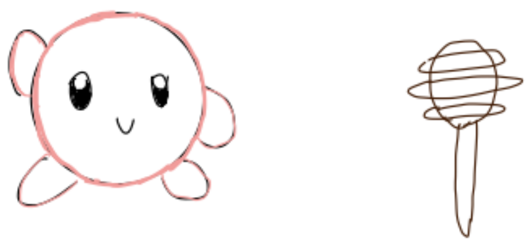
Final Report



ME 340-2 Team 12

Project: Kirby Weilding a Lollipop
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Date: March 15, 2023

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1. Introduction and Description

Our final project consisted of using computer aided manufacturing (CAM) and plastic injection molding to create two parts that would assemble together.

For our parts, our team designed a popular video game character, Kirby, to be holding a lollipop (later revised to be a lollipop). The two parts would be assembled through a pin and hole interference fit. As the individual components would be difficult to injection mold at once, Kirby and the lollipop would be constituted of halves assembled by pins and holes as well.

Figure 1.1: Original Concept Drawings (left) and Combined Product Sketch of Kirby holding a lollipop (right)

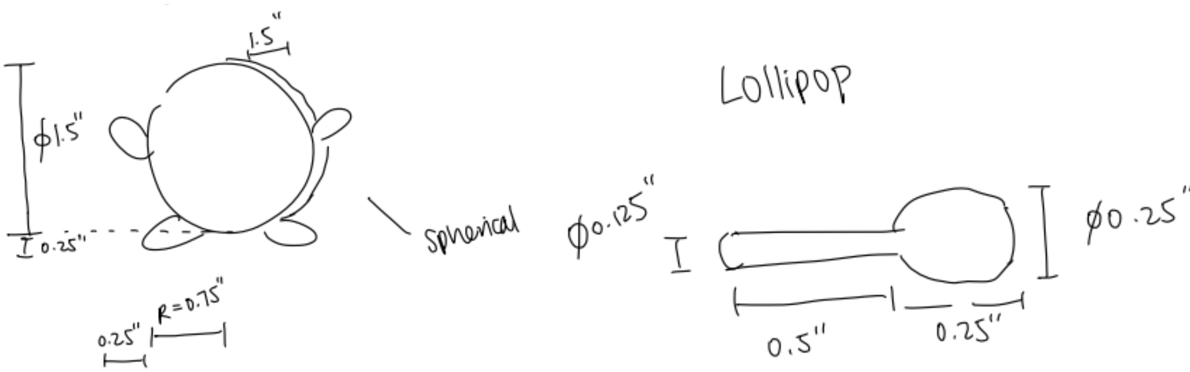


Figure 1.2: Basic Dimensioning of Kirby (left) and Lollipop (right)

Upon designing CAM for the lollipop, our team realized the ring features of the lollipop would be non-machineable, so we instead opted for a simple lollipop structure.

Figure 1.3: Lollipop with pins (left) and insert (right)

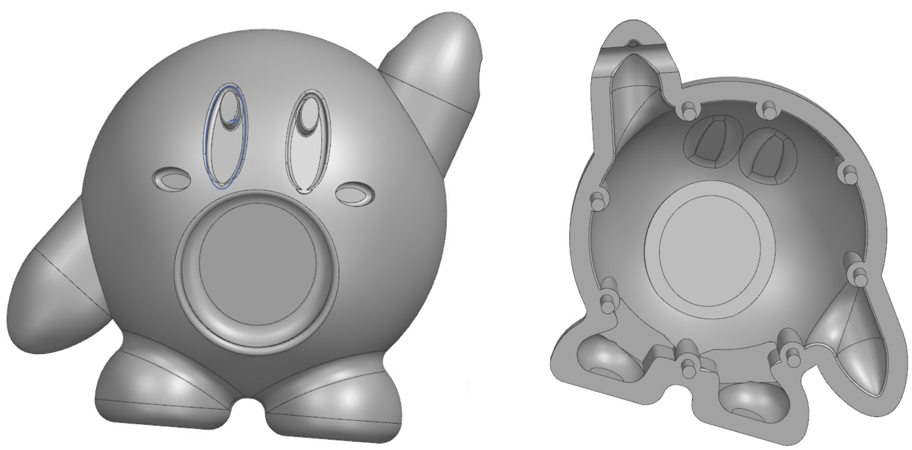


Figure 1.4: Kirby Front side to be put machining pins (left) and back (right)

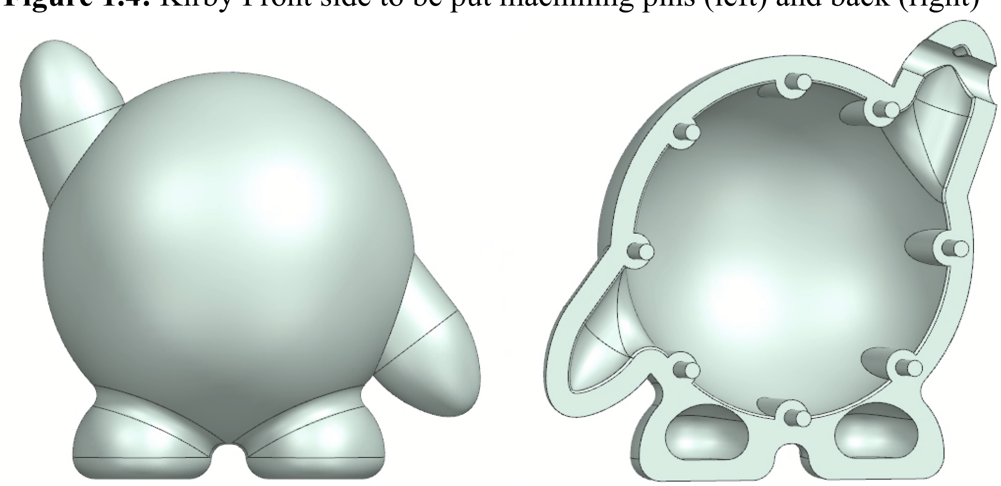


Figure 1.5: Kirby Back side with inserts (left) and back (right)

2. Overview of Part Design

2.1. Design Features for Injection Molding

Kirby Halves

Design features that we employed for Kirby include draft for pins, uniform wall thickness and curved corners to reduce stress. On straight surfaces, a draft of 3 degrees was applied to allow the plastic to flow better into the part. Uniform wall thickness was also employed throughout the shell of the part to minimize net shrinkage and uniform cooling time. The initial sharp corners were edge blended to be a curvature that would reduce stress concentration (see Figures below). See the detailed dimensioned CAD images in Appendix B.

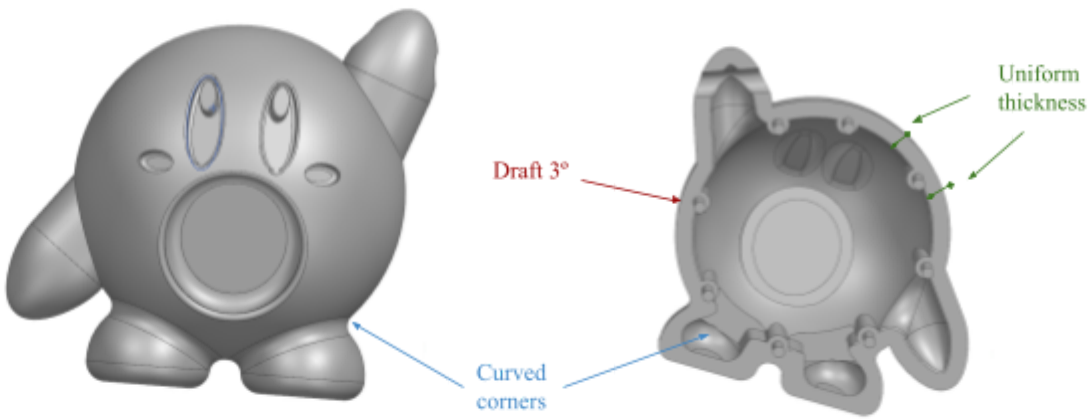


Figure 2.1: CAD images of Kirby Front with Design Features

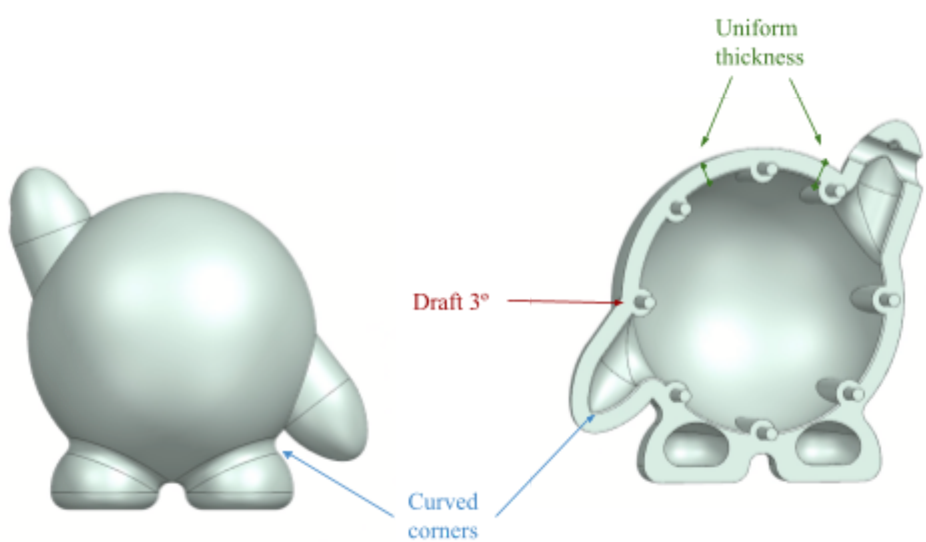


Figure 2.2: CAD images of Kirby Back with Design Features

Lollipop Halves

Similar to the Kirby halves, the Lollipop halves also employed draft, uniform wall thickness and curved corners as mentioned above. For the insert, the hole was strategically placed to reduce stress between wall sections, at a recommended distance of 3*Diameter of the hole away from walls (see Figures below). See the detailed dimensioned CAD images in Appendix B.

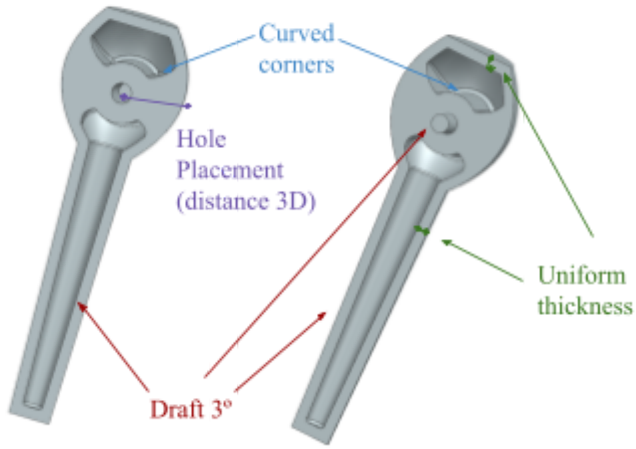


Figure 2.3: CAD images of Lollipop with Design Features

2.2. Pin and Hole Interference Method and Calculations

<u>Kirby and Lollipop Assembly Point</u>

A pin and hole interference fit was employed between Kirby's hand and the shaft of the lollipop. This type of interference fit was chosen because we wanted the parts to be easily assembled and disassembled. Compared to a snap fit interference method, the pin method allows for simplicity in design and removal. Further, the interfering assembly between Kirby and the Lollipop was chosen because there was no other way to create a realistic part without an undercut in the mold design.

The pin geometry interference fit is given in the equation following:

$$I = [\frac{Sd * d}{W}] * [(\frac{W + Vh}{Eh}) + (\frac{1 - Vs}{Es})]$$

$$I = d - d1$$

$$W = \frac{1 + (\frac{d}{D})^2}{1 - (\frac{d}{D})^2}$$

Where I is the diametral interference in mm, and W is the geometry factor

Given that we want to use a shaft pin of d = 0.1275in, and assuming D = 3*d, we obtain:

$$W = \frac{1 + (\frac{0.1275}{3*0.1275})^2}{1 - (\frac{0.1275}{3*0.1275})^2}$$

$$W = 1.25$$

Assuming a design stress S_d of 35.5 MPa and Young's Modulus of 1325 MPa for polypropylene[1,2]:

$$I = [\frac{Sd * 0.1275}{1.25}] * (\frac{2.25}{Eh})$$

$$I = [\frac{35.5MPa * 0.1275}{1.25}] * (\frac{2.25}{1325MPa})$$

$$I = 0.00615\ in$$

$$d1 \approx 0.122\ in$$

This hole size was used for Kirby's hand where he holds the Lollipop shaft (see Drawing for location and dimension used).

3. Mold Design Process

3.1. Mold and Manufacturing Considerations

Part Division and Parting Line

As aforementioned, Kirby and the lollipop were manufactured as an assembly of two halves. The division of these part halves will be explained here. To begin, it was clear that Kirby would need to be created in two halves in order to be manufactured in a simple cavity/core configuration. The lollipop was also split in two, despite initial attempts to create a part small enough to be shot as a single piece.

To decide what plane to cut the part across, there were two main criteria: visibility and feasibility. Visibility refers to how noticeable the dividing line would be on the final assembled part. Feasibility refers to whether the part would still be able to be manufactured in a simple cavity/core configuration.

On Kirby, most division lines were simply too visible. Kirby's visage needed to be free of imperfections, since this would be the section of the part that would be in the limelight. For this reason, it was most reasonable to place the dividing line along the XY plane. This plane was also considered since it allowed the geometry of Kirby's arms to be manufactured. Any other division line and Kirby's arms or feet would simply be nonmachinable.

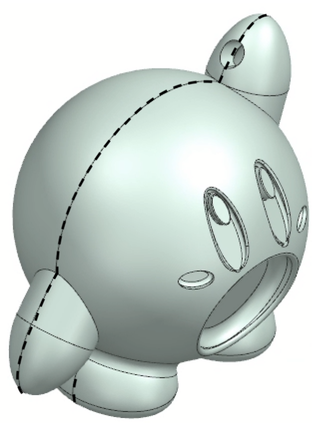


Figure 3.1: Division Line

With the resolved geometry now established, a parting line was needed in order to begin creating molds. The parting lines were developed according to traditional injection molding knowledge. They were placed along a simple curved surface in order to avoid complex core geometry. They placed all cores and bosses on a single side. Most importantly, the parting lines ensured that the parts would have a uniform wall thickness.

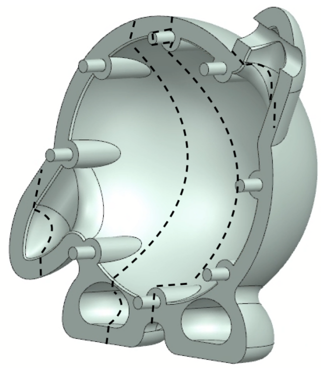


Figure 3.2: Parting Lines Indicate the Parting Plane

<u>Orientation</u>

Part orientation on the mold was arranged in order to conform to gating standards. To begin, we will take a look at Kirby's Back/Face orientation on the mold. See Fig. 3.3 for a visualization.

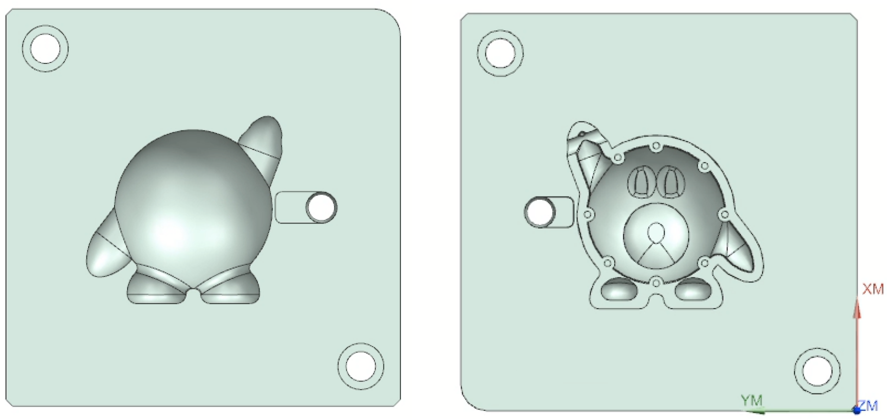


Figure 3.3: Kirby's Back Orientation (left), Kirby's Face Orientation(right)

This orientation was chosen since the runner would run into a less visible region, since it was hidden under the upraised arm of Kirby. Note that this placement was against a wall (in the core) to prevent common injection molding defects, and enabled the part to fill evenly.

These same governing principles were applied to the placement of the gates for the lollipop. However, the taper at the bottom of the lollipop was the deciding factor. The gate into the part would need to be at the top since it was the thicker section of the mold, and would ensure that the part would fill evenly from top to bottom.

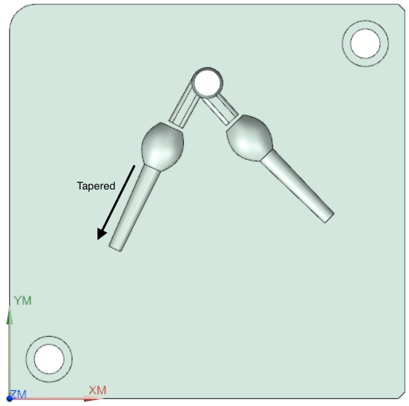


Figure 3.4: Tapered Lollipop

Draft Considerations

The team first created a prototype with a draft angle on the pins to enable them to slide out of the mold easily. However, it was soon realized that this geometry would create a core that had a pin circumference of less than 1/16” — which we would be unable to machine. Therefore, the mold was redesigned to be able to accommodate machining pins of 1/16” thickness and 0.12” height. These pins were installed in the post-machining part of the process.

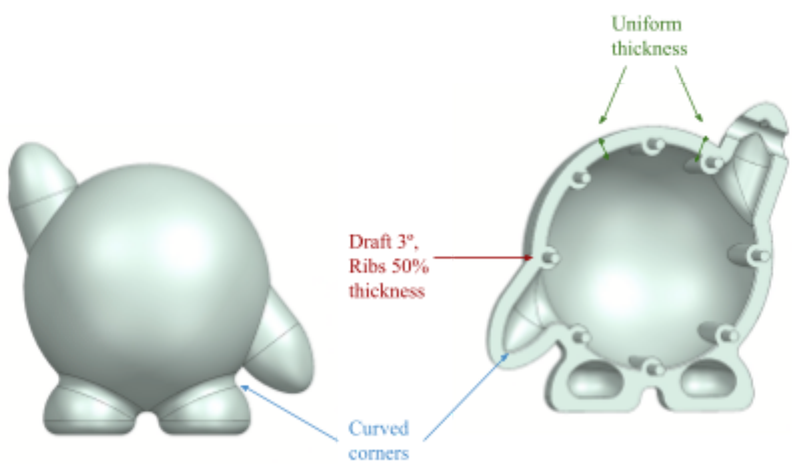


Figure 3.5: Draft Angle Design.

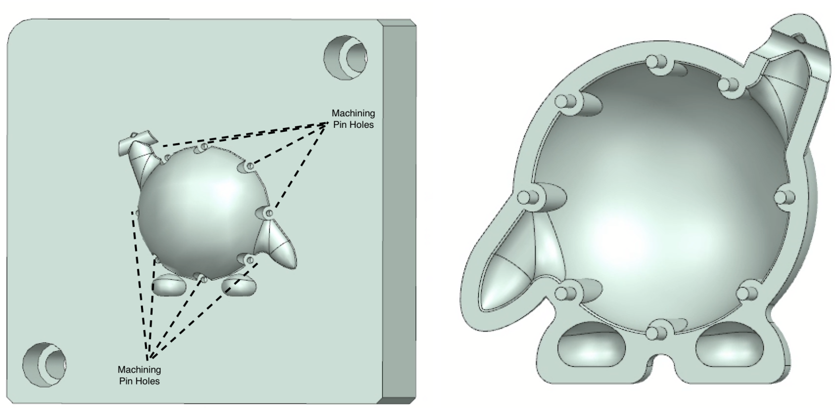


Figure 3.6: Machining Pin Holes Final Design.

3.2. Mold Layout and Runner Design

Runner Design

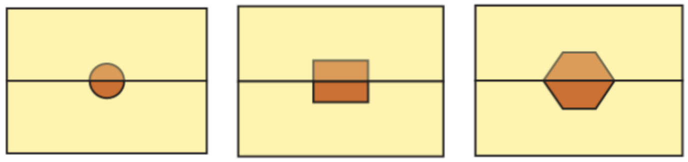


Figure 3.7: Circle (left), Rectangle, Trapezoidal (right)

For all runners, cross-sectional geometry was designed to minimize temperature loss. The three options to choose from were a circular cross-section, rectangular cross-section, and a trapezoidal cross-section. This decision was informed by Eq. (1), where the full calculations can be observed in Appendix A.

$$C_{TL} = \frac{Surface\ Area}{Cross-Sectional\ Area} \quad (1)$$

The chosen geometry was a rectangular cross section since it yielded the smallest temperature loss coefficient. Despite the trapezoidal cross-section yielding the smallest temperature loss coefficient, there was concern that manufacturing limitations would not yield a perfect slanted surface – compromising the surface area to cross-section ratio. Therefore, the perfect middle ground was a rectangular cross section which could be machined to precision.

Table 3.1: Temperature Loss Coefficients

Geometry	**Cross Section Area (m^2)**	**Surface Area (m^2)**	C_{TL}
Circle	0.39	12.56	31.7
Trapezoid	0.375	6.74	17.259
Rectangle	0.5	8	16

For both halves of Kirby, the runner was a wide rectangle directly from the sprue to the part. The runner was made the exact diameter of the sprue in order to ensure that enough material would be transported through. The runner length is also relatively short, to prevent any pressure drops that might compromise the mold filling. Note that the runner leaves a 0.03” wall between itself and the part. This small sliver of wall would be where the gate into the part would be filed.

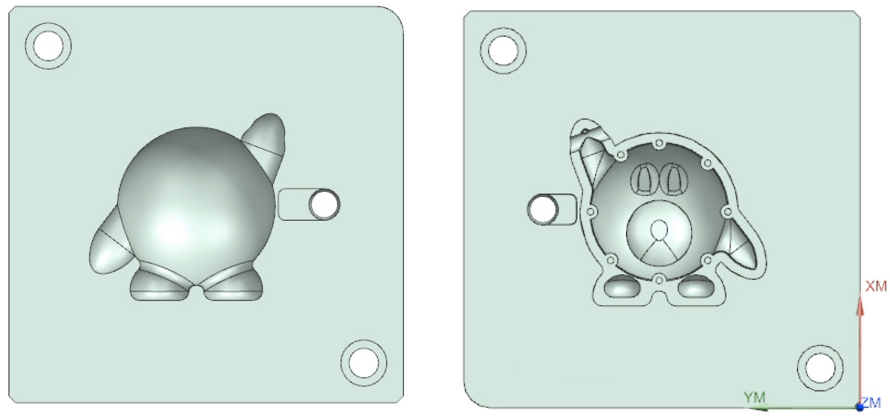


Figure 3.8: Kirby Runner Design

Since the lollipop pins and inserts were on the same mold, the runner design had to take into account that these parts needed to be filled at the same time. It is for this reason that the runners were made equidistant from the sprue.

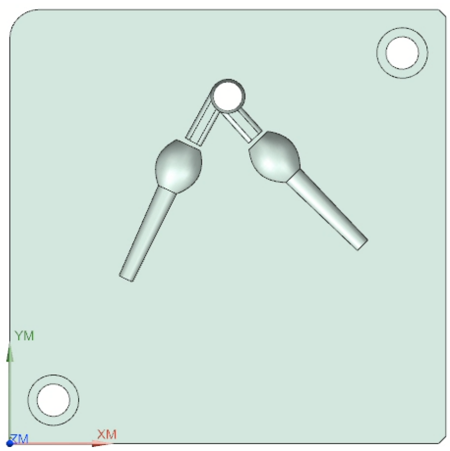


Figure 3.9: Lollipop Runner Design

3.3. CAD Images of Mold Halves

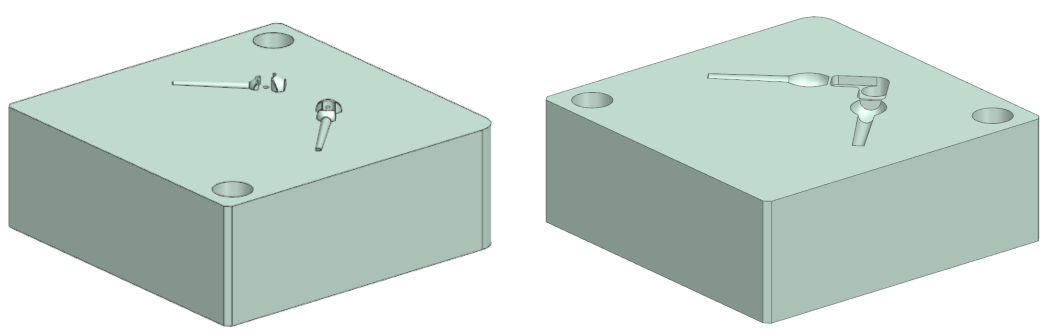


Figure 3.10: Core & Cavity for lollipop Pins and Insert

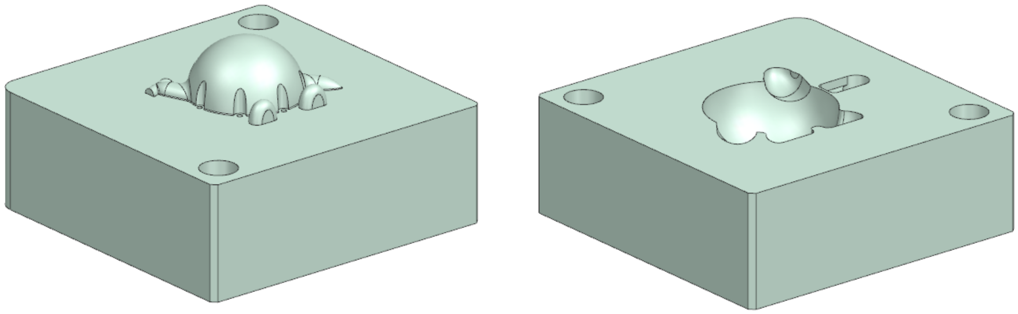


Figure 3.11: Core & Cavity for Kirby Back Half Molds

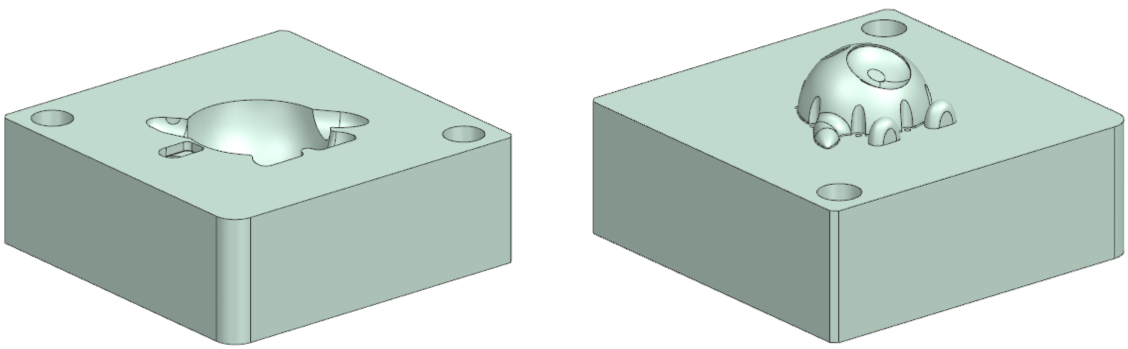


Figure 3.12: Core & Cavity for Kirby Front Half Molds

The design features are highlighted in previous sections.

4. Mold Manufacturing Process

4.1. Outline of CAM Process and Operations

<u>Kirby Cores</u>

For the sake of brevity, the machining operations for the back half and the front half of the Kirby molds will be discussed together since the operations choice and manufacturing results for both pairs of molds is mostly the same. Differences in operations and results will be discussed.

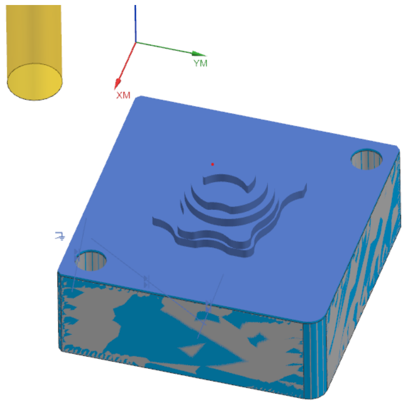


Figure 4.1: ¾” Cavity Mill Roughing

The first operation for the cores is a cavity milling roughing pass with a ¾” end mill. The cavity milling operation was chosen because it is able to cut out the contoured geometry of the core, and the ¾” tool size was chosen so that the bulk of the core material could be removed quickly in a single operation.

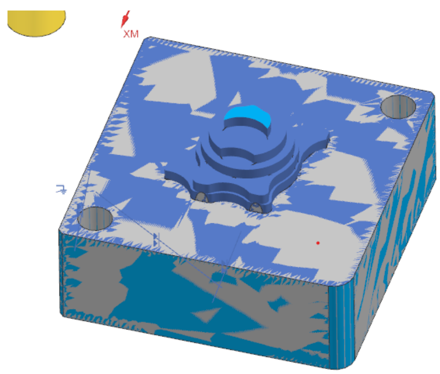


Figure 4.2: ¾” Cavity Mill Roughing

A finishing pass using the same cavity milling operation with a ¾” end mill followed to take off a little bit more material and to finish the planar clamping surface with the best surface finish. For the back half, another cavity milling roughing operation with a ½” end mill was performed before a cavity milling finishing operation was performed using that same ½” end mill. Differences in the surface finish of these two choices will be discussed.

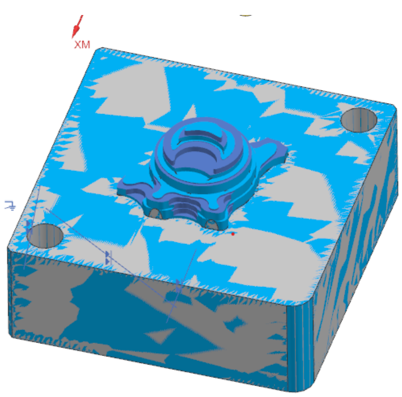


Figure 4.3: ¼” Cavity Mill Roughing

Another cavity milling roughing operation was performed, this time with a ¼” end mill to take off as much material as possible before area milling operations could be used. In general, multiple cavity milling operations were performed with decreasing tool sizes until the desired amount of material left before area milling was achieved.

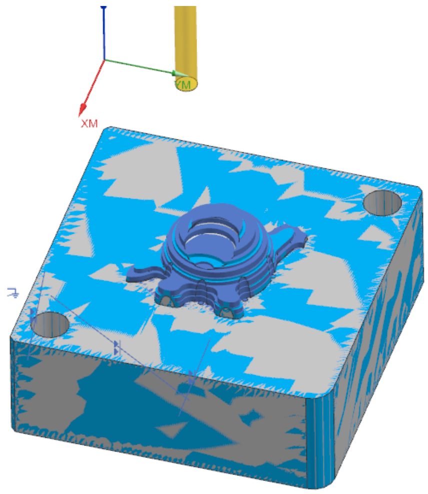


Figure 4.4: ¼” Cavity Mill Finishing

The cavity milling roughing operation with the ¼” end mill was again followed up with a finishing operation.

Once the overall shape of the core was machined, the smooth, curved surfaces were machined using area milling operations. Multiple area milling operations were performed with decreasing tool sizes in order to achieve the best surface finish and to reach all of the detailed areas of the mold. Additionally, a separate area milling operation focusing on the concave mouth section was used to achieve the better quality.

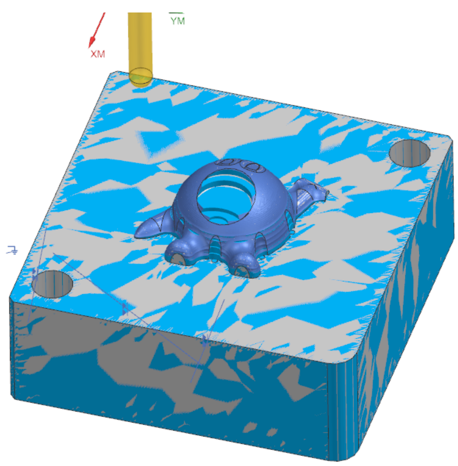


Figure 4.5: ⅛” Face Area Mill

Since larger diameter tools will yield a better surface finish for this type of geometry, a ¼” ball mill was used to cut the majority of the spherical surface of Kirby’s face. An area milling operation with both steep and non-steep cutting was used with a steep angle of 60 degrees.

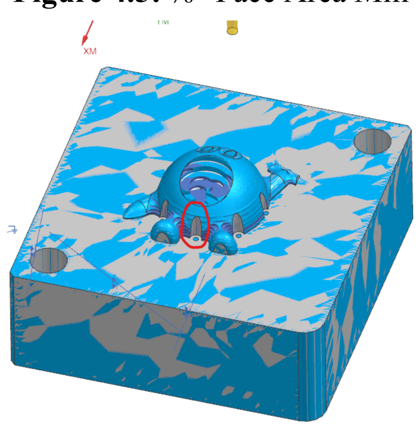


Figure 4.6: ⅛” Hole Boss Finishing

Next, the hole bosses were finished using an ⅛” end mill. This cavity milling operation was performed at this stage since the previous area milling operations removed material that was in the way. It was also located in this order because the next operation uses a ⅛” ball mill, and it was desirable to finish these features first with an end mill.

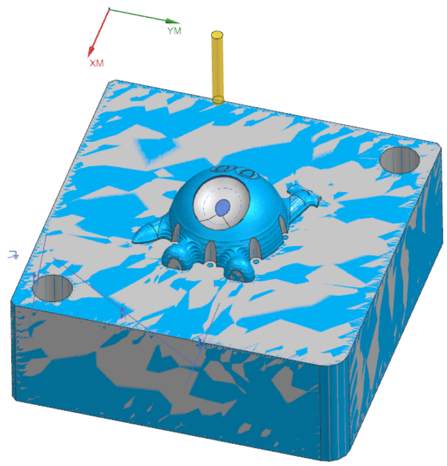


Figure 4.7: ⅛” Mouth Area Mill

Another area milling operation with a ⅛” ball mill was used to finish Kirby’s mouth. This operation uses both steep and non-steep cutting maneuvers with a steep angle of 60 degrees.

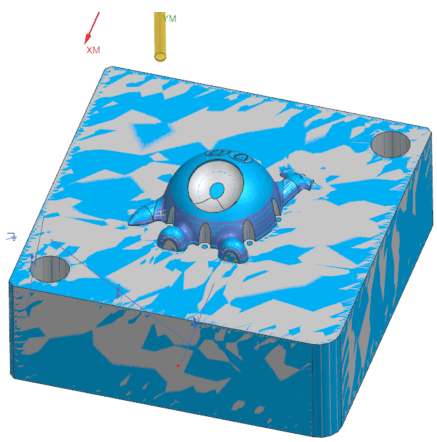


Figure 4.8: ⅛” Legs and Arms Area Mill

The final milling operation is an area milling finishing with a ⅛” ball mill of the steep parts of Kirby’s face and of the smaller arm and leg features. This tool size was able to achieve a more desirable surface finish around the face edges and was able to get around all of the smaller features. It left a less desirable surface finish than the non-steep cutting of Kirby’s face using the ½” ball mill, but the result was acceptable for being on the inside of the injection molded part.

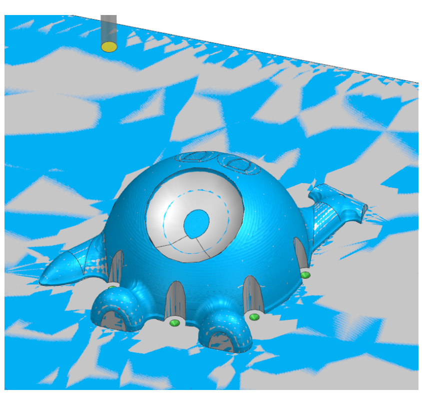


Figure 4.9: Spot Drilling

A spot drilling operation was performed using a 1/10” spot drill to set up the deep drilling operation for the part’s pins.

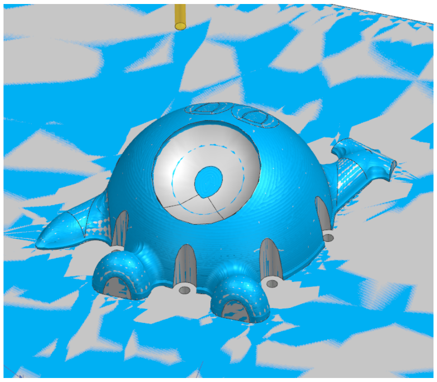


Figure 4.10: Deep Drilling

The holes for the machining pins were deep drilled to a depth of an ⅛” with a 1/16” drill bit. The fits for the pins and holes were verified after machining by test fitting 1/16” machining pins.

<u>Kirby Cavities</u>

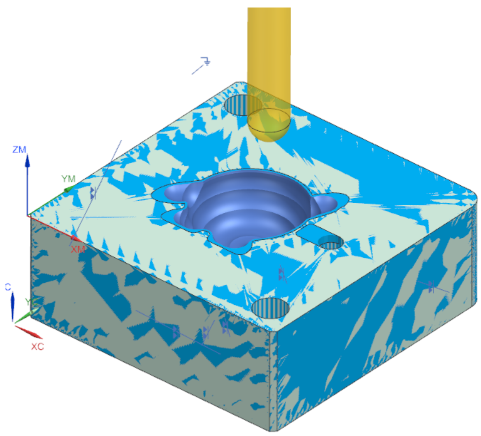


Figure 4.11: ½” Cavity Milling

A ½” ball mill was used to rough out most of the material from the core. A cavity milling operation was used to be able to cut away the concave contours of Kirby’s spherical body.

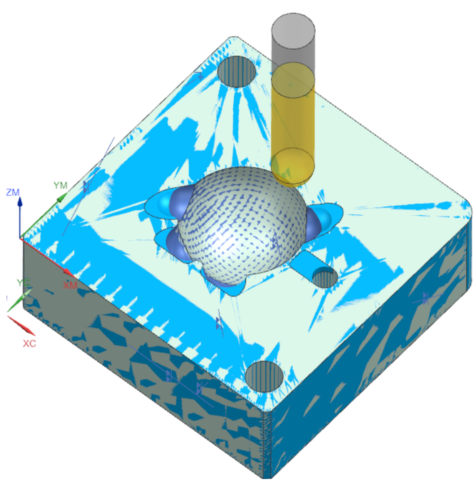
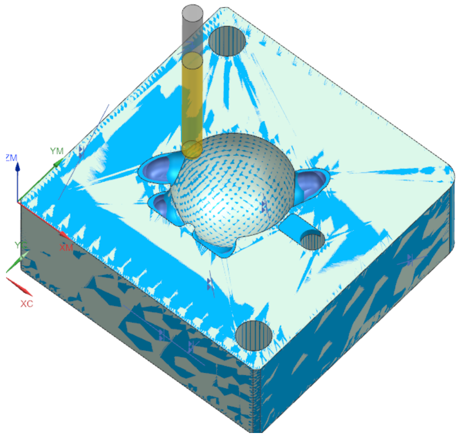


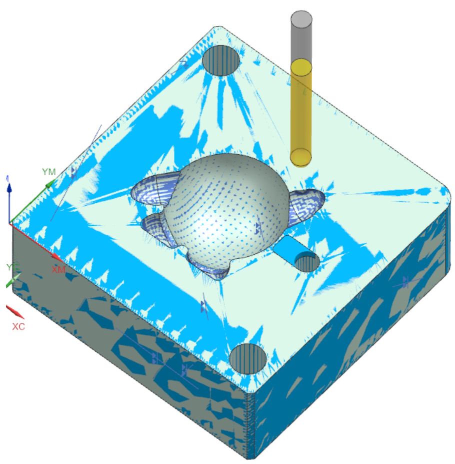
Figure 4.12: ½” Area Milling

The same ball mill was used to finish the spherical part of the cavity, and area milling operation was used to obtain a desirable surface finish since a larger tool will leave less of a scallop.



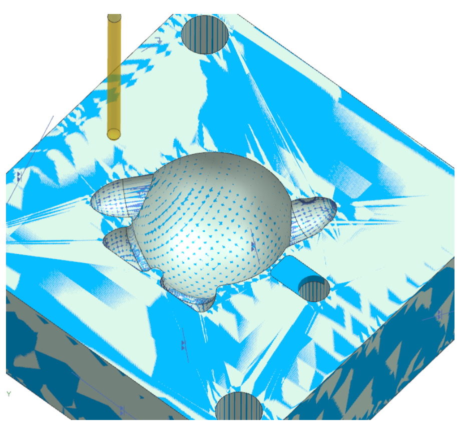
Since the ½” ball mill was unable to reach into Kirby’s smaller arm and leg features, a cavity milling operation with a ¼” ball mill was used to rough out the rest of the arms and legs.

Figure 4.13 : ¼” Cavity Milling



The arms and legs were then finished with an area milling operation using that same ¼” ball mill.

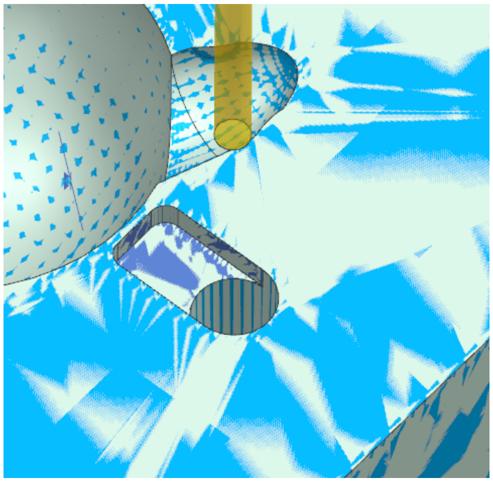
Figure 4.14: ¼” Area Milling



The shape and surface finish of the arms and legs was further refined with a second area milling operation using a ⅛” ball mill.

For the front half cavity mold, an additional 1/16” area milling operation was used to refine Kirby’s facial features such as the eyes, mouth, and cheek marks. To reach the features, the 1/16” ball mill was elongated in the tool holder so that the tool holder did cross the clearance plane. The feed rate was reduced to 70% so as to not break the tool, and no tools were broken in any operation.

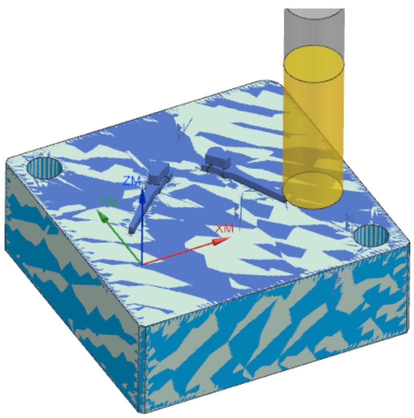
Figure 4.15: ⅛” Area Milling



A ⅛" flat end mill was used rough out the runner via a cavity milling operation. This was followed up with a finishing operation to get the final runner geometry.

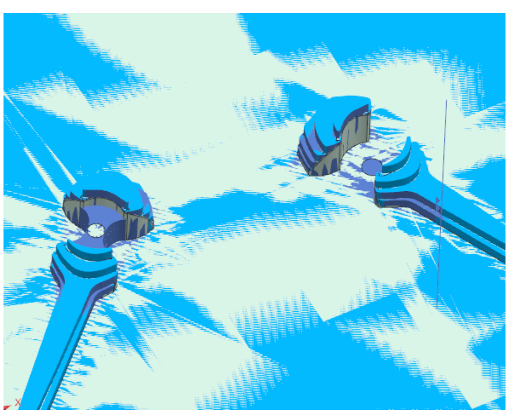
Figure 4.16: ⅛" Runner Roughing and Finishing

<u>Lollipop Core</u>



The core was initially roughed with a 0.75" end mill to get rid of the general regions outside of the lollipop core. It was then proceeded with a 0.75" ball mill for a finishing operation to clean the edges.

Figure 4.17: Roughing and Finishing Operation

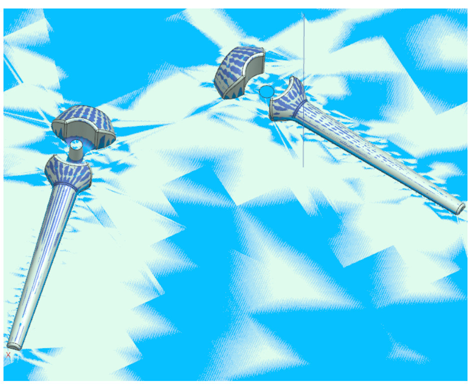


Using a smaller tool of size 0.125", a roughing and finishing operation were then employed to further detail the curvature of the part. These were performed by a 0.125" end mill and ball mill respectively. Finally, a 0.0625" was used as a finishing operation to clean details.

Figure 4.18: Detail Roughing and Finishing Operation

An area mill operation was then performed using the 0.0625" ball end mill to clean the areas around the pin and inserts in the middle.

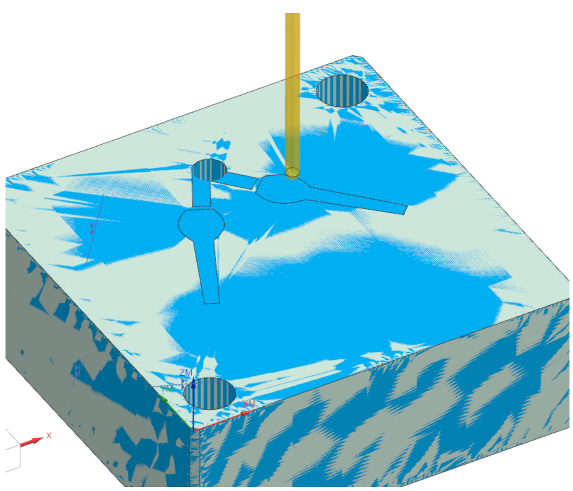
Figure 4.19: Area Milling Operation



Finally, a spot drilling operation with the 0.0625" drill bit was used to start the drilling operation. Next, a depth of 0.1" was drilled down using the deep drilling operation with the same tool.

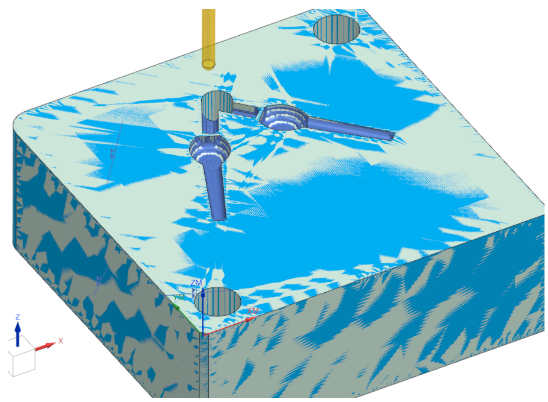
Figure 4.20: Spot and deep drilling operation

<u>Lollipop Cavity</u>



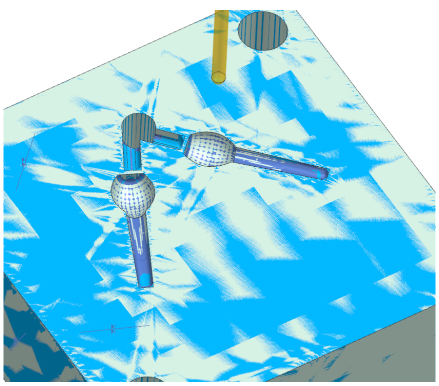
The lollipop cavity was machined using the 0.125" diameter end mill and ball mill. The two cavities for the pins and insert part were combined together. This size was chosen as the smallest diameter on the lollipop is 0.125".

Figure 4.21: Cavity roughing operation



A roughing operation using the 0.125” end mill was first performed that cored the general regions of the lollipop. Next, the 0.125” ball mill was chosen for a finishing operation for cleaning the edges and the runner areas.

Figure 4.22: Detail roughing and finishing operation



Finally, an area mill operation, using the 0.125” ball mill, was chosen to clean the important edges of the cavity (i.e. the shaft and runners).

Figure 4.23: Detail area milling operation

4.2. Manufacturing Results and Performance

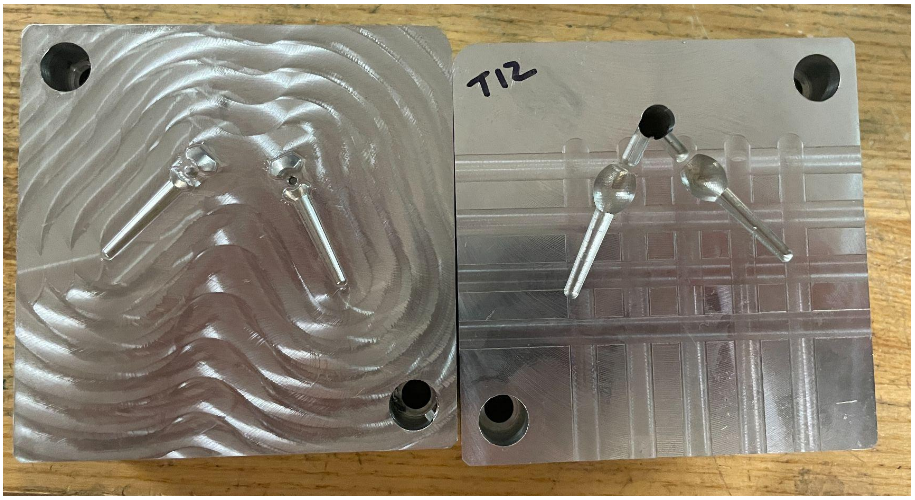


Figure 4.2.1: Core and Cavity Molds for the Lollipop Part

The lollipop molds were straightforward and easy to manufacture. The manufacturing time was only thirty minutes for the cavity and about two hours for the core. The surface finish of both parts was acceptable, and no changes or re-machining were required for these two molds.

Figure 4.2.2: Core and Cavity Molds for Kirby's Front Half

The machining for Kirby's front half was the most complicated of all of the molds. The small facial features were a challenge to manufacture, and extra care was taken when machining them with the 1/16" ball mill. Fortunately, no changes to the manufacturing program were required, and the resulting molds were acceptable for injection molding. The one defect from the milling operations was the surface finish of the steep angle portion on the core. There is a visible surface finish transition from alternating tool sizes which is undesirable. Since the core will only affect the inside of the part, though, it was decided that the defect was acceptable to leave in the final mold.

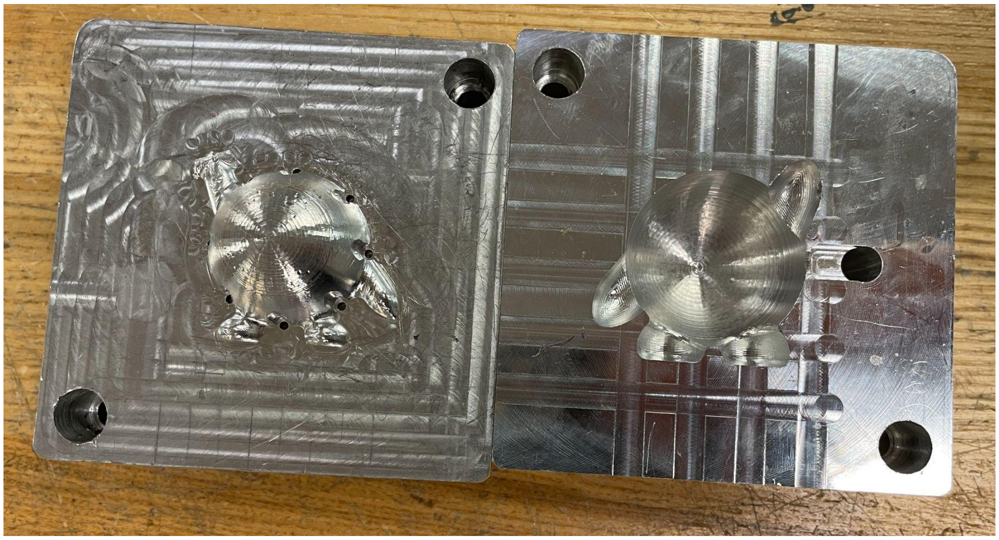


Figure 4.2.3: Core and Cavity Molds for Kirby's Front Half

The cavity of Kirby's back half was machined easily and the quality of the resulting mold was very good. The surface finish of both the large spherical part and the smaller leg and arm sections was exceptional, and there were no visible defects from the milling operations. The core was more difficult to manufacture. The surface finish was acceptable, but not as good as it was for the cavity, and the holes and hole bosses caused some issues. It was difficult to fit a center drill into the boss cavities since the boss diameter is only small, and the resulting holes ended up being slightly oversized.

4.3. Manufacturing Process Documentation

Figure 4.3.1: Toll Holder Setup

Figure 4.3.2: Finished Tool Setup

Figure 4.3.3: Loading Tools

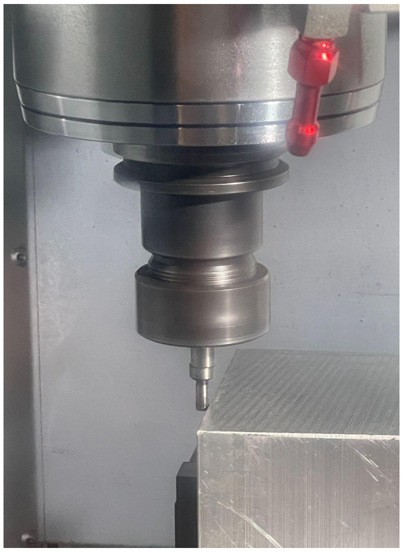


Figure 4.3.4: x Zeroing **Figure 4.3.5**: Kirby Front Cavity **Figure 4.3.6**: Kirby Front Core

5. Metrology

The below CAD images show the measured region for each of the parts. For Kirby, the outer sphere diameter was measured. The specified part dimension was 1.5" with an expected tolerance of 0.01". For the lollipop, the overall height of the component was measured. The specified part dimension was 1.275" with an expected tolerance of 0.01". These values are shown in the graph below.

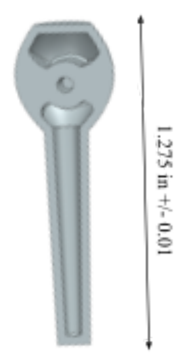


Figure 5.1: Kirby Measured geometry **Figure 5.2:** Lollipop Measured geometry

Figure 5.3: injection molded Assembly

Table 5.1: Kirby production data (in inches)

1. 1.500	**2.** 1.520	**3.** 1.510	**4.** 1.500	**5.** 1.498
6. 1.510	**7.** 1.527	**8.** 1.501	**9.** 1.510	**10.** 1.518
11. 1.502	**12.** 1.538	**13.** 1.530	**14.** 1.500	**15.** 1.511
16. 1.495	**17.** 1.540	**18.** 1.503	**19.** 1.521	**20.** 1.517
AVG:	**1.513**		**ST DEV:**	0.0131

Table 5.2: Lollipop production data (in inches)

1. 1.280	**2.** 1.282	**3.** 1.284	**4.** 1.270	**5.** 1.261
6. 1.275	**7.** 1.287	**8.** 1.288	**9.** 1.271	**10.** 1.287
11. 1.290	**12.** 1.270	**13.** 1.267	**14.** 1.286	**15.** 1.266
16. 1.273	**17.** 1.285	**18.** 1.281	**19.** 1.275	**20.** 1.270
AVG:	**1.277**		**ST DEV:**	0.0084

Overall the Molded parts are close in value with the original CAD design. For the first part, Kirby, the CAD design measured geometry was 1.5 inches, compared to the production run, which averaged 1.513 inches, and ranged in values from 1.495 to 1.540 inches. While for the second part, Lollipop, the CAD design measured geometry was 1.275, and the production run yielded values ranging from 1.261 to 1.290 inches, averaged to 1.277 inches. The tolerance of ± 0.1” for the CAD design was met for the production run. Most of the dimensioned parts met this tolerance, with some outliers. The yielded standard deviation of 0.0131” and 0.0084”, for the Kirby and lollipop part respectively, compared with the intended tolerance of the parts.

As close in values as we came with most of the parts, the outliers may have been conceived by a change in the machine. While producing the parts, one of the machines we initially used was unreliable and often malfunctioned. These parts that were not within the tolerance were made by the malfunctioned machine, which often had defects such as flashings, and warping. This caused irregularity in the measurements of the parts. Another factor that caused incorrect dimensions was the method of removing the mold and lack of consideration for shrinkage. Removing the mold was difficult and often resulted in expanding the parts, and caused plastic parts to chip for the Kirby part. Although we weren't too affected by it, we neglected to anticipate shrinkage.

Our target dimension was met after multiple attempts to choose the most suitable injection time and pressure. After we yielded a good part, we maintained the same parameters throughout, which allowed for a reliable replication of procedure and yielded parts with our targeted dimension. Along with that, our CAD design features, such as draft, were overall reliable and allowed for consistent production for each part.

6. Concluding Summary

In conclusion, our overall project was a success. We successfully manufactured and injection molded the parts to our satisfaction. What went well in our project was specifically the part design, CAM programming and injection molding stage. We had no trouble figuring out the general design of our parts and how they would interact with each other. The CAM for the lollipop and Kirby proved to be very simple as well. The injection molding process was also very smooth as the parts all filled completely into the molds, and can be attached together as expected.

However, during the machining stage, our team experienced difficulties. Due to initially setting a wrong Machine Coordinate System (MCS) for the Kirby front cavity, we had to revisit our CAM and reprogram the g-code. Further, as Kirby's features are very complicated as well, the machining process required a lot more tools and time than we initially expected. Additionally, due to the depth limitations for the end and ball mills, our team needed to change our design from a lollipop to a lollipop as the 1/16in end mill could not go deeper than ⅛ in. This required changing a bit of our part design so that it would be machineable.

Some modifications to our mold that we could change is removing the machined pins and creating pin/hole structures in the mold (given that these structures are machineable). This would greatly reduce the time to injection mold Kirby's part as we would not require the use of manually putting in machining pins. Further, we could also employ the use of slight trapezoidal runners for better plastic flow throughout the part.

7. Sources

1. Plastics. (n.d.). Retrieved March 11, 2023, from https://sites.esm.psu.edu/courses/emch13d/design/design-tech/materials/plastics2.html
2. PP. Designerdata. (n.d.). Retrieved March 11, 2023, from https://designerdata.nl/materials/plastics/thermo-plastics/polypropylene-(cop.)

8. Appendices

Appendix A: Runner Cross Section Calculations

In order to ensure that cross-sectional areas were consistent a comparison was made where the runner height was 0.5", width was 1", and length was 4".

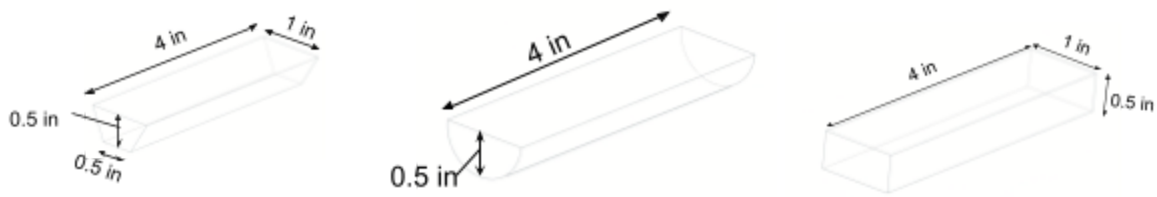


Fig. A1. Cross-Sectional Area Visualization.

$$C_{TL} = \frac{Surface\ Area}{Cross-Sectional\ Area} \tag{A.1}$$

$$C_{TL} = \frac{8\ in^2}{0.5\ in^2} \tag{A.2}$$

$$C_{TL} = 16 \tag{A.3}$$

Appendix B: CAD Drawing of Parts and Molds

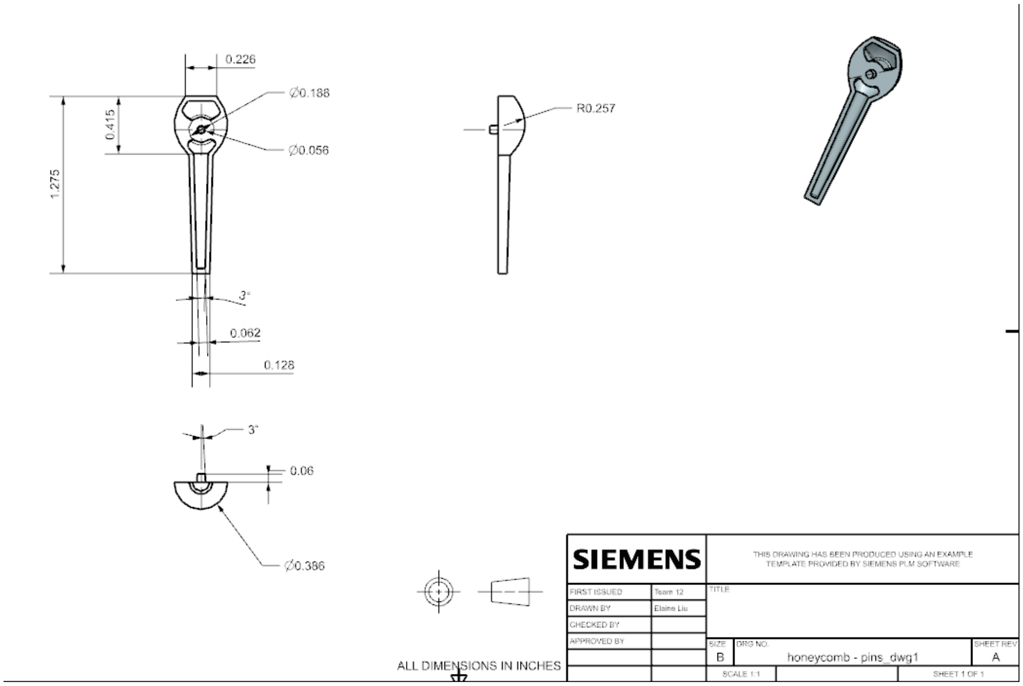


Figure B.1: Dimensioned CAD Drawing of Lollipop with Pins

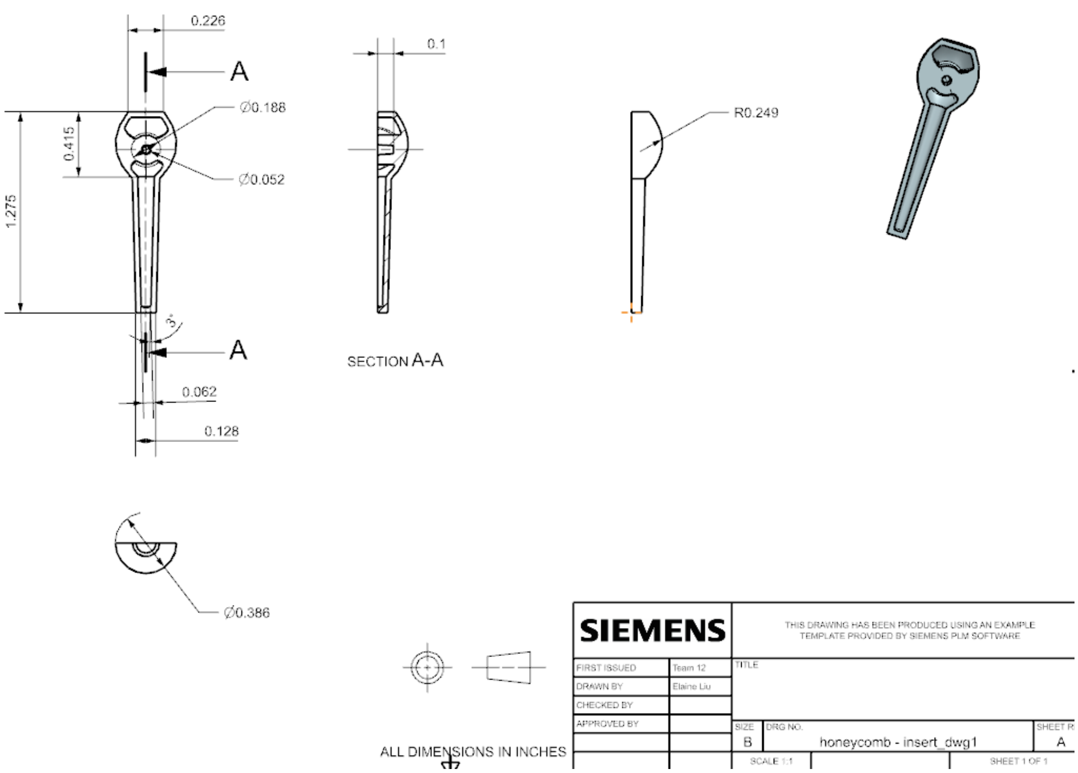


Figure B.2: Dimensioned CAD Drawing of Lollipop with Insert

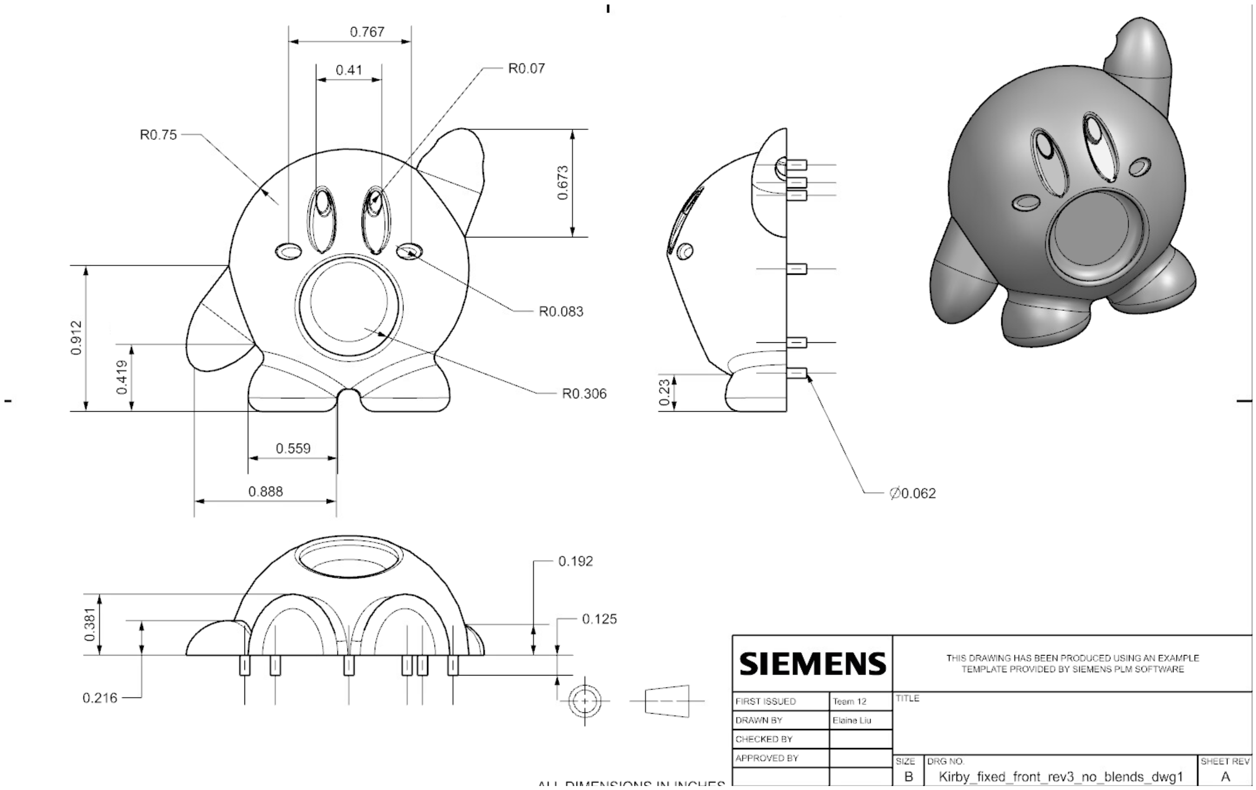


Figure B.3: Dimensioned CAD Drawing of Kirby's Front with Dowel Inserts (Sheet 1/2)

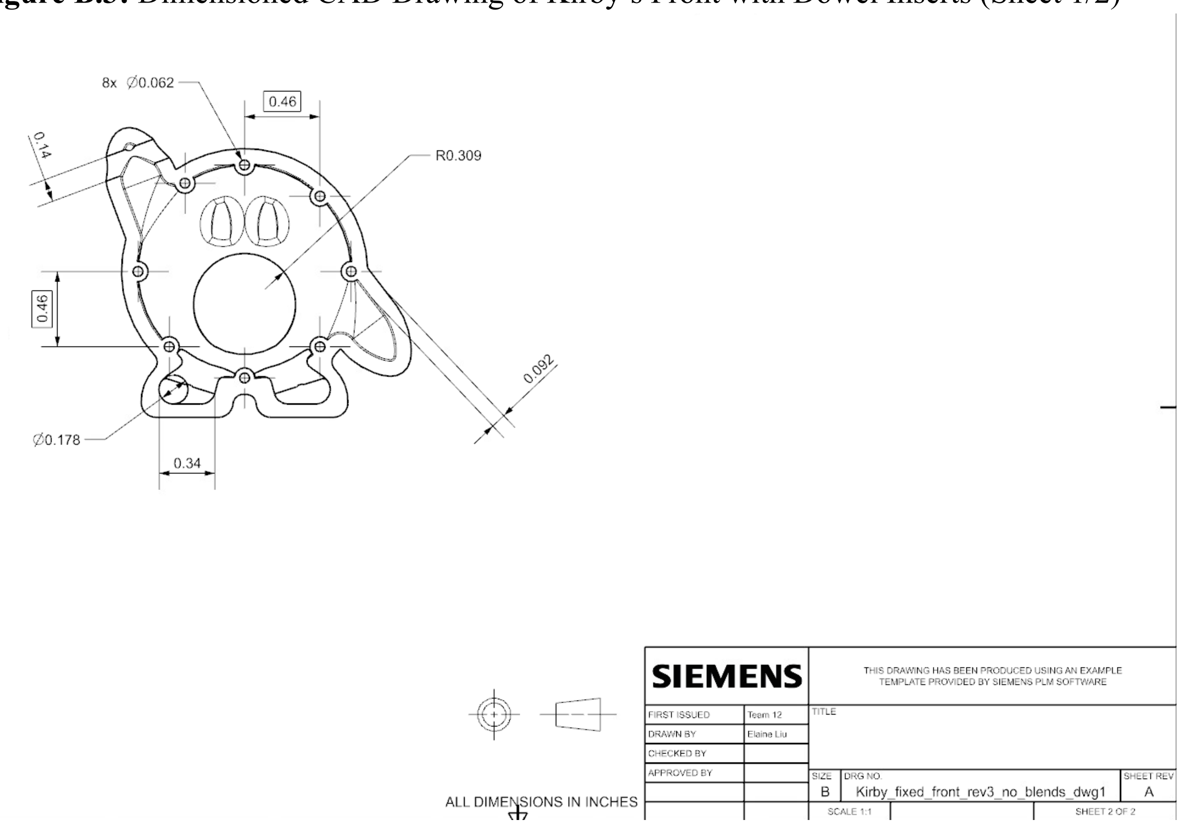


Figure B.4: Dimensioned CAD Drawing of Kirby's Front with Dowel Inserts (Sheet 2/2)

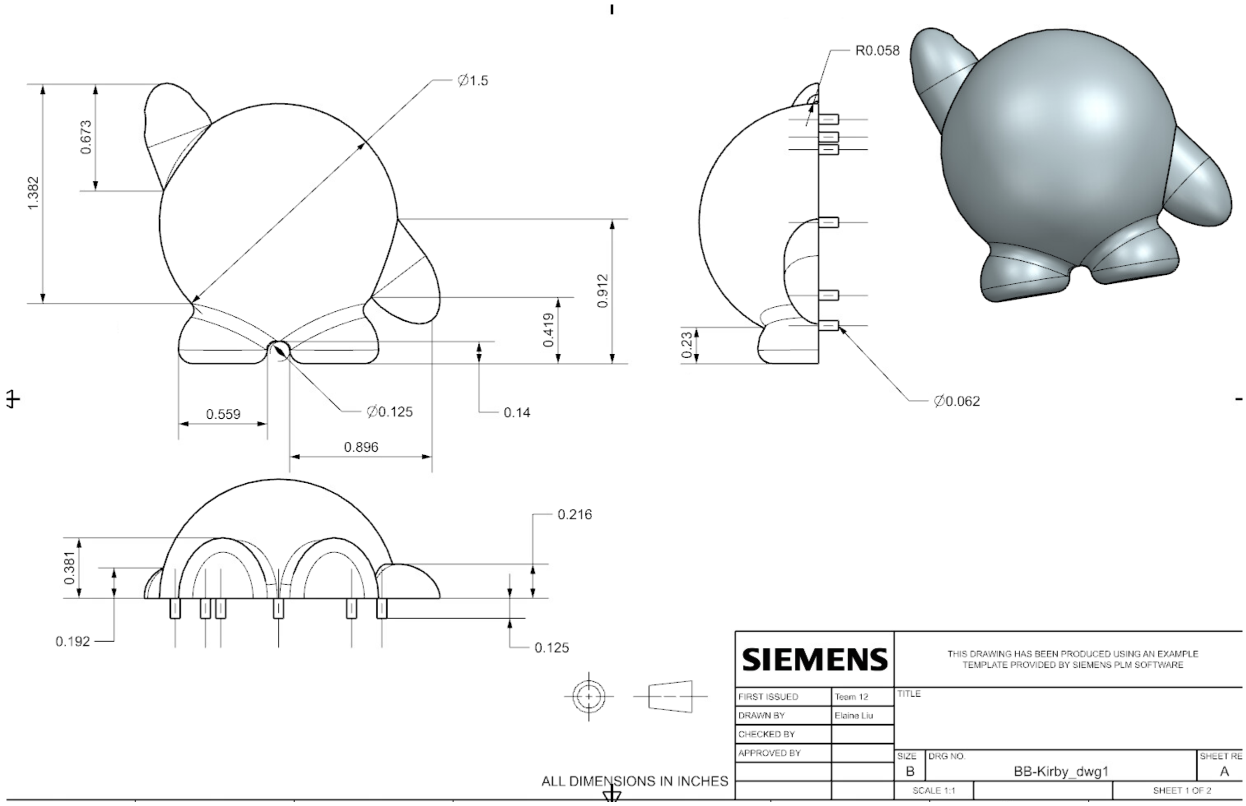


Figure B.5: Dimensioned CAD Drawing of Kirby's Back (Sheet 1/2)

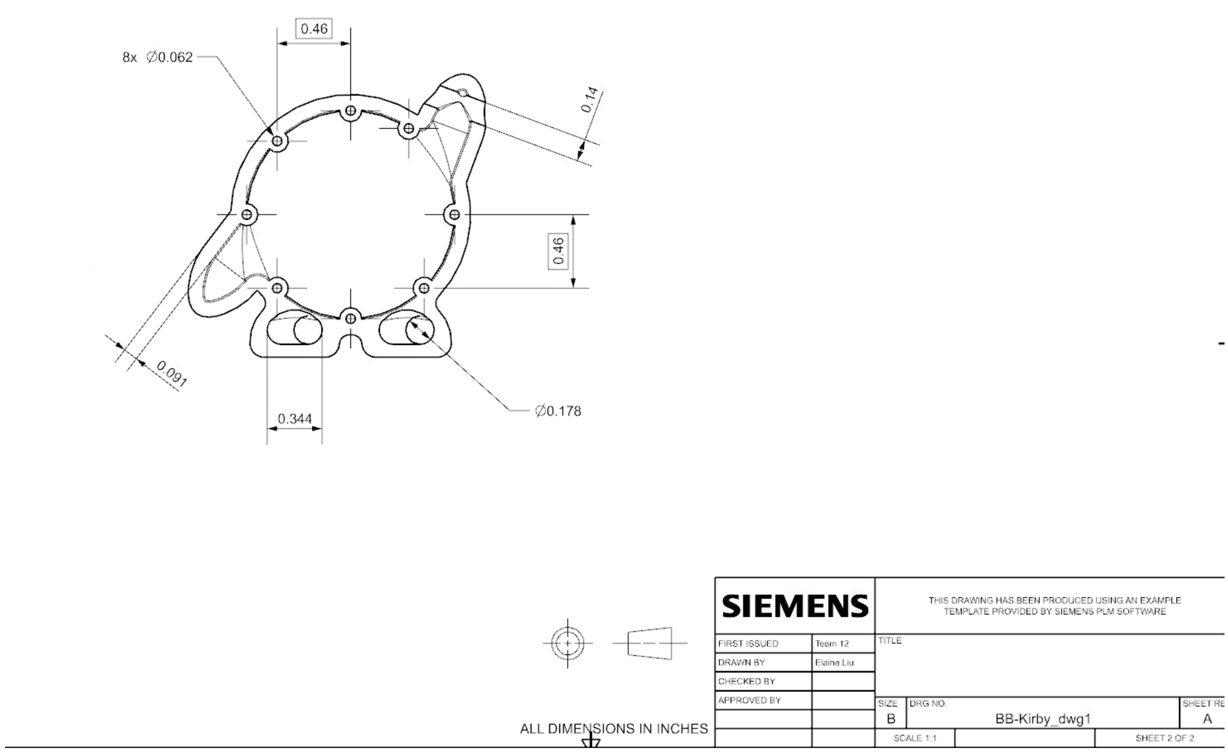


Figure B.6: Dimensioned CAD Drawing of Kirby's Back (Sheet 2/2)

Appendix C: Tables of Mold Operations and Parameters

Table C.1: *Kirby Front Half Core* Mold Operations and Parameters

Op. No.	Type	Finish	Tool	Depth of Cut*	Stepover*	Feed (ipm)	Speeds (rpm)
1.1	Cavity Milling	Rough	$\frac{3}{4}$" End Mill	0.1500	33%	18	2037
1.2	Cavity Milling	Finish	$\frac{3}{4}$" End Mill	0.1500	33%	18	2037
1.3	Cavity Milling	Rough	$\frac{1}{4}$" End Mill	0.0833	33%	12	6112
1.4	Cavity Milling	Finish	$\frac{1}{4}$" End Mill	0.0833	33%	12	6112
1.5	Area Milling	Finish	$\frac{1}{4}$" Ball Mill	33%	0.0005	12	6112
1.6	Cavity Milling	Finish	$\frac{1}{8}$" End Mill	0.0417	33%	6	10000
1.7	Area Milling	Finish	$\frac{1}{8}$" Ball Mill	33%	0.0005	6	10000
1.8	Area Milling	Finish	$\frac{1}{8}$" Ball Mill	10%	0.0005	6	10000
1.9	Spot Drilling		$\frac{1}{10}$" Spot Drill			15	3000
1.10	Drilling		$\frac{1}{16}$" Drill			10	2000

* Stepover and depth of cut are measured in inches or in % of tool flat where indicated

Table C.2: *Kirby Front Half Cavity* Mold Operations and Parameters

Op. No.	Type	Finish	Tool	Depth of Cut*	Stepover*	Feed (ipm)	Speeds (rpm)
2.1	Cavity Milling	Rough	$\frac{1}{8}$" End mill	0.0417	33%	6	10000
2.2	Cavity Milling	Finish	$\frac{1}{8}$" End mill	0.0417	33%	6	10000
2.3	Cavity Milling	Rough	$\frac{1}{4}$" Ball mill	0.0833	33%	12	6112
2.4	Cavity Milling	Finish	$\frac{1}{4}$" Ball mill	0.0833	33%	12	6112
2.5	Cavity Milling	Rough	$\frac{1}{8}$" Ball mill	0.0417	33%	6	10000

2.6	Cavity Milling	Finish	⅛” Ball mill	0.0417	33%	6	10000
2.7	Area Milling	Finish	⅜” Ball mill	10%	0.0005	14	4074
2.8	Area Milling	Finish	⅛” Ball mill	10%	0.0005	6	10000
2.9	Area Milling	Finish	1⁄16” Ball mill	10%	0.0005	6	10000

* Stepover and depth of cut are measured in inches or in % of tool flat where indicated

Table C.3: *Kirby Back Half Core* Mold Operations and Parameters

Op. No.	**Type**	**Finish**	**Tool**	**Depth of Cut***	**Stepover***	**Feed (ipm)**	**Speeds (rpm)**
3.1	Cavity Milling	Rough	¾” End mill	0.1500	33%	18	2037
3.2	Cavity Milling	Rough	½” End mill	0.1667	33%	16	3056
3.3	Cavity Milling	Finish	½” End mill	0.1667	33%	16	3056
3.4	Cavity Milling	Rough	¼” End mill	0.0833	33%	12	6112
3.5	Cavity Milling	Rough	⅛” End mill	0.0417	33%	6	10000
3.6	Cavity Milling	Finish	⅛” End mill	0.0400	33%	6	10000
3.7	Area Milling	Finish	½” Ball mill	10%	0.0005	16	3056
3.8	Area Milling	Finish	¼” Ball mill	10%	0.0005	12	6112
3.9	Area Milling	Finish	⅛” Ball mill	10%	0.0005	6	10000
3.10	Spot Drilling		1⁄10” Spot Drill			10	3000
3.11	Drilling		1⁄16” Drill			2	3000

* Stepover and depth of cut are measured in inches or in % of tool flat where indicated

Table C.4: *Kirby Back Half Cavity* Mold Operations and Parameters

Op. No.	**Type**	**Finish**	**Tool**	**Depth of Cut***	**Stepover***	**Feed (ipm)**	**Speeds (rpm)**
4.1	Cavity Milling	Rough	½” Ball mill	0.1667	33%	16	3056

4.2	Area Milling	Finish	½" Ball mill	10%	0.0005	16	3056
4.3	Cavity Milling	Rough	¼" Ball mill	0.0833	33%	12	6112
4.4	Area Milling	Finish	¼" Ball mill	10%	0.0005	12	6112
4.5	Area Milling	Finish	⅛" Ball mill	10%	0.0005	6	10000
4.6	Cavity Milling	Rough	⅛" End mill	0.0417	33%	5.922	10000
4.7	Cavity Milling	Finish	⅛" End mill	0.0417	33%	5.922	10000

* Stepover and depth of cut are measured in inches or in % of tool flat where indicated

Table C.5: *Lollipop Core* Mold Operations and Parameters

Op. No.	**Type**	**Finish**	**Tool**	**Depth of Cut***	**Stepover***	**Feed (ipm)**	**Speeds (rpm)**
1	Cavity Milling	Rough	¾" End mill	0.1500	33%	18	2037
2	Cavity Milling	Finish	¾" End mill	0.0400	33%	18	2037
3	Cavity Milling	Rough	⅛" End mill	0.0400	33%	6	9992
4	Cavity Milling	Finish	⅛" End mill	0.0400	33%	6	9992
5	Cavity Milling	Finish	1⁄16" Ball mill	0.0400	33%	2	10023
6	Area Milling	Finish	1⁄16" Ball mill	10%	10%	2	10023
7	Spot Drilling		1⁄10" Spot drill			2	3000
8	Drilling**		1⁄16" Drill			2	3000

* Stepover and depth of cut are measured in inches or in % of tool flat where indicated

Table C.6: *Lollipop Cavity* Mold Operations and Parameters

Op. No.	**Type**	**Finish**	**Tool**	**Depth of Cut***	**Stepover***	**Feed (ipm)**	**Speeds (rpm)**
1	Cavity Milling	Rough	⅛" Ball mill	0.0400	33%	6	9992
2	Cavity Milling	Finish	⅛" Ball mill	0.0400	33%	6	9992

3	Area Milling	Finish	⅛" Ball mill	10%	10%	6	9992

* Stepover and depth of cut are measured in inches or in % of tool flat where indicated

Appendix D: Dimensioned Mold Drawings

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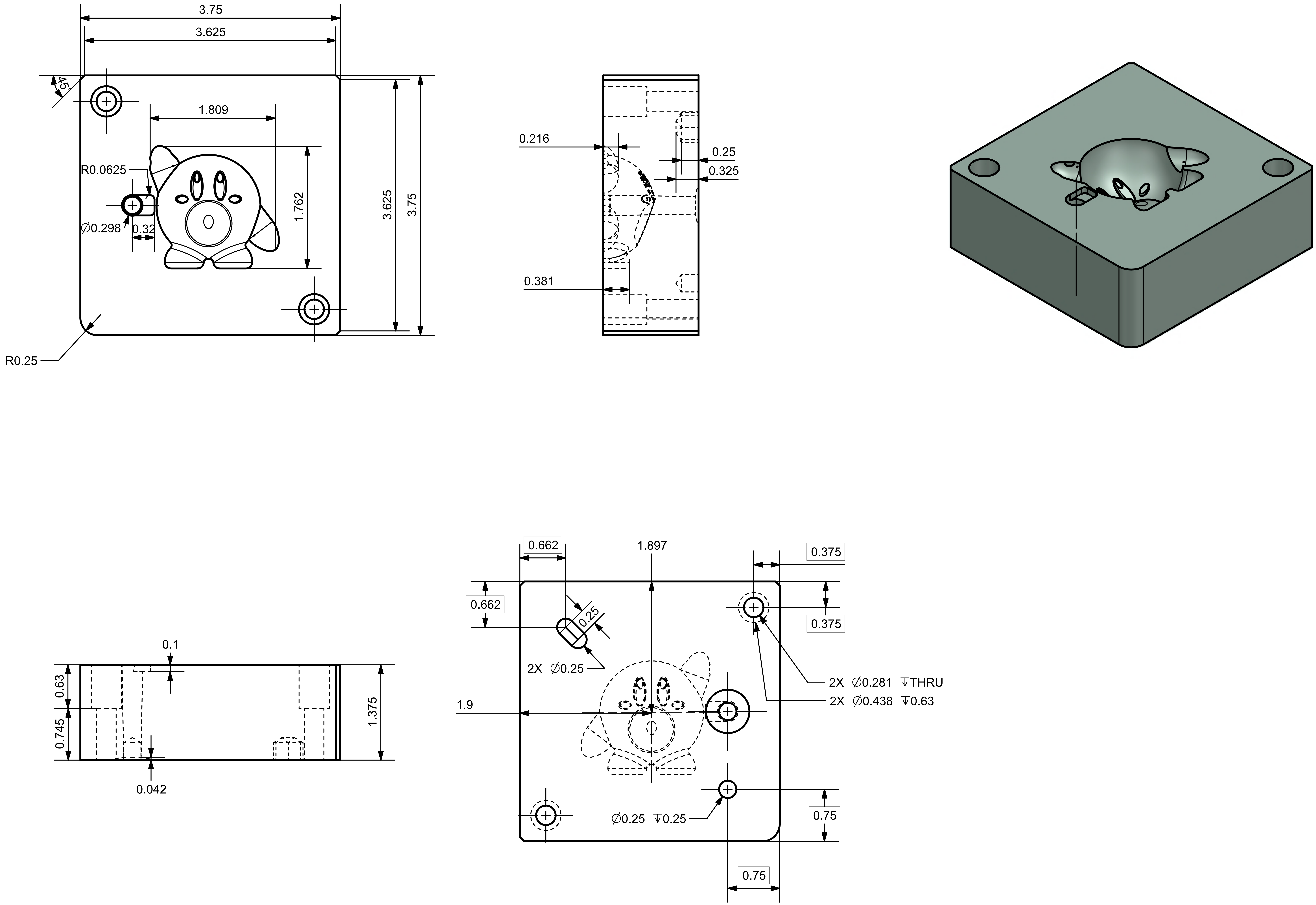

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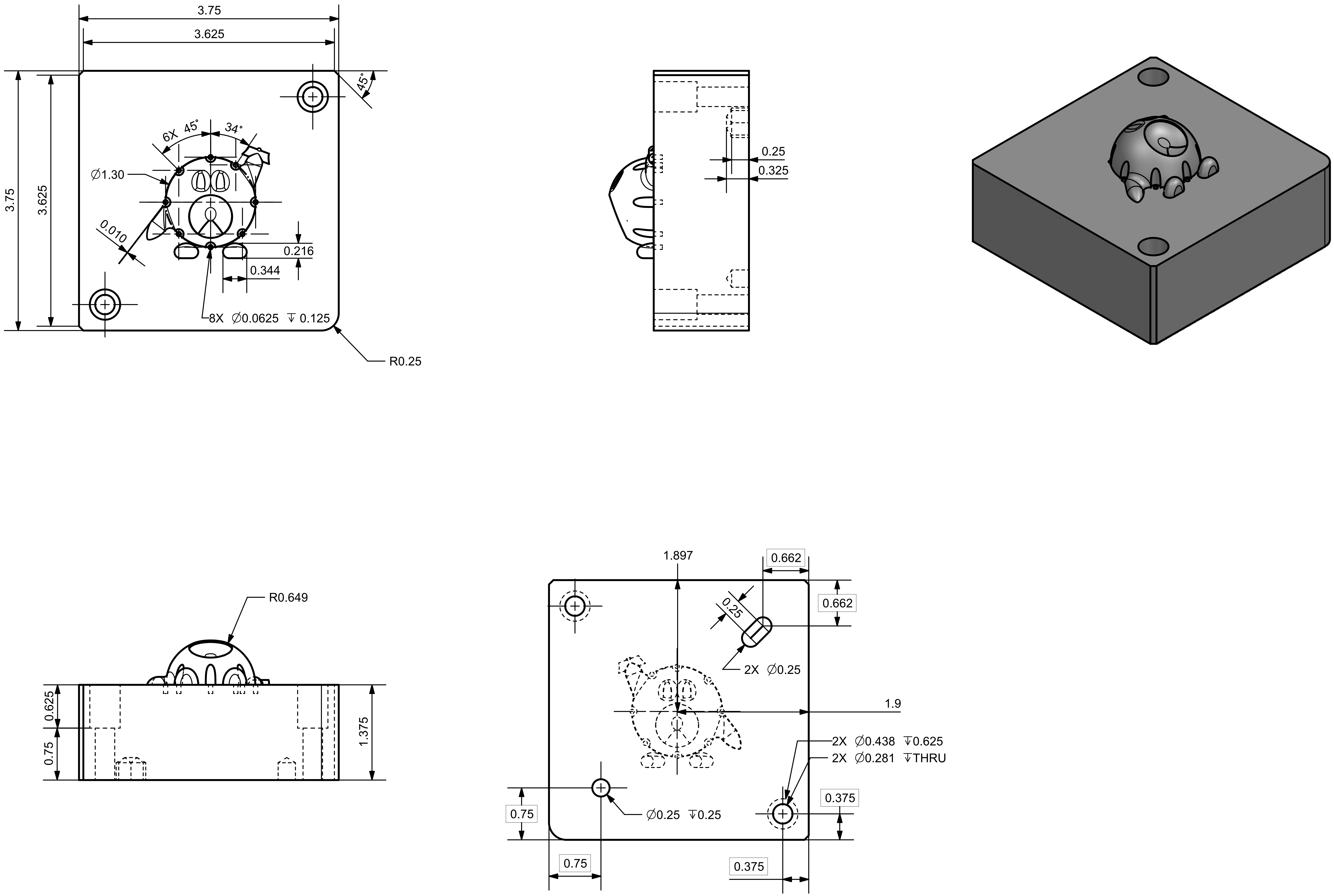

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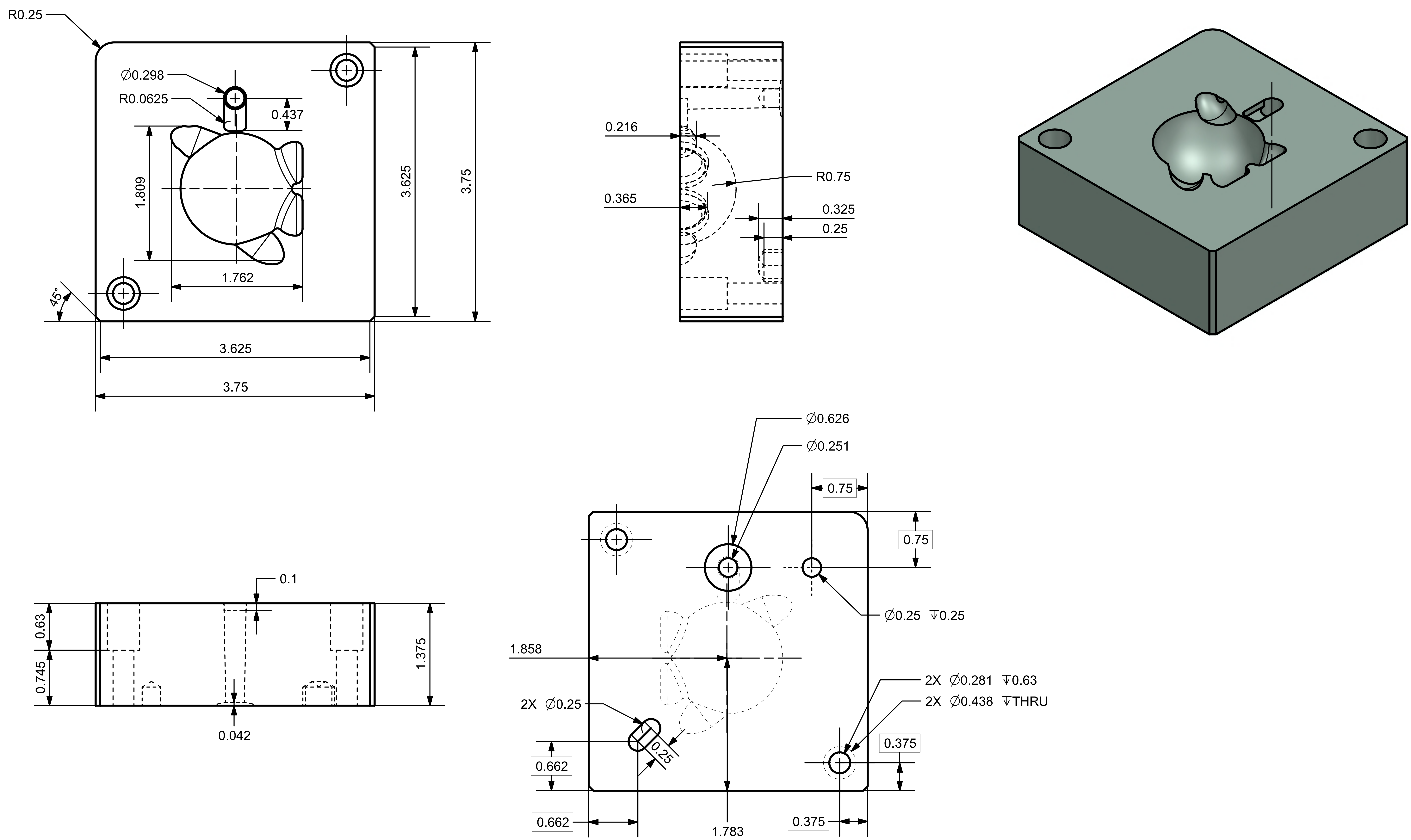

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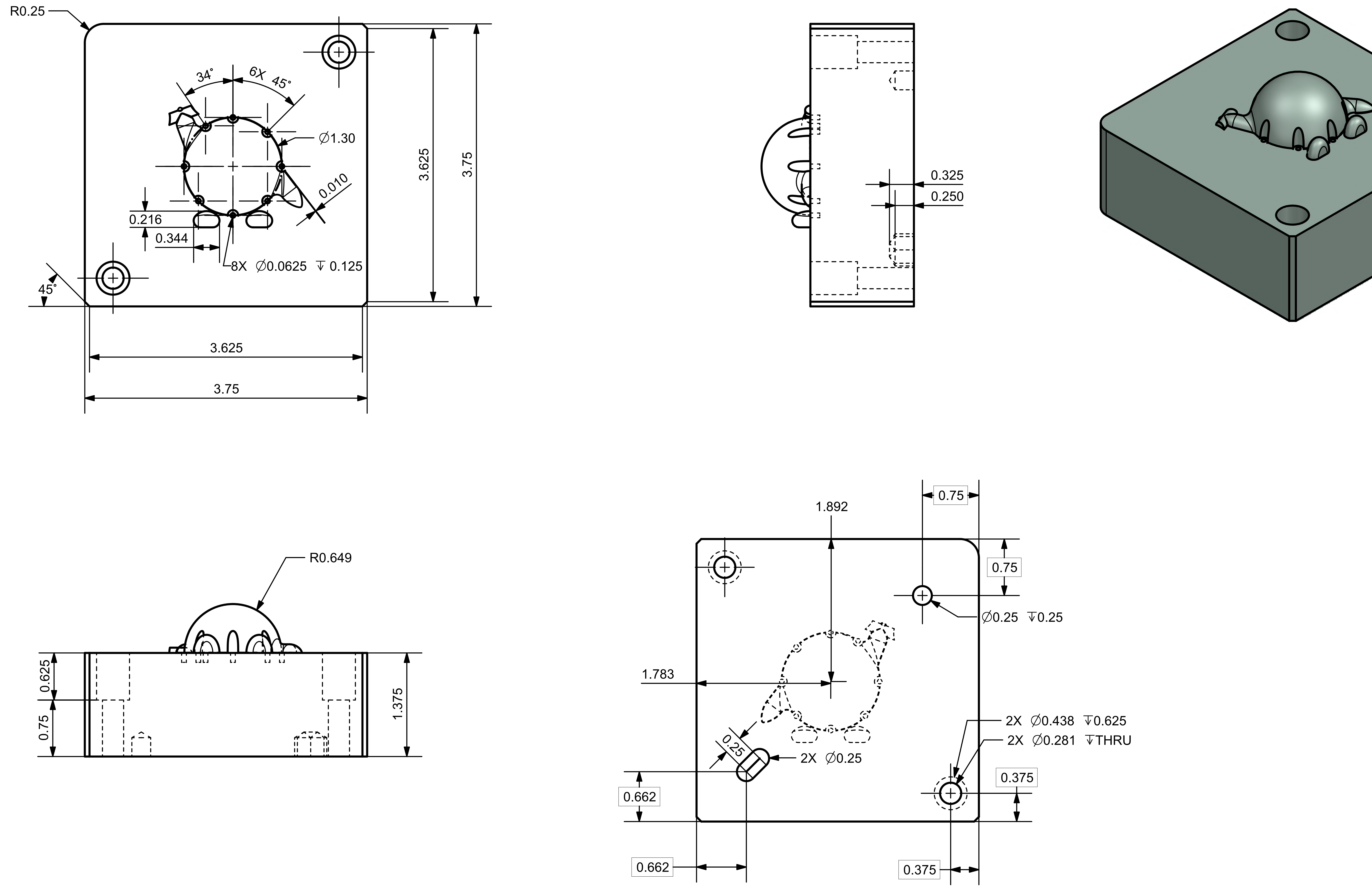

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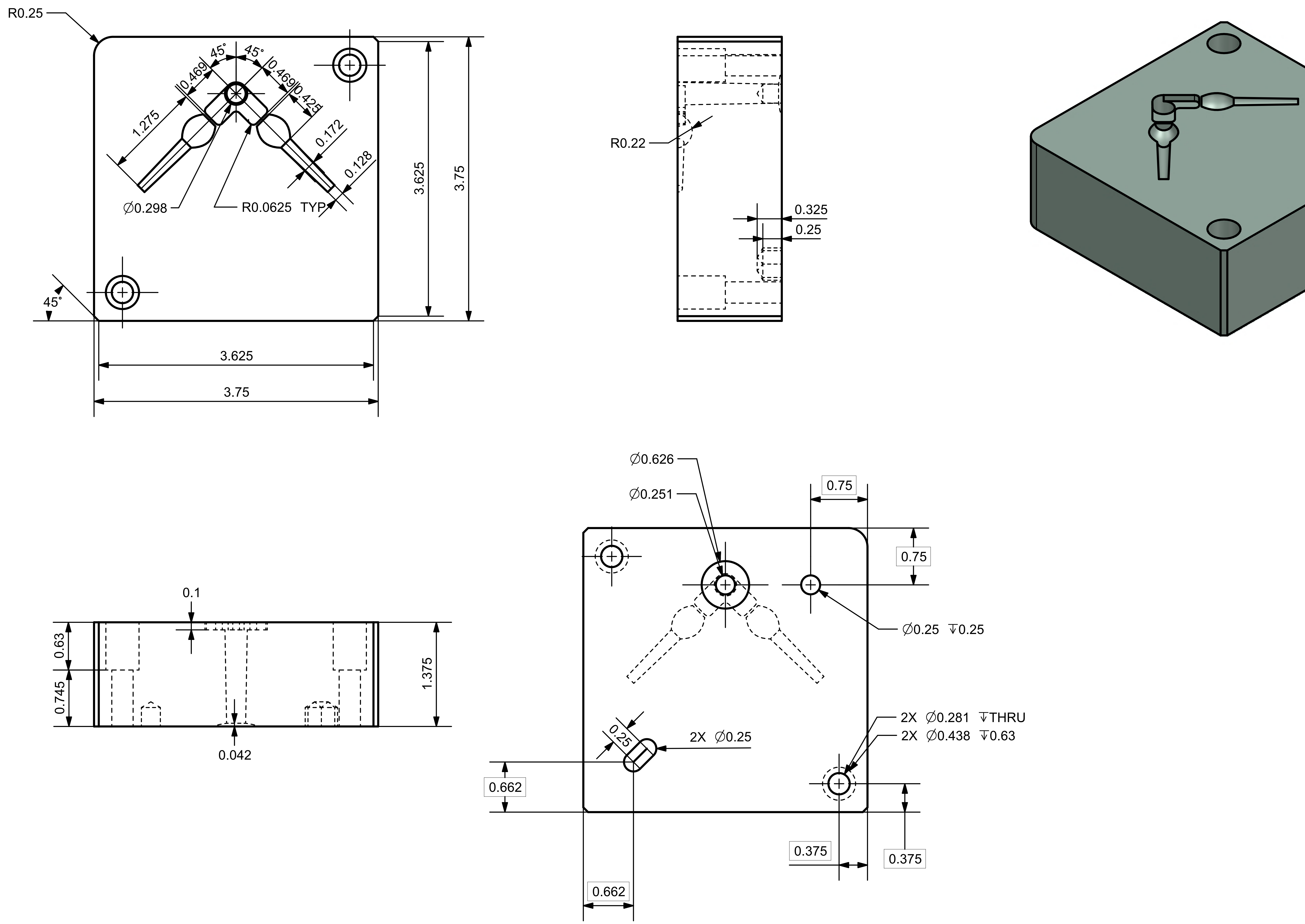

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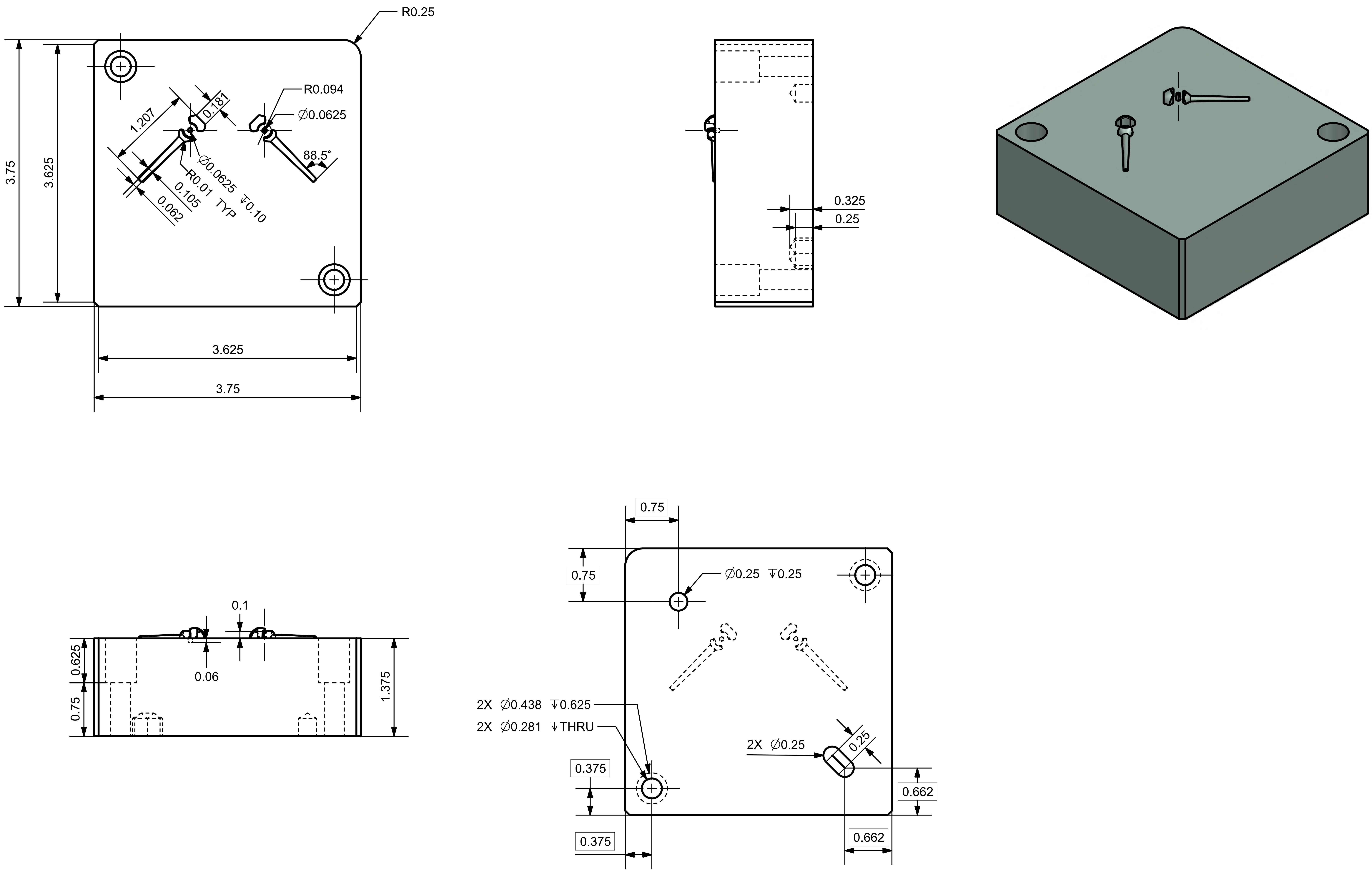

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