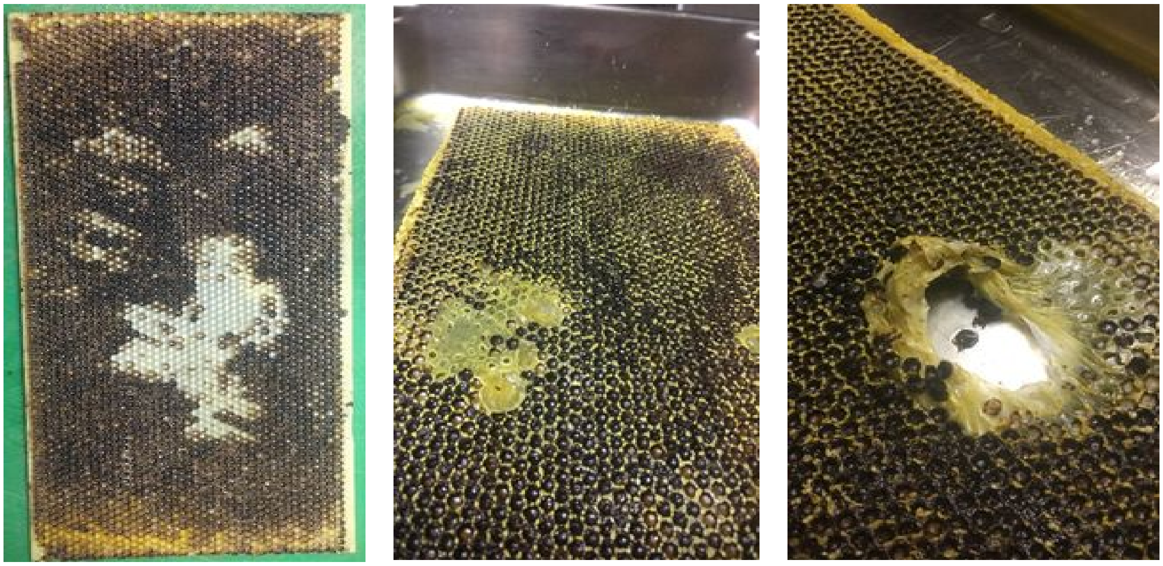

Figure C1.3: Used Plasticell Sheets Before Soaking in Acetone (Left), After Soaking (Center), and After Scrubbing (Right)

4) Coca Cola

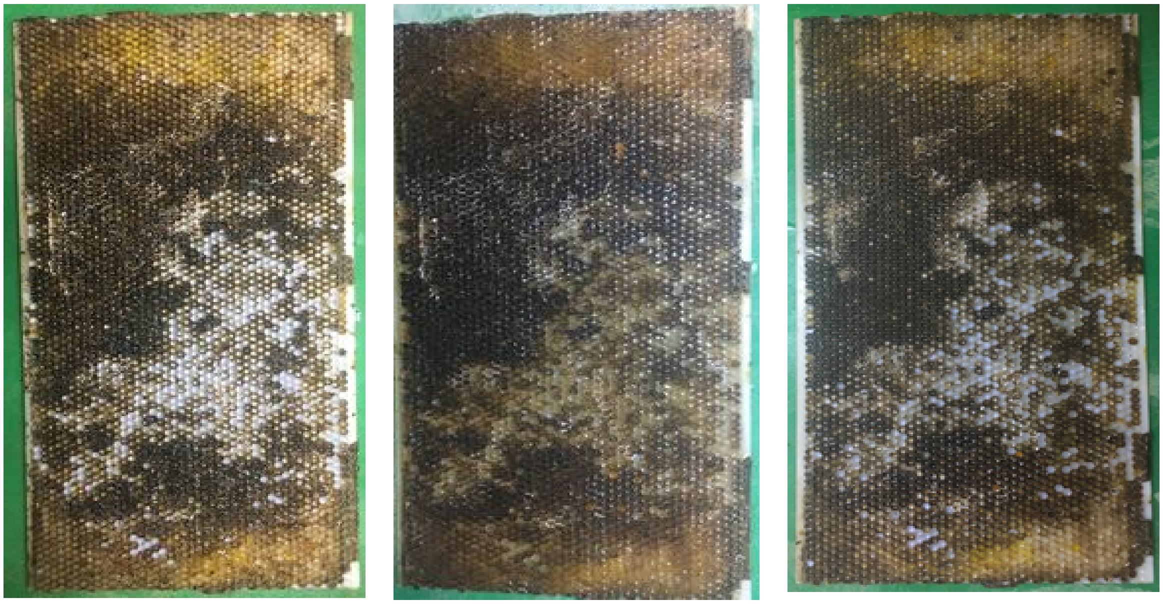

Figure C1.4: Used Plasticell Sheets Before Soaking in Coca Cola (Left), After Soaking (Center), and After Scrubbing (Right)

5) Lemon Juice

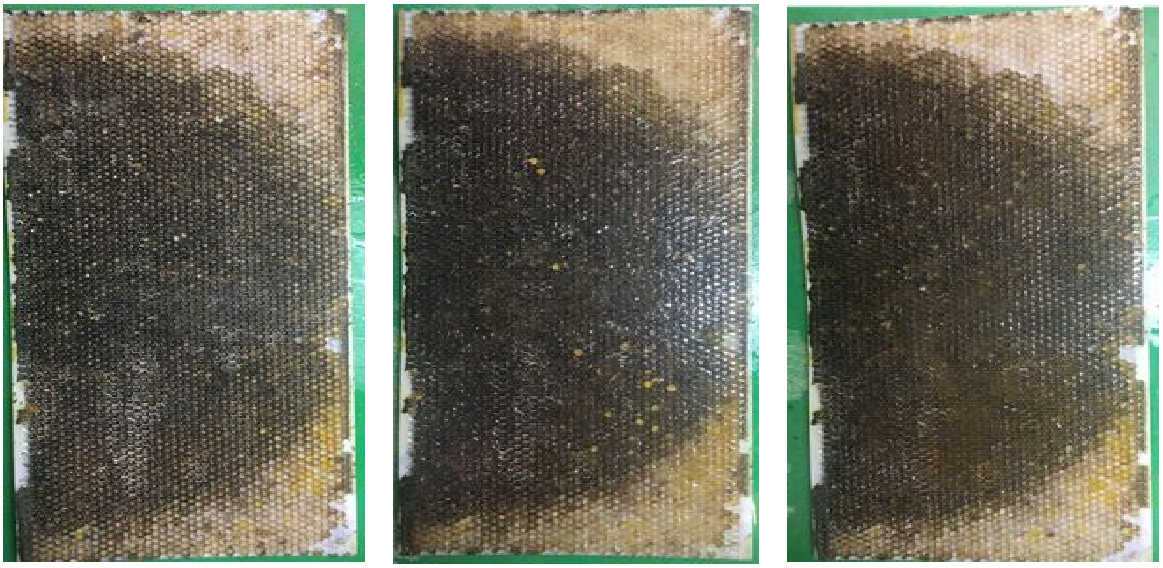

Figure C1.5: Used Plasticell Sheets Before Soaking in Lemon Juice (Left), After Soaking (Center), and After Scrubbing (Right)

6) Bleach and Dish Soap (6:2:1 Water to Bleach to Soap Ratio)

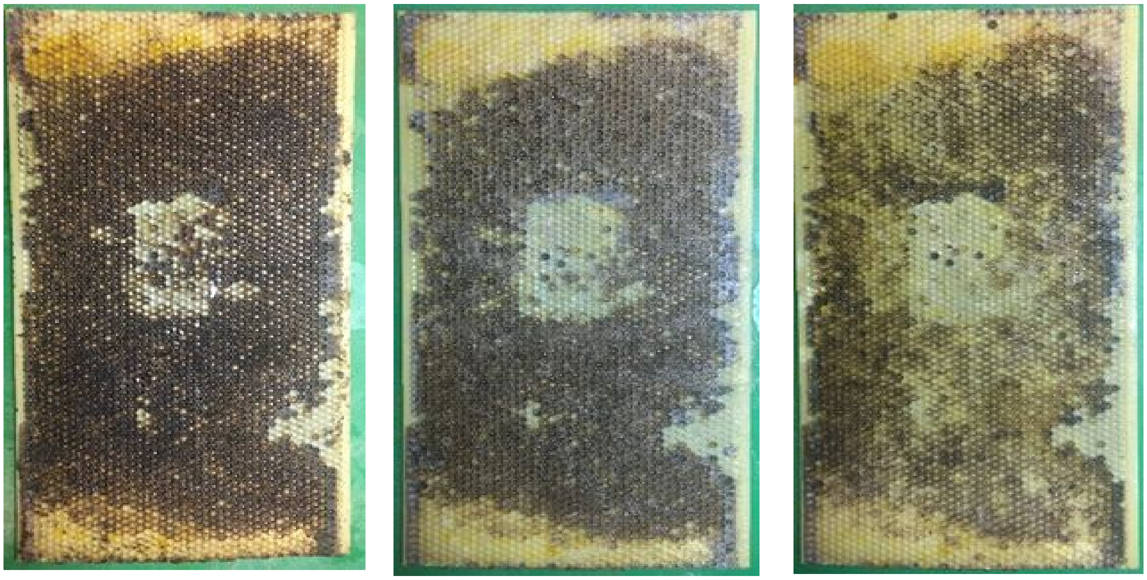

Figure C1.6: Used Plasticell Sheets Before Soaking in Bleach and Dish Soap (Left), After Soaking (Center), and After Scrubbing (Right)

7) Cold (Covered in snow, ~-10° Ambient Temperature)

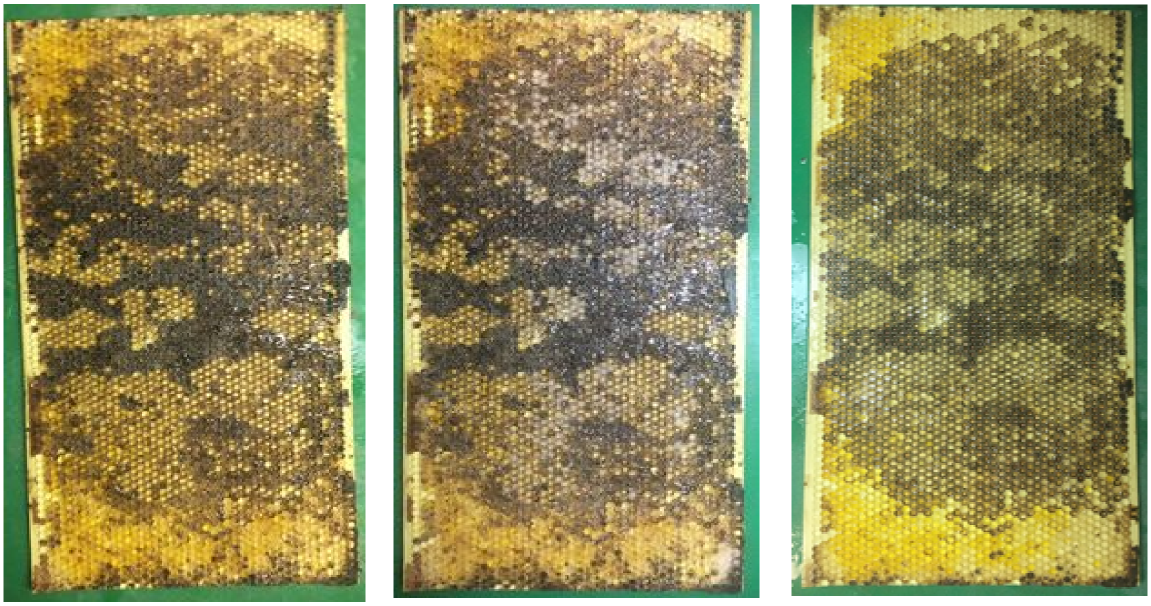

Figure C1.7: Used Plasticell Sheets Before Leaving in Cold Snow (Left), After Freezing (Center), and After Scrubbing (Right)

PHASE II

Since bleach and soap was by far the most effective solution in Phase I, it will be carried on into the next round of experiments which involves soaking for 4 days in different concentrations of the bleach/soap solution. These sheets will also be washed using a pressure washer instead of a hand brush.

Note: Since a personal pressure washer was not available, the sheets were cleaned at a car wash which typically runs at around 1,000 to 1,200 PSI. For quicker and deeper cleaning, it is suggested to use a personal unit which can reach upwards of 2000 PSI on average.

Solution #1: 1500 mL Water, 250 mL Bleach

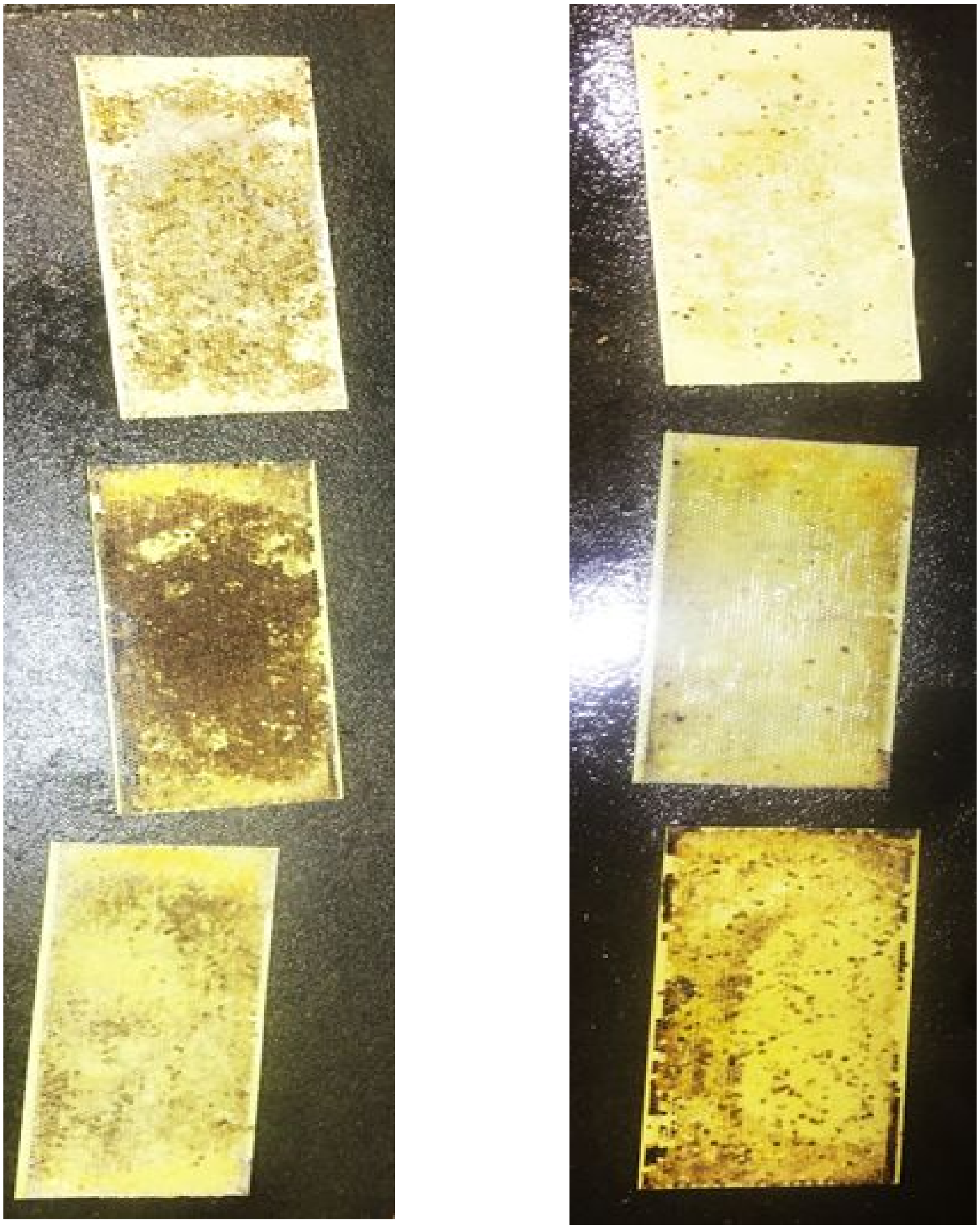

Figure C1.8: Used Plasticell Sheets Soaked in the First Solution Before Pressure Washing (Left) and After (Right)

Solution #2: 1500 mL Water, 250 mL Bleach, 250 mL Soap

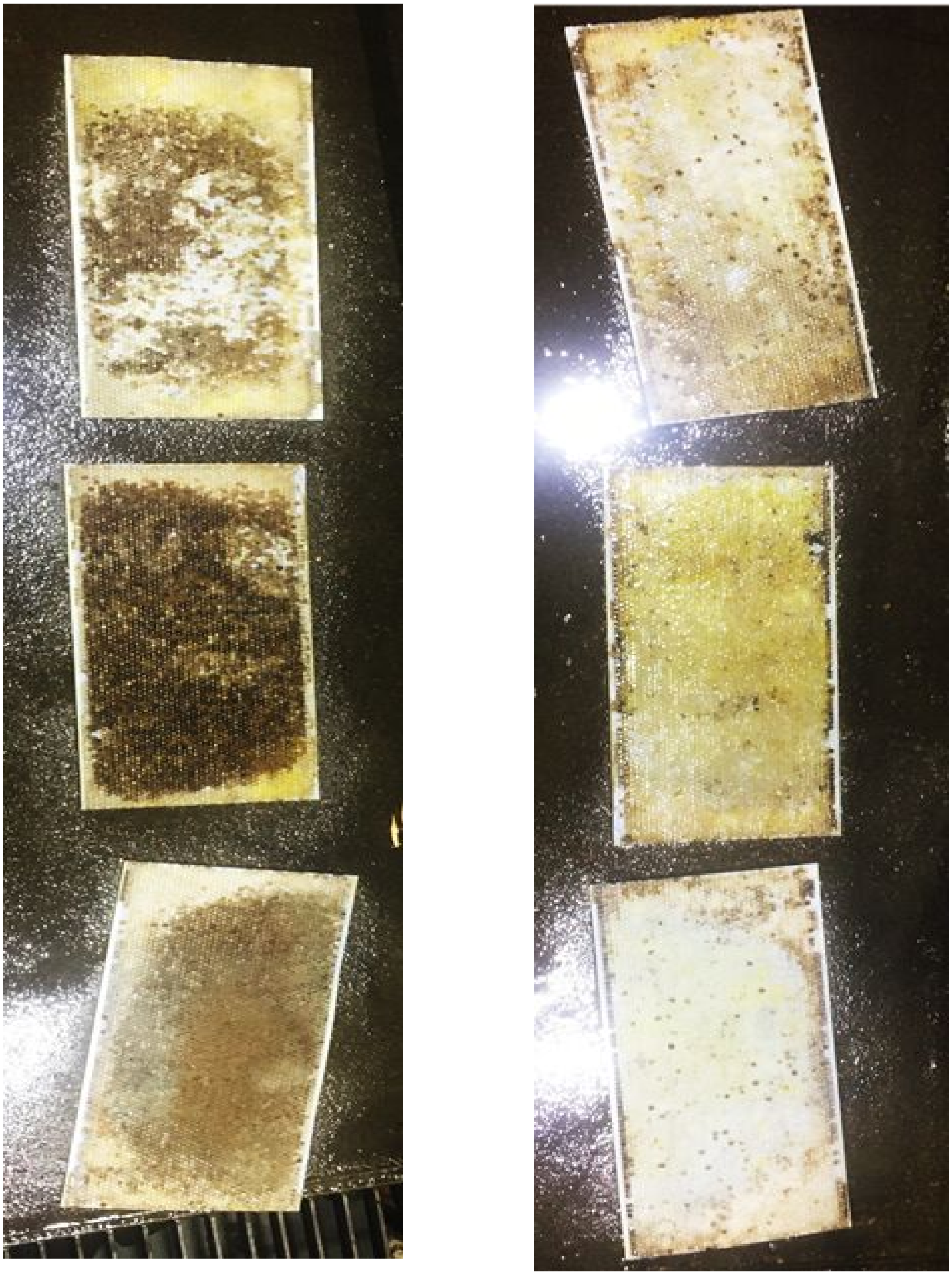

Figure C1.9: Used Plasticell Sheets Soaked in the Second Solution Before Pressure Washing (Left) and After (Right)

Solution #3: 1500 mL Water, 500 mL Bleach, 250 mL Soap

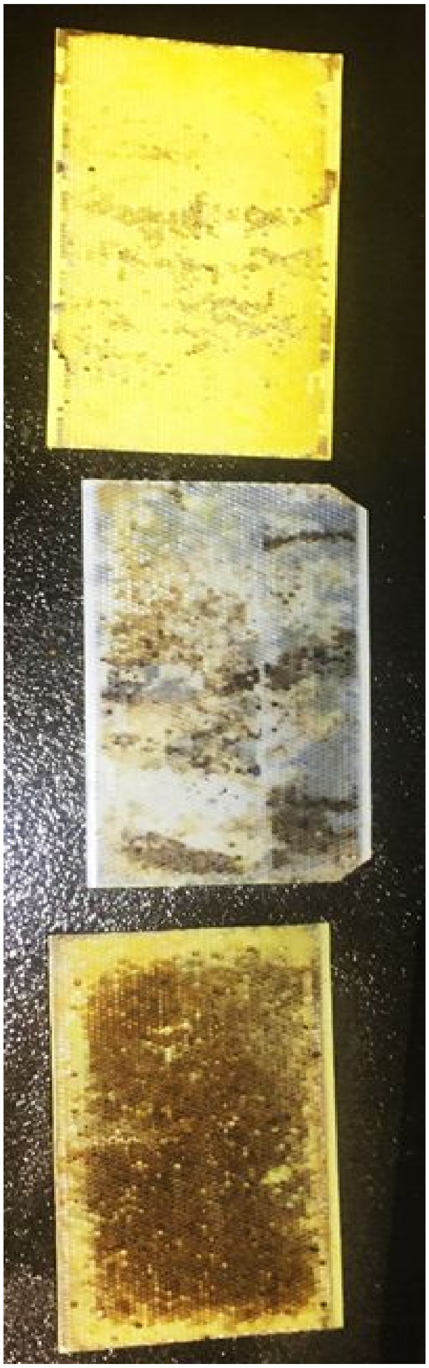

Figure C1.10: Used Plasticell Sheets Soaked in the Third Solution Before Pressure Washing (Left) and After (Right)

PHASE II SUMMARY

It should first be mentioned that the sheets in the photos above are in fact cleaner than they appear due to staining of the plastic (from the wax and grime).

Using a pressure washer proved to be far more efficient than scrubbing by hand. The high-pressure water penetrated the pockets of the comb much deeper than the bristles of the brush making cleaning each side of the sheets take less than 15 seconds. One problem, however, with the pressure washer is that it sprays the wax and grime everywhere which can be quite messy for whoever is performing the washing as well as the facility that they are in. The wash basin of a car wash works well since concrete floors and adequate drainage allow for containment of the mess and environmental protection from the chemicals (like bleach) seeping from the sheets. The second problem with the washer is that, if not used correctly, the sheets can be lifted up and blown away by the pressure. This can be remedied by a technique adjustment: by aiming straight down on the middle of the sheet and working outwards with the wand, the sheet should stay still throughout the process.

By observing the results from the 3 different specimens it can be concluded that the addition of dish soap is important in the cleanliness of the sheets. The solution with the most soap (#3) cleaned the fastest and the most thoroughly indicating that the higher concentration of soap and bleach also helps.

There was a worry that bleach may negatively affect the integrity of the sheets, though this was not evident at all in these specimens. In meeting with some local beekeepers it was noted that they often use bleach to sanitize hives but, to be safe, lower concentrations of bleach should be tested to see if similar effects can be obtained if not for the plastic, for the environment.

CONCLUSION

Unfortunately, due to limited supplies of used foundation sheets, no further testing could be completed. Had there been more resources available, the following tests would have also been conducted:

- Try roughing up the wax/grime before soaking using a bristle brush to see if mechanical disturbance prior to contact with the chemicals expedites the loosening process
- Use lower concentrations of bleach (one solution just soap) to see if bleach is even necessary in the solution
- Soak the sheets for shorter and longer amounts of time to find the minimum amount of time needed to obtain a completely clean sheet in a reasonable amount of time.
- Use a higher-powered pressure washer to see if the added pressure will overcome the need for stronger solutions and longer soak times

Based on the results of the experiment, it seems reasonable to predict that with a more refined solution, longer soak time (at least one week), mechanical disturbance prior to soaking, and higher washer pressure, the used Plasticell sheets could be completely washed in 10 seconds or less.

The tables below were used to rank each of the methods used in both phases. The ratings are based purely on the unbiased opinion of the person conducting the experiments. To be accepted by a recycling facility, these sheets must rank 10 in the final cleanliness category.

Table C1.1: Foundation Cleaning Phase I Results

Solvent	Initial Cleanliness Rating (1-10)	Soak Time (Hrs)	Pre-Scrub Cleanliness Rating (1-10)	Scrub Time (Mins)	Final Cleanliness Rating (1-10)	Overall Effectiveness Score (1-10)
Vinegar	6	24	6	5	7	5
Paint Thinner	4	24	5	5	7	4
Acetone	3	24	2	N/A	1	1
Coca Cola	5	24	5	5	5	3
Lemon Juice	3	24	3	5	3	2

Bleach/Dish Soap	4	24	6	5	9	9
Cold	7	24	7	5	8	6

Table C1.2: Foundation Cleaning Phase II Results

	Pre-Wash Cleanliness Rating (1-10)	Wash Time Per Side (s)	Final Cleanliness Rating (1-10)	Overall Effectiveness Score (1-10)
Solution #1	6	20	8	7
Solution #2	4	15	9	8
Solution #3	8	10	10	9

Appendix C2: Static Loading Test

Preface:

A prototype that was 3D printed from high impact polystyrene (HIPS) by a local business (Union 3D) was obtained for the purpose of this experiment. Unfortunately, HIPS is not a standard 3D printing material and the model arrived with significant cracks and deformations. As compensation, Union 3D provided a second prototype made out of a much more reliable PLA free of charge. An attempt was made to fix the HIPS model using store bought JB Weld (see Figure C2.1 below). The JB Weld selected had a similar tensile strength to HIPS and held up decently well through the first few tests. All tests were performed on the HIPS model to get a “worse case scenario” result as well as test the repairability of this design.

Figure C2.1: Attempted JB Weld Repair on HIPS Prototype

Equipment Required:

- 3D Printed Plastic Feeder Prototype
- Simple Syrup (~3 Gallons)
- Wooden Hive Frame
- Distance Measurement Device (Ruler, Dial Indicator)
- Camera

When fully loaded with syrup, it is imperative to ensure that the entrance gap at the center of the feeder maintains a width of ⅜”. To test this, the goal was to either measure the deflection of the wall with a dial indicator after filling with syrup and/or hand measure the gap at the top both when loaded and unloaded. Unfortunately, due to COVID restrictions at the University, a dial indicator was not able to be obtained for experimentation. Also, deformation in the front wall of the HIPS model protruded far enough to make contact with the PLA model's front wall. This made it very difficult to get an accurate result. Lastly, a mistake was made while handling the full HIPS model, causing it to fail along one of the seams in the 3D print.

Due to these extensive complications, an accurate testing of the deflection was not achieved with this prototype. Fortunately, the HIPS model had been statically loaded with syrup independently prior to failing. No quantitative data was collected by this trial but observations were made including the following:

- No visual displacement was witnessed while loading
- No signs of significant deformation were observed after loading (see Figure C2.2)
- The JB Welded feeder did not break under the weight of nearly 3 gallons of syrup

Figure C.2.2: Fully Loaded HIPS Prototype Supporting Static Load with No Visible Displacement

Appendix C3: Abrasion Test

Equipment Required:

- 3D Printed Plastic Feeder Prototype
- Current Top Feeder on the Market [19]
- Scraping Tools (see Figure C3.1)
    - Plastic Scraping Knife
    - Steel Blade Putty Knife
    - Butter Knife
- Camera

Figure C3.1: Scraping Utensils: (Left to Right) Plastic Scraping Knife, Steel Blade Putty Knife, Butter Knife

When in use, these feeders have to be cleaned periodically. The bees will sometimes build comb in the empty corners and spaces at the bottom of the top feeder which the beekeepers scrape off using whatever tools are available. To ensure that our design is comparable to, if not better than, current feeders on the market, both were scratched on their bottoms using 3 separate tools. The first tool will be a plastic scraping knife which was intended for use in oil painting, but can be repurposed for a task such as this. This knife may not be the most effective at scraping away wax and comb but should be completely harmless to the plastic feeders. The second tool is a steel blade putty knife. This is a tool that most farmers/beekeepers have on hand that would be one of the first tools they reach for to complete a task like this. It will likely be highly effective at cleaning the feeder bottoms but the fact that the blade is made of steel poses a high risk that it will score the plastic surface. The final tool is a simple kitchen butter knife. This is something that everyone has on hand and would be reasonable to grab for a task such as this. This blade is also steel but has a thick narrow blade instead of a thin flat blade.

Results:

After scraping both the HIPS prototype and the store-bought top feeder, it was concluded that, despite being 3D printed as opposed to injection molded (more coarse surface finish) and having more force applied to the cleaning tools, the grooves in the prototype feeder were much less significant than those on the store-bought feeder. Visually analyzing the two feeders presented a complication since the market feeder is black and the HIPS feeder is white, but physically touching the scratched areas made the difference much more apparent. Even the butter knife grooves, which were the deepest and most noticeable to the touch, were effectively undetectable on the HIPS prototype. Figures C3.2 to C3.9 show the surface markings on each of the feeders before and after each tool was used (in separate locations):

Figure C3.2: Market Feeder Before Scraping

Figure C3.3: Market Feeder After Scraping with Plastic Knife

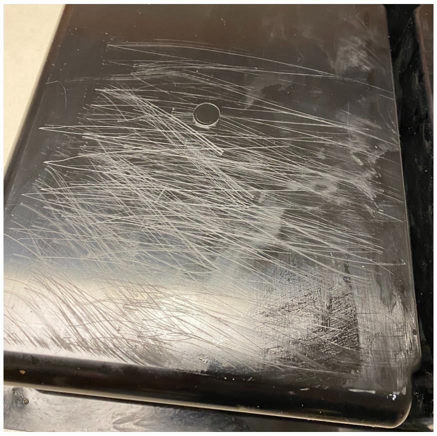

Figure C3.4: Market Feeder After Scraping with Putty Knife

Figure C3.5: Market Feeder After Scraping with Butter Knife

Figure C3.6: HIPS Prototype Before Scraping

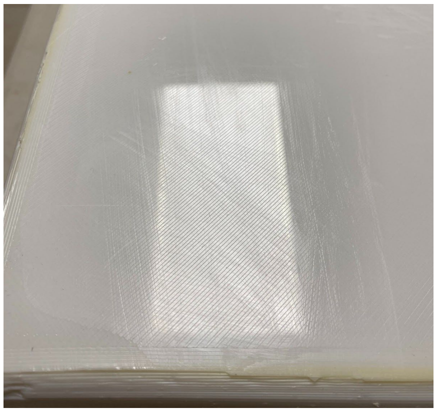

Figure C3.7: HIPS Prototype After Scraping with Plastic Knife

Figure C3.8: HIPS Prototype After Scraping with Putty Knife

Figure C3.9: HIPS Prototype After Scraping with Butter Knife

Appendix C4: Impact (Drop) Test

Equipment Required:

- 3D Printed Plastic Feeder Prototype
- Current Top Feeder on the Market
- Slow Motion Camera

Throughout its lifespan, this feeder will likely be handled, stacked, and transported several times, thus putting it at risk of falling from heights of around 1 meter. To ensure that a drop from that height will not immediately compromise the structural integrity of the feeder, both the HIPS prototype and market feeder will be dropped and filmed in slow motion. It should be noted before this experiment begins that due to the nature of 3D printing, especially with an atypical material like HIPS, the prototype feeder is already at a disadvantage. The seams between layers have already shown to be weak points within the structure so a sharp impact onto a hard surface will very likely cause the prototype to fail prematurely.

Procedure:

1. With a meter stick, mark heights from 0-1 m in increments of 0.25 m on a wall (by flat hard ground) with tape.
2. Weigh the existing plastic feeder on the scale and record the results.
3. Drop feeder from each marked height onto the ground. Attempt to drop feeder at an angle of 45° from the ground (landing on the same edge each drop). After each drop document the damages sustained.
4. Repeat steps 2-3 for 3D printed plastic feeder prototype.

Results:

Prototype Mass: 803 g

Market Feeder Mass: 915 g

Prototype:

From short heights (≤ 0.5 m), the prototype showed no real signs of damage, though after 0.5 m the feeder started to crack along the 3D print seam as expected. It was also observed that the prototype feeder had a tendency to bounce a lot more than the market feeder. An identical test should be performed with an injection molded part to achieve more accurate results.

Market Feeder:

Strangely, when dropped, the market feeder tended to flatten out as it fell resulting in relatively even contact with the floor for many of the trials. It was also noted that if proper angular contact was made, the feeder was very quick to dampen out and come to rest. A weak point in the structure is very clear in the slow motion videos [20]: Since the two halves of the feeder are almost entirely separate from one another, and each half of the feeder experiences different forces at different times; a large amount of bending can be seen in the thin connecting pieces along the top of the bee entrance gap.

Note: In the interest of preserving the expensive prototype/feeder for the client, no drops higher than 1 meter were completed. Since these objects are not intended for dropping from any height, it is not imperative that they survive greater impacts.

Appendix C5: Fit/Stackability/Pourability/Cleanability Test

Preface:

For these tests, high quality secondary prototypes printed from ASA and Nylon by the University of Alberta Mechanical Engineering Workshop were used. These differed slightly from the previous prototypes since they were around 2 inches shorter in order to fit the depth of the shallow hive box that came with the market feeder as well as fit the workshops 3D printing machine. These prototypes also feature the updated screw hole tab and bee entrance gap tabs which will be the ones used in the final design. Everything else however, is exactly the same, making them the perfect candidates for these simple geometry tests.

<u>Experiment:</u>

To ensure that the feeders were in fact compatible with existing hive boxes, the prototypes were simply placed within the standard box that came with the market feeder. From an empirical standpoint, the feeder fit perfectly (See Figure C5.1) and the bee entrance gap measured exactly ⅜" across. The support edge that runs around the top of the feeder sits flush with all edges of the hive box and there is an appropriate amount of clearance between the bottom of the feeder and the bottom of the hive box.

To save space when storing or transporting, the feeders were designed to be stackable. To test stackability, the feeders were stacked within one another (see Figure C5.2). The fit was tighter than what was expected however, with an injection molded part instead of a 3D printed part, the fit may be significantly more smooth. According to the solidworks assembly, the stacked feeders should differ by a vertical distance of 63 mm. The prototypes, when measured, differed by around 64 mm, which is within an acceptable range and can likely be attributed to a simple factor such as inconsistencies within the chosen method of manufacturing.

Figure C5.1: Shallow Prototype Feeders in Standard Hive Box

Figure C5.2: Stacked Prototype Feeders

Lastly, since these feeders will be emptied and washed on occasion, it was worth noting how easy they were to clean. After the static loading test was completed, the remaining syrup was poured back into a pot and the prototype was washed. The pouring was fairly easy since the fillets on the inside of the reservoir guide the syrup into a thick single stream; the only trouble came from the flat lip at the top of the feeder which widened the stream (see Figure C5.3). This can be overcome by using the corners at the front of the feeder instead of the back (see Figure C5.4). Once emptied every face of the feeder was washed with a sponge and wiped dry with a towel. Due to the simple geometry of the feeder, this was no issue whatsoever.

Figure C5.3: Pouring Stream Using Rear Corner

Figure C5.4: Pouring Stream Using Front Corner

Appendix C6: References

[19] Bee Maid Honey, www.beemaidbeestore.com/product.php?txtCatID=17

[20] Tokariuk, Stephen, director. MecE 460 Fall 2020 Beehive Top Feeder Drop Test Slow Mo. YouTube, 5 Dec. 2020, youtu.be/4JgQmsquSSo.

Appendix D: Project Management

Appendix D1: Final GANTT Chart and Project Schedule

This section shows the final GANTT Chart and project schedule used by SCFAX Engineering.

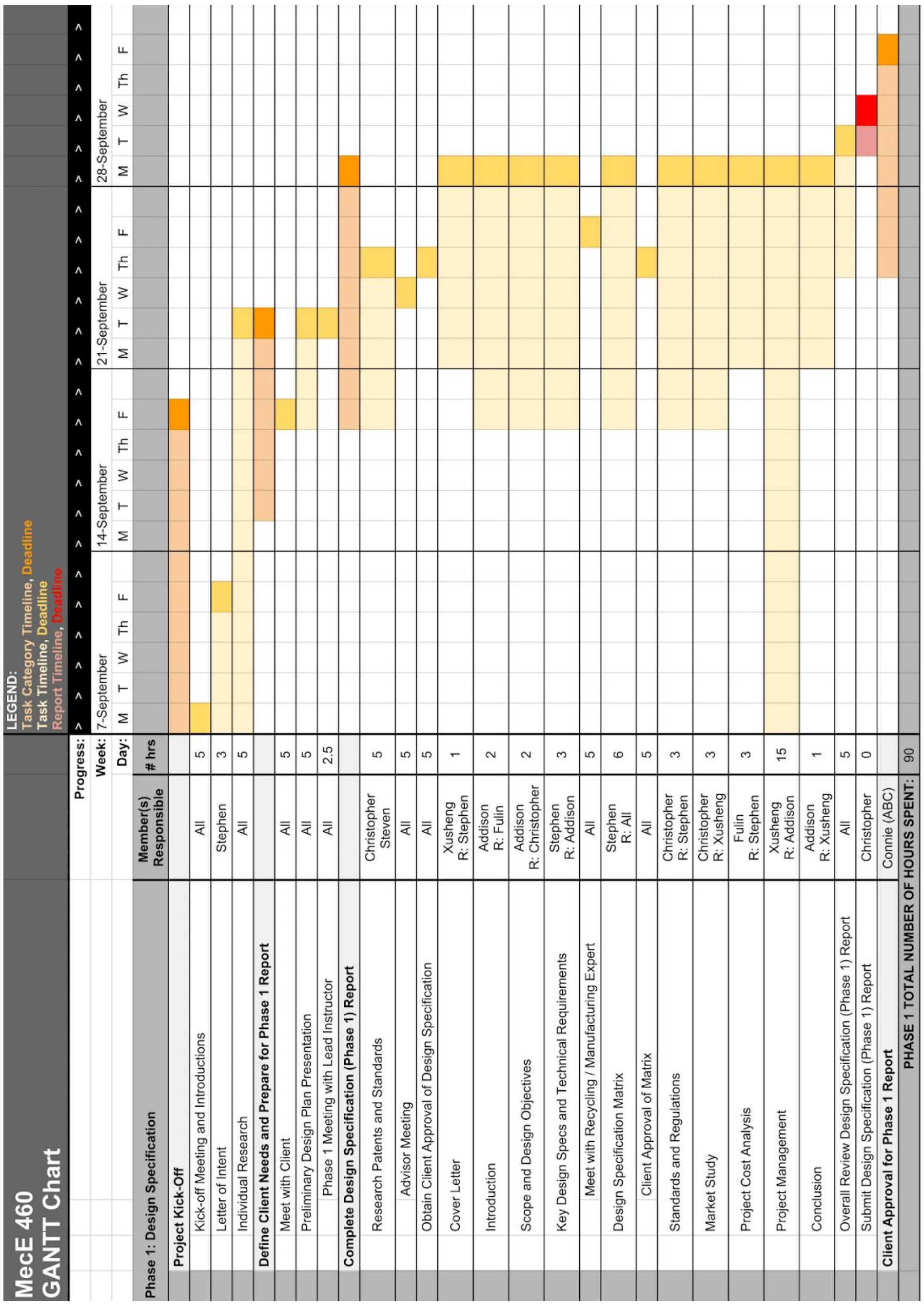

Figure D1.1: Phase I GANTT Chart

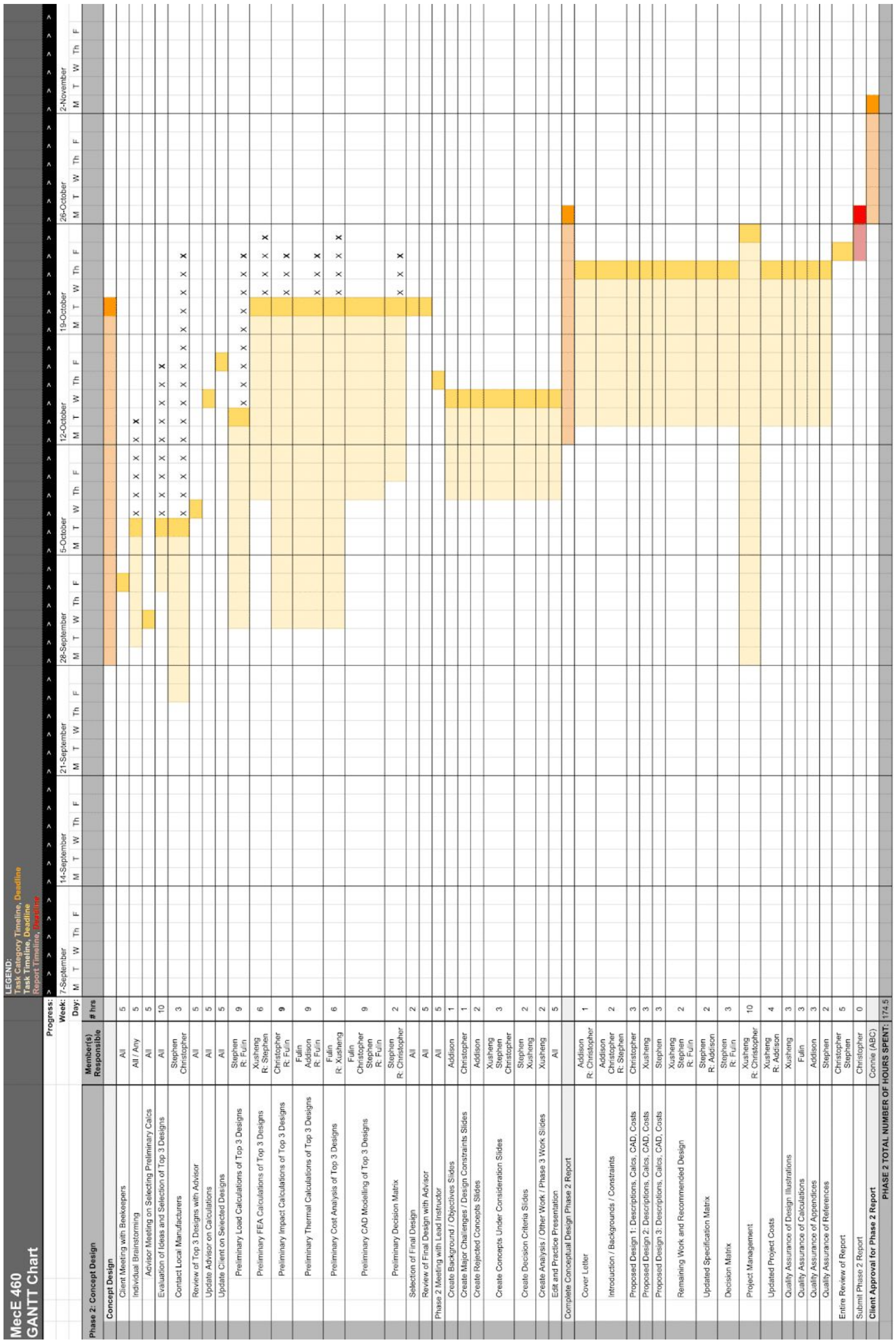

Figure D1.2: Phase II GANTT Chart

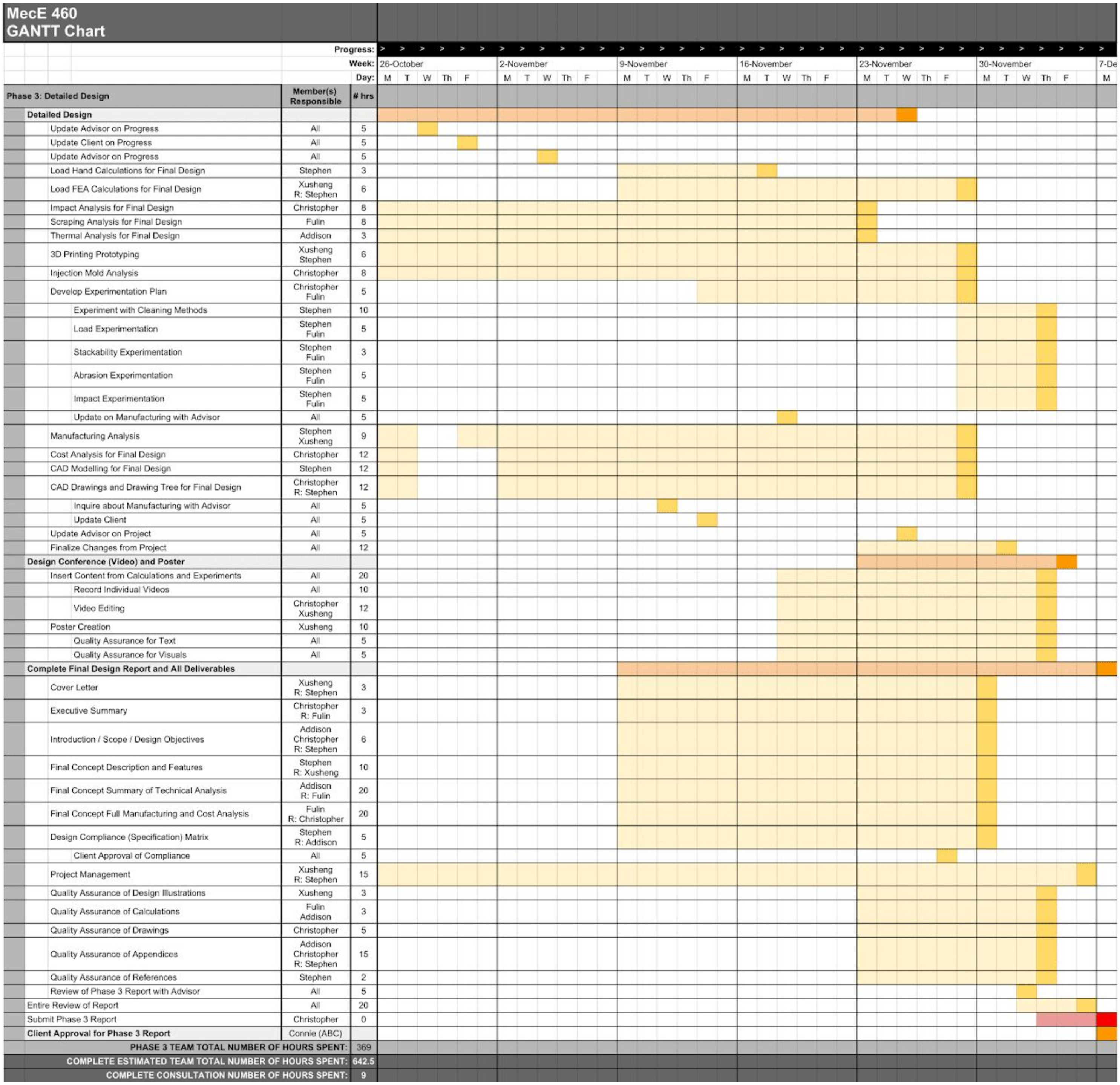

Figure D1.3: Phase III GANTT Chart

Appendix D2: Team Member Timesheets

This section shows the team members’ timesheets throughout the project.

MecE 460 Timesheet

Progress:		>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>
		7-September						14-September						21-September						28-September						5-October						12-October					
		M	T	W	Th	F		M	T	W	Th	F		M	T	W	Th	F		M	T	W	Th	F		M	T	W	Th	F		M	T	W	Th	F	
Xusheng Yu: # of Hours																																					
Research	10			1					1							1.5								1							2						
Meetings	49.5	0.5				1						1		0.5	1	1	1	1				1					2	0.5		1.5			1	1	1	1	
Report Writing / Presentation Creation	48												2	3		1		3	3	0.5	2	3										1	1				
Design	4																																				
Analysis / Calculations	19																																				2
DAILY TOTAL	-	0.5	0	1	0	1	0	0	1	0	0	1	2	3.5	1	3.5	1	4	3	0.5	2	4	0	1	0	0	2	0.5	0	1.5	2	1	2	1	1	1	2
CUMULATIVE TOTAL	**130.5**	**0.5**	**0.5**	**1.5**	**1.5**	**2.5**	**2.5**	**2.5**	**3.5**	**3.5**	**3.5**	**4.5**	**6.5**	**10**	**11**	**14.5**	**15.5**	**19.5**	**22.5**	**23**	**25**	**29**	**29**	**30**	**30**	**30**	**32**	**32.5**	**32.5**	**34**	**36**	**37**	**39**	**40**	**41**	**42**	**44**
Fulin Song: # of Hours																																					
Research	13		1								1					0.5																					
Meetings	32.5	0.5				1						1		0.5	1	1	1	1				1		1			2	0.5		1.5			1	1	1		
Report Writing / Presentation Creation	17												1			1				0.5	0.5	1											1				
Design	4.5																									1.5						1	0.5				
Analysis / Calculations	39.5																																	2.5			0.5
DAILY TOTAL	-	0.5	1	0	0	1	0	0	0	0	1	1	1	0.5	1	2.5	1	1	0	0.5	0.5	2	0	1	0	1.5	2	0.5	0	1.5	0	1	2.5	3.5	1	0	0.5
CUMULATIVE TOTAL	**106.5**	**0.5**	**1.5**	**1.5**	**1.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**3.5**	**4.5**	**5.5**	**6**	**7**	**9.5**	**10.5**	**11.5**	**11.5**	**12**	**12.5**	**14.5**	**14.5**	**15.5**	**15.5**	**17**	**19**	**19.5**	**19.5**	**21**	**21**	**22**	**24.5**	**28**	**29**	**29**	**29.5**
Christopher MacDonald: # of Hours																																					
Research	18		0.5	0.5									1.5			0.5																					
Meetings	36	0.5				1						1		0.5	1	1	1	1				1		1			2	0.5		1.5			1	1	1	1	
Report Writing / Presentation Creation	51.5												3			0.5			1.5	0.5	1										0.5		0.5		0.5		
Design	12																								1		0.5				0.5		0.5			1	
Analysis / Calculations	11																																				3
DAILY TOTAL	-	0.5	0.5	0.5	0	1	0	0	0	0	0	1	4.5	0.5	1	2	1	1	1.5	0.5	1	1	0	1	1	0	2.5	0.5	0	1.5	1	0	2	1	1.5	2	3
CUMULATIVE TOTAL	**128.5**	**0.5**	**1**	**1.5**	**1.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**3.5**	**8**	**8.5**	**9.5**	**11.5**	**12.5**	**13.5**	**15**	**15.5**	**16.5**	**17.5**	**17.5**	**18.5**	**19.5**	**19.5**	**22**	**22.5**	**22.5**	**24**	**25**	**25**	**27**	**28**	**29.5**	**31.5**	**34.5**
Addison Tse: # of Hours																																					
Research	5.5							0.5				0.5														0.5					2.5						
Meetings	36	0.5				1						1		0.5	1	1	1	1				1		1			2	0.5		1			1	1	1	1	
Report Writing / Presentation Creation	38														1		0.5	0.5		0.5	0.5	0.5	0.5								1.5				0.5		
Design	4.5																							1		1.5											
Analysis / Calculations	15.5																																			2.5	
DAILY TOTAL	-	0.5	0	0	0	1	0	0.5	0	0	0	1.5	0	0.5	2	1	1.5	1.5	0	0.5	0.5	1.5	0.5	2	0	2	2	0.5	0	1	4	0	1	1	1.5	3.5	0
CUMULATIVE TOTAL	**99.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1.5**	**1.5**	**2**	**2**	**2**	**2**	**3.5**	**3.5**	**4**	**6**	**7**	**8.5**	**10**	**10**	**10.5**	**11**	**12.5**	**13**	**15**	**15**	**17**	**19**	**19.5**	**19.5**	**20.5**	**24.5**	**24.5**	**25.5**	**26.5**	**28**	**31.5**	**31.5**
Stephan Tokariuk: # of Hours																																					
Research	23												3		1		2														2						
Meetings	37.5	0.5				1						1		0.5	1	1	1	1				1		1			2	0.5		1.5			1	1	2	1	
Report Writing / Presentation Creation	69												1			3		1		2	4	2															
Design	21																																3				
Analysis / Calculations	18																																				
DAILY TOTAL	-	0.5	0	0	0	1	0	0	0	0	0	1	4	0.5	2	4	3	2	0	2	4	3	0	1	0	0	2	0.5	0	1.5	2	0	4	1	2	1	0
CUMULATIVE TOTAL	**168.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**2.5**	**6.5**	**7**	**9**	**13**	**16**	**18**	**18**	**20**	**24**	**27**	**27**	**28**	**28**	**28**	**30**	**30.5**	**30.5**	**32**	**34**	**34**	**38**	**39**	**41**	**42**	**42**
GROUP TOTAL RESEARCH	69.5	0	1.5	1.5	0	0	0	0.5	1	0	1	0.5	4.5	0	1	2.5	2	0	0	0	0	0	0	1	0	0.5	0	0	0	0	6.5	0	0	0	0	0	0
GROUP TOTAL MEETINGS	191.5	2.5	0	0	0	5	0	0	0	0	0	5	0	2.5	5	5	5	5	0	0	0	5	0	4	0	0	10	2.5	0	7	0	0	5	5	6	4	0
GROUP TOTAL REPORT / PRESENTATION	223.5	0	0	0	0	0	0	0	0	0	0	0	7	3	1	5.5	0.5	4.5	4.5	4	8	6.5	0.5	0	0	0	0	0	0	0	2	1	2.5	0	1	0	0
GROUP TOTAL DESIGN	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	0.5	0	0	0	0.5	1	4	0	0	1	0
GROUP TOTAL ANALYSIS / CALCULATIONS	103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	2.5	5.5
GROUP DAILY TOTAL	-	2.5	1.5	1.5	0	5	0	0.5	1	0	1	5.5	11.5	5.5	7	13	7.5	9.5	4.5	4	8	11.5	0.5	6	1	3.5	10.5	2.5	0	7	9	2	11.5	7.5	7	7.5	5.5
GROUP CUMULATIVE TOTAL	**633.5**	**2.5**	**4**	**5.5**	**5.5**	**10.5**	**10.5**	**11**	**12**	**12**	**13**	**18.5**	**30**	**35.5**	**42.5**	**55.5**	**63**	**72.5**	**77**	**81**	**89**	**100.**	**101**	**107**	**108**	**111.**	**122**	**124.**	**124.**	**131.**	**140.**	**142.**	**154**	**161.**	**168.**	**176**	**181.**

Figure D2.1: First Half of Project Timesheet

MecE 460 Timesheet

		19-October						26-October						2-November					
Progress:		>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>
		M	T	W	Th	F		M	T	W	Th	F		M	T	W	Th	F	
Xusheng Yu: # of Hours																			
Research	10					1													
Meetings	49.5		1	1		1	0.5		1			0.5			1.5	0.5	1		
Report Writing / Presentation Creation	48					2	1	5										0.5	
Design	4																		
Analysis / Calculations	19			2	1		10												
DAILY TOTAL	-	0	1	3	1	4	11.5	5	1	0	0	0.5	0	0	1.5	0.5	1	0.5	0
CUMULATIVE TOTAL	**130.5**	**44**	**45**	**48**	**49**	**53**	**64.5**	**69.5**	**70.5**	**70.5**	**70.5**	**71**	**71**	**71**	**72.5**	**73**	**74**	**74.5**	**74.5**
Fulin Song: # of Hours																			
Research	13				0.5			2			2	2				2	1		
Meetings	32.5		1	1		1	0.5		1			0.5			1.5	0.5			
Report Writing / Presentation Creation	17							1		1									
Design	4.5					1													
Analysis / Calculations	39.5	0.5		1		2	3	1.5	2			2		2	2				
DAILY TOTAL	-	0.5	1	2	0.5	4	3.5	4.5	3	1	2	4.5	0	2	3.5	2.5	1	0	0
CUMULATIVE TOTAL	**106.5**	**30**	**31**	**33**	**33.5**	**37.5**	**41**	**45.5**	**48.5**	**49.5**	**51.5**	**56**	**56**	**58**	**61.5**	**64**	**65**	**65**	**65**
Christopher MacDonald: # of Hours																			
Research	18					0.5	1.5						0.5						
Meetings	36		1	1		1	0.5		1			0.5			1.5	0.5	1		
Report Writing / Presentation Creation	51.5	1			1		3	1.5											
Design	12	0.5			0.5														
Analysis / Calculations	11	1.5					3.5												
DAILY TOTAL	-	3	1	1	1.5	1.5	8.5	1.5	1	0	0	0.5	0.5	0	1.5	0.5	1	0	0
CUMULATIVE TOTAL	**128.5**	**37.5**	**38.5**	**39.5**	**41**	**42.5**	**51**	**52.5**	**53.5**	**53.5**	**53.5**	**54**	**54.5**	**54.5**	**56**	**56.5**	**57.5**	**57.5**	**57.5**
Addison Tse: # of Hours																			
Research	5.5													1					
Meetings	36		1	1		1	0.5		1			0.5			1.5	0.5	1		
Report Writing / Presentation Creation	38						1.5												
Design	4.5																		
Analysis / Calculations	15.5	4					7												
DAILY TOTAL	-	4	1	1	0	1	9	0	1	0	0	0.5	0	1	1.5	0.5	1	0	0
CUMULATIVE TOTAL	**99.5**	**35.5**	**36.5**	**37.5**	**37.5**	**38.5**	**47.5**	**47.5**	**48.5**	**48.5**	**48.5**	**49**	**49**	**50**	**51.5**	**52**	**53**	**53**	**53**
Stephan Tokariuk: # of Hours																			
Research	23															4			
Meetings	37.5		1	1		1	0.5		1			0.5			1.5	0.5	1		
Report Writing / Presentation Creation	69																		
Design	21													6	3				
Analysis / Calculations	18	3	1		2	4	6												
DAILY TOTAL	-	3	2	1	2	5	6.5	0	1	0	0	0.5	0	6	4.5	4.5	1	0	0
CUMULATIVE TOTAL	**168.5**	**45**	**47**	**48**	**50**	**55**	**61.5**	**61.5**	**62.5**	**62.5**	**62.5**	**63**	**63**	**69**	**73.5**	**78**	**79**	**79**	**79**
GROUP TOTAL RESEARCH	69.5	0	0	0	0.5	1.5	1.5	2	0	0	2	2	0.5	1	0	6	1	0	0
GROUP TOTAL MEETINGS	191.5	0	5	5	0	5	2.5	0	5	0	0	2.5	0	0	7.5	2.5	4	0	0
GROUP TOTAL REPORT / PRESENTATION	223.5	1	0	0	1	2	5.5	7.5	0	1	0	0	0	0	0	0	0	0.5	0
GROUP TOTAL DESIGN	46	0.5	0	0	0.5	1	0	0	0	0	0	0	0	6	3	0	0	0	0
GROUP TOTAL ANALYSIS / CALCULATIONS	103	9	1	3	3	6	29.5	1.5	2	0	0	2	0	2	2	0	0	0	0
GROUP DAILY TOTAL	-	10.5	6	8	5	15.5	39	11	7	1	2	6.5	0.5	9	12.5	8.5	5	0.5	0
GROUP CUMULATIVE TOTAL	**633.5**	**192**	**198**	**206**	**211**	**226.**	**265.**	**276.**	**283.**	**284.**	**286.**	**293**	**293.**	**302.**	**315**	**323.**	**328.**	**329**	**329**

		9-November						16-November					
Progress:		>	>	>	>	>	>	>	>	>	>	>	>
		M	T	W	Th	F		M	T	W	Th	F	
Xusheng Yu: # of Hours													
Research	10							0.5		2			
Meetings	49.5		1.5			0.5			1	0.5		0.5	
Report Writing / Presentation Creation	48						1						
Design	4	4											
Analysis / Calculations	19												
DAILY TOTAL	-	4	1.5	0	0	0.5	1	0.5	1	2.5	0	0.5	0
CUMULATIVE TOTAL	**130.5**	**78.5**	**80**	**80**	**80**	**80.5**	**81.5**	**82**	**83**	**85.5**	**85.5**	**86**	**86**
Fulin Song: # of Hours													
Research	13	1											
Meetings	32.5		1.5			0.5			1	0.5		0.5	
Report Writing / Presentation Creation	17								2		2		
Design	4.5												
Analysis / Calculations	39.5			2		2		1	2	2	2	2	
DAILY TOTAL	-	1	1.5	2	0	2.5	0	1	5	2.5	4	2.5	0
CUMULATIVE TOTAL	**106.5**	**66**	**67.5**	**69.5**	**69.5**	**72**	**72**	**73**	**78**	**80.5**	**84.5**	**87**	**87**
Christopher MacDonald: # of Hours													
Research	18			0.5	0.5		0.5	2	1	1			0.5
Meetings	36		1.5						1	0.5		0.5	
Report Writing / Presentation Creation	51.5												1
Design	12												
Analysis / Calculations	11												
DAILY TOTAL	-	0	1.5	0.5	0.5	0	0.5	2	2	1.5	0	0.5	1.5
CUMULATIVE TOTAL	**128.5**	**57.5**	**59**	**59.5**	**60**	**60**	**60.5**	**62.5**	**64.5**	**66**	**66**	**66.5**	**68**
Addison Tse: # of Hours													
Research	5.5												
Meetings	36		1.5			0.5			1	0.5		0.5	
Report Writing / Presentation Creation	38												
Design	4.5			1			0.5						
Analysis / Calculations	15.5												
DAILY TOTAL	-	0	1.5	1	0	0.5	0.5	0	1	0.5	0	0.5	0
CUMULATIVE TOTAL	**99.5**	**53**	**54.5**	**55.5**	**55.5**	**56**	**56.5**	**56.5**	**57.5**	**58**	**58**	**58.5**	**58.5**
Stephan Tokariuk: # of Hours													
Research	23			4					2	2			
Meetings	37.5		1.5			0.5			1	0.5		0.5	
Report Writing / Presentation Creation	69												
Design	21			2					1				6
Analysis / Calculations	18												
DAILY TOTAL	-	0	1.5	6	0	0.5	0	0	4	2.5	0	0.5	6
CUMULATIVE TOTAL	**168.5**	**79**	**80.5**	**86.5**	**86.5**	**87**	**87**	**87**	**91**	**93.5**	**93.5**	**94**	**100**
GROUP TOTAL RESEARCH	69.5	1	0	4.5	0.5	0	0.5	2.5	3	5	0	0	0.5
GROUP TOTAL MEETINGS	191.5	0	7.5	0	0	2	0	0	5	2.5	0	2.5	0
GROUP TOTAL REPORT / PRESENTATION	223.5	0	0	0	0	0	1	0	2	0	2	0	1
GROUP TOTAL DESIGN	46	4	0	3	0	0	0.5	0	1	0	0	0	6
GROUP TOTAL ANALYSIS / CALCULATIONS	103	0	0	2	0	2	0	1	2	2	2	2	0
GROUP DAILY TOTAL	-	5	7.5	9.5	0.5	4	2	3.5	13	9.5	4	4.5	7.5
GROUP CUMULATIVE TOTAL	**633.5**	**334**	**341.**	**351**	**351.**	**355.**	**357.**	**361**	**374**	**383.**	**387.**	**392**	**399.**

		23-November						30-November						7-De
Progress:		>	>	>	>	>	>	>	>	>	>	>	>	>
		M	T	W	Th	F		M	T	W	Th	F		M
Xusheng Yu: # of Hours														
Research	10													
Meetings	49.5		1	1		1			2	1	1.5	14		
Report Writing / Presentation Creation	48	0.5	1.5			1	2		1		3		10	
Design	4													
Analysis / Calculations	19					4								
DAILY TOTAL	-	0.5	2.5	1	0	6	2	0	3	1	4.5	14	10	0
CUMULATIVE TOTAL	**130.5**	**86.5**	**89**	**90**	**90**	**96**	**98**	**98**	**101**	**102**	**106.5**	**120.5**	**130.5**	**130.5**
Fulin Song: # of Hours														
Research	13													
Meetings	32.5		1						2	1	1.5			
Report Writing / Presentation Creation	17	2						2			1	1		
Design	4.5					0.5								
Analysis / Calculations	39.5						1.5		2		3		1	
DAILY TOTAL	-	2	1	0	0	0.5	1.5	2	4	1	5.5	1	1	0
CUMULATIVE TOTAL	**106.5**	**89**	**90**	**90**	**90**	**90.5**	**92**	**94**	**98**	**99**	**104.5**	**105.5**	**106.5**	**106.5**
Christopher MacDonald: # of Hours														
Research	18			1	0.5	1.5	3.5							
Meetings	36		1	1		1			2	1	1.5			
Report Writing / Presentation Creation	51.5	1					6.5	4.5		3.5	9	8.5	3	
Design	12			1	0.5	0.5	5.5							
Analysis / Calculations	11						2.5	0.5						
DAILY TOTAL	-	1	1	3	1	3	18	5	2	4.5	10.5	8.5	3	0
CUMULATIVE TOTAL	**128.5**	**69**	**70**	**73**	**74**	**77**	**95**	**100**	**102**	**106.5**	**117**	**125.5**	**128.5**	**128.5**
Addison Tse: # of Hours														
Research	5.5		0.5											
Meetings	36		1	1		1			2	1	1.5			
Report Writing / Presentation Creation	38	0.5				0.5	3.5	1.5	0.5	4.5	8.5	2	9	
Design	4.5		0.5											
Analysis / Calculations	15.5									2				
DAILY TOTAL	-	0.5	2	1	0	1.5	3.5	1.5	2.5	7.5	10	2	9	0
CUMULATIVE TOTAL	**99.5**	**59**	**61**	**62**	**62**	**63.5**	**67**	**68.5**	**71**	**78.5**	**88.5**	**90.5**	**99.5**	**99.5**
Stephan Tokariuk: # of Hours														
Research	23	1	2											
Meetings	37.5		1	1		1			2	1	1.5			
Report Writing / Presentation Creation	69						14	8	6	8	10	2	8	
Design	21													
Analysis / Calculations	18								2					
DAILY TOTAL	-	1	3	1	0	1	14	8	10	9	11.5	2	8	0
CUMULATIVE TOTAL	**168.5**	**101**	**104**	**105**	**105**	**106**	**120**	**128**	**138**	**147**	**158.5**	**160.5**	**168.5**	**168.5**
GROUP TOTAL RESEARCH	69.5	1	2.5	1	0.5	1.5	3.5	0	0	0	0	0	0	0
GROUP TOTAL MEETINGS	191.5	0	5	4	0	4	0	0	10	5	7.5	14	0	0
GROUP TOTAL REPORT / PRESENTATION	223.5	4	1.5	0	0	1.5	26	16	7.5	16	31.5	13.5	30	0
GROUP TOTAL DESIGN	46	0	0.5	1	0.5	1	5.5	0	0	0	0	0	0	0
GROUP TOTAL ANALYSIS / CALCULATIONS	103	0	0	0	0	4	4	0.5	4	2	3	0	1	0
GROUP DAILY TOTAL	-	5	9.5	6	1	12	39	16.5	21.5	23	42	27.5	31	0
GROUP CUMULATIVE TOTAL	**633.5**	**404.**	**414**	**420**	**421**	**433**	**472**	**488.**	**510**	**533**	**575**	**602.**	**633.**	**633.**

Figure D2.2: Second Half of Project Timesheet