ISE 316 – Manufacturing Engineering I: Processes
SPRING 2025

NC State Coaster Technical Report

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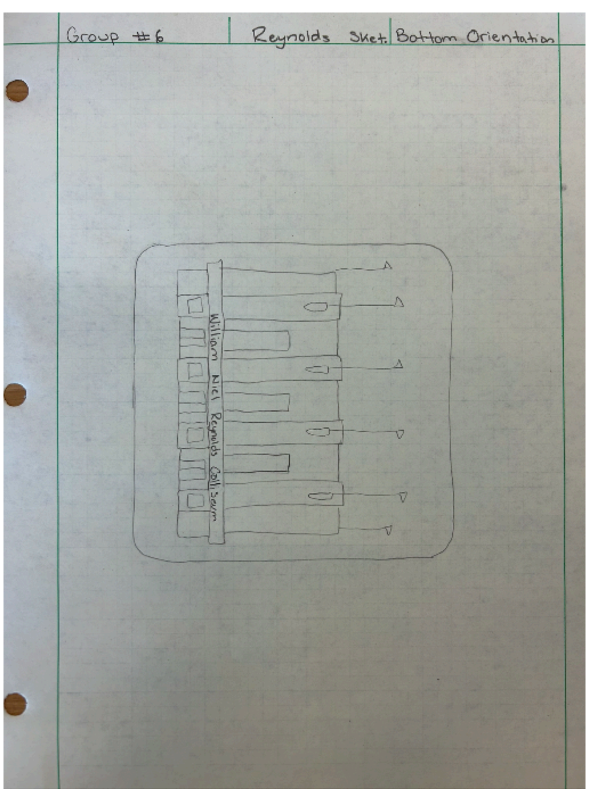
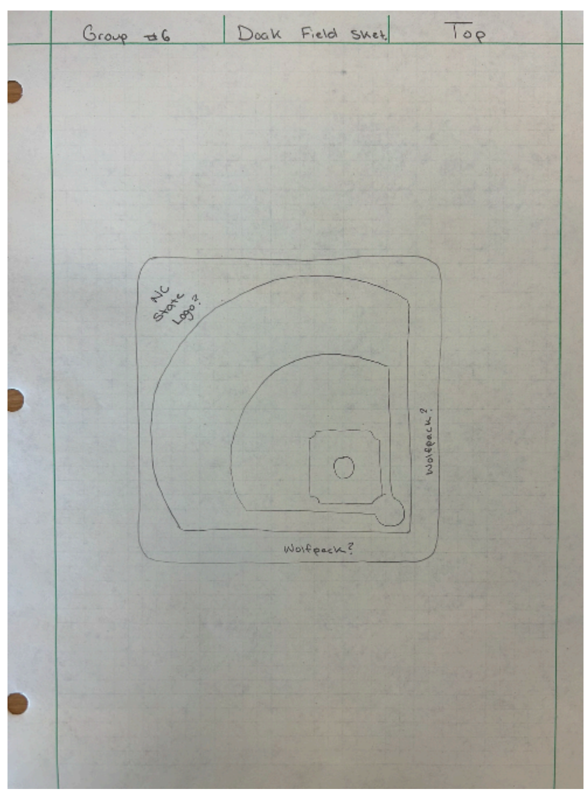
Abstract

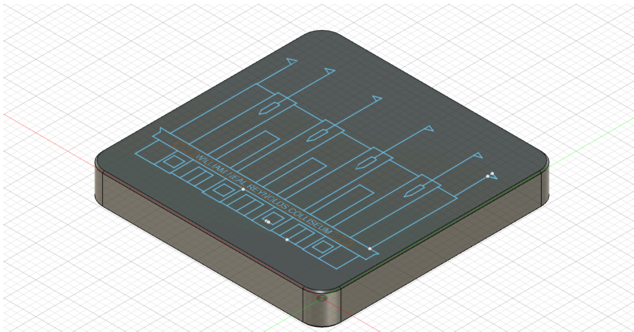
This report outlines our team's process to develop a new NC State-themed coaster. The main goal is to design a functional and aesthetically pleasing product by designing and manufacturing using the necessary toolpaths. To reach a final product by using proper engineering documentation to mass manufacture the design, our group made sure to also remain within the cost/production constraints. Overall, this report will demonstrate our process in understanding these specific concepts within Manufacturing Engineering - Processes and our ability to manufacture, design, and produce an NC State-themed coaster.

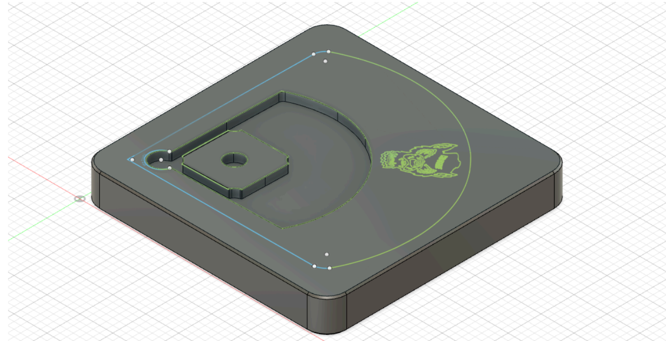
PRODUCT DESIGN AND SPECIFICATIONS

Design: Our project design originally started with brainstorming specific ways we wanted to create an NC State theme product. By attending weekly lab sessions, our group was able to explore previous projects created by past students who were also assigned a very similar project. Many of which had Tuffy (Our Mascot), Footballs (Stadiums or players), and basketballs (to represent a Final Four March Madness run). After inspecting many of the projects, each of our group members designed their ideal coaster for submission. From there, we decided that we wanted to incorporate Reynolds Coliseum and Doak Field, NC State's baseball stadium. Each of which had not been previously designed before. Initially, we had some trouble in our approach to incorporating both of these themed details. After further discussion, our group decided to have a dual-sided coaster. One side was the baseball field, while the other side was Reynolds Coliseum. To properly design each of these features into our coaster, we created SVG images from JPEGs found online. From there, we would extract the images in InkScape (The software we used to create our SVG files) and import them into Fusion 360. Another important aspect during our importation process was the basis on the field, which could be adequately drawn using the same SVG file as the rest of the stadium. To solve this problem, we created a separate sketch that held the bases, lining them up correctly with the field that was previously traced. Shown below are our previous coaster designs and a final 3D CAD model of our finished part.









Functional Features:

1. Initial design of Doak Field
2. Initial Design of Reynolds Coliseum
3. Final Design (both sides) of the product

Engineering Considerations:

After the implementation of both the Reynolds Coliseum and Doak Field on either side, our group came across some specific engineering considerations that would ultimately affect the overall design and outcome of our coaster. Firstly, the design for Reynolds on one side was without issues and easy to manufacture. For the baseball field, we needed to find the specific area that should be pocketed for acrylic assertion. Although we initially thought it would be a complex challenge to have both the infield and outer edge of the field lined with acrylic, we found that it would not be a big enough width for the outer edge and would cause future issues. Although this idea would have been very fun and interesting to implement in our design, we ended up only pocketing out the infield, which gave the smallest width between .150". After the creation of the first coaster, we realized that this was the correct decision and did not cause any breakage of the acrylic when hammering the part in. From there, we were able to create low tolerances since this part would have to be manufactured 100,000 times. Each of these features had Go/No-Go gauges created for each of the pockets for the acrylic; reference section D for information. The rest of the remaining tolerances and constraints were based upon the size of the part and each specific feature highlighted within the design to create our final product.

Coaster Holder:

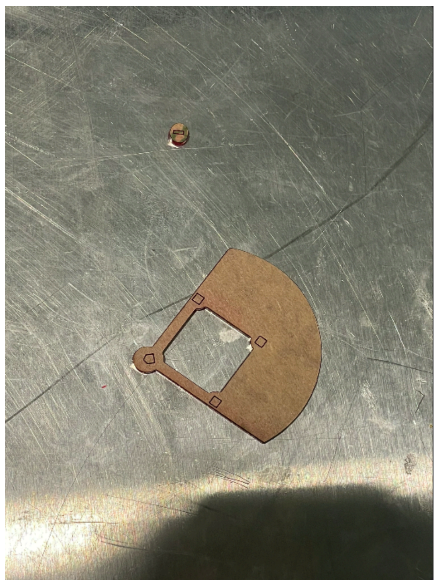
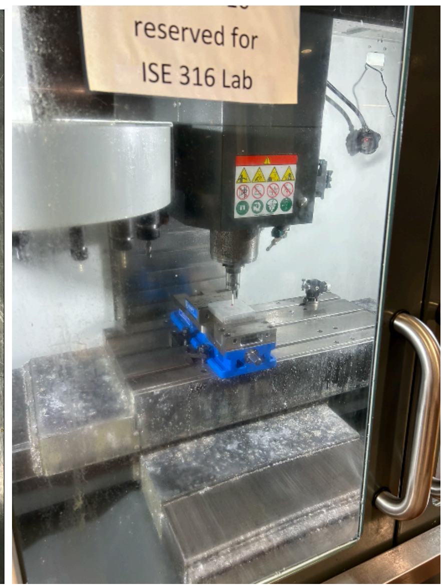
The last part that had to be designed was the coaster holder. Our group decided that we would create a holder that had a flat base extruded .50" for the coasters to be set on and four mirrored rods that will hold up to four coaster pieces in place on either side. Initially, when trying to design this holder, our group looked up reference images to try and create ideas on a simplistic design that would not take away from our NC State-themed coasters. The design that we stuck with allowed for the stacking of multiple coasters on top of one another and enough space on either side for an individual to pick each of them up and out of the holder. By the course description, the holder must be within the constraints of 5.75" by 5.75" by 5.75", and also the stock sizes (L/W/T/Ø) should be 0.25" larger than the finished size. With this in mind, we were able to create our final design and dimensions of what we deemed a proper holder. Also, with this part not having to be machined, it was a lot easier for us to design this without regard for proper machining capability. See reference C for more information on assembly and dimensions.

2. MANUFACTURING PROCESS PLANNING

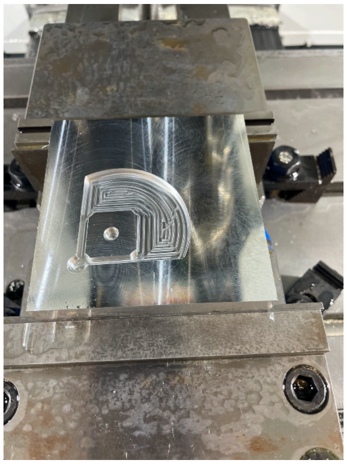
Process Plan:

Setup- Initially, other groups had to take a 6-foot aluminum beam and cut it into 18 separate 4" sections using the saw embedded in the CNC. Once cut into separate sections, one of our group members would place the first aluminum square into the vice jaw. To ensure that the aluminum is tightly fastened, hammer firmly into the center until neither jaw moves in any horizontal direction. After securing, use the handle jog feature on the machine, and zero each axis to the center of the part. From there, using a ruby tip, calculate and dimension the proper x,y,z axes for correct machining.

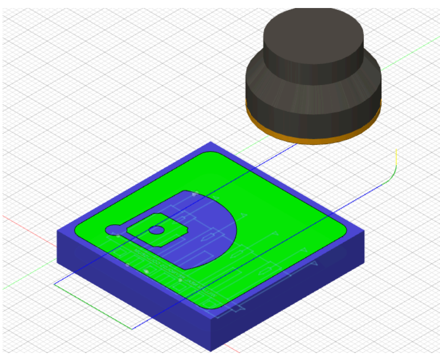
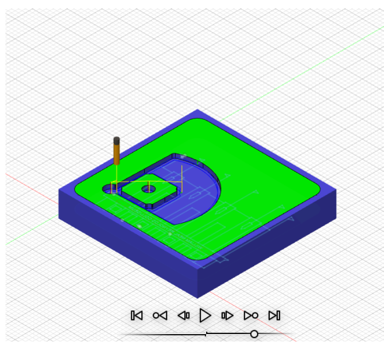
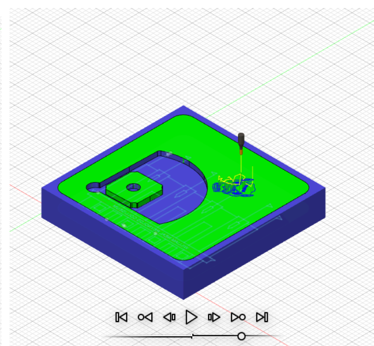
Importing- After saving the CAD file and reviewing the final manufacturing steps, import the file into Glowforge (cut and create our acrylic). From there, use the focal length ofthe head by using an embedded laser and set the thickness. Shown below are the pictures taken during the laser cutting process.

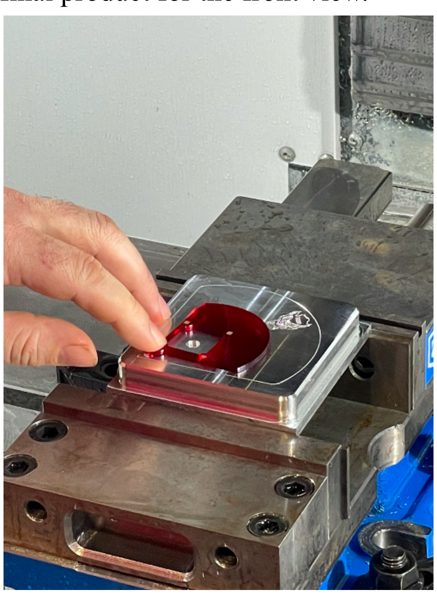
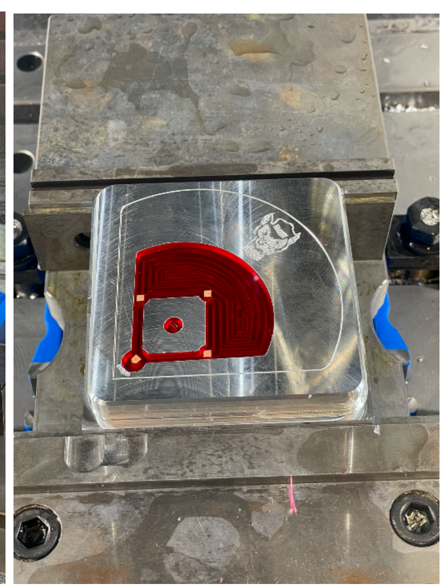
Machining- After the Glowforge has been run, we got ready to machine the part. Reviewing and downloading the G code onto a flash drive allowed the code to be given to the CNC machine to be programmed. Firstly, we used a 2.5" Face Mill (Tool 1) to face the top of our part and remove material to prepare for subsequent operations. Then a tool changed to use a .125" end mill roughing (Tool 4) to remove a majority of the pocket feature and pitcher mound in the center of part. Then go back through and finish to create a much smoother cutout. From there, it ran a contour program using the same tool on the inside edges. This will help remove the sharp edges that were produced by the endmill. After that, there was a tool change for the 1/16" engraving mill (Tool 10) for all the engravings using a trace program (Wolfpack mascot and wolfpack writing underneath home plate). From there change to a ½" endmill (Tool 2) to contour the outside edge. Then the tool changed one more time to a ⅜" chamfer mill to chamfer each part. A chamfer is performed around the outer edge to smooth the piece and allow individuals to pick the part up. Once finished, spray air to remove any remaining chips and remove Burr around outside (using a metal ruler) for proper insertion of acrylic. See images below for machining steps.

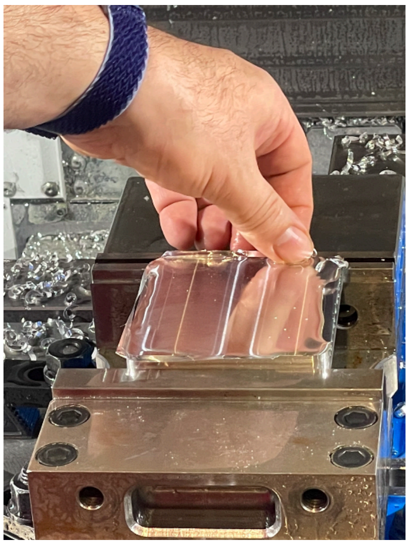
Shown below are screenshots taken from Fusion 360 showing three different programs being run from left to right we have our Face Program, 2D contour, and lastly one of the Trace programs.

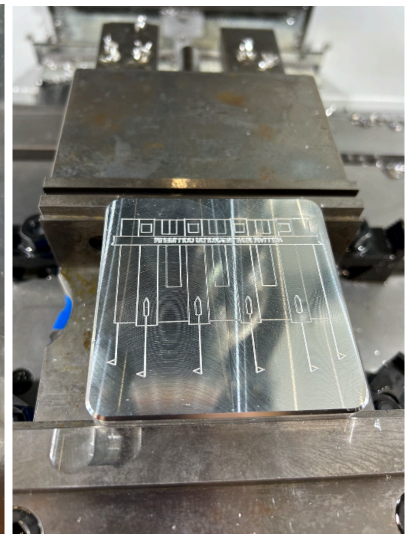
  

Acrylic- After the front is machined, remove the aluminum part and place it on the tabletop. From there, feel around with your finger to ensure that the chamfer will fit the acrylic piece. Slowly fit each side of the acrylic into place; any interference fits must be hammered in softly with a mallet. See images below for this step and the final product for the front view.

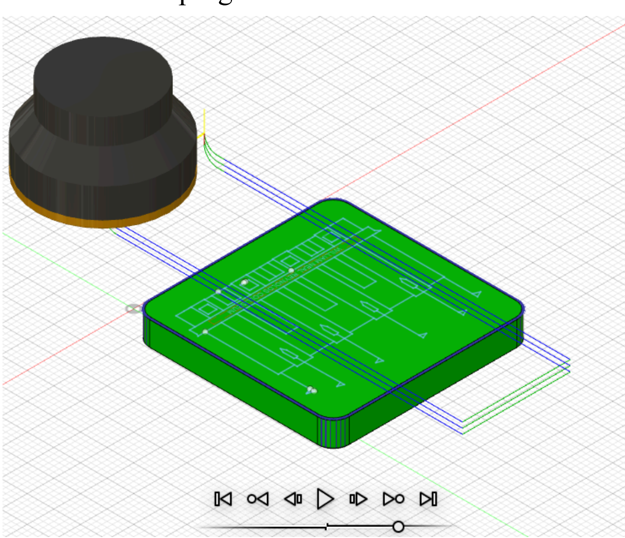
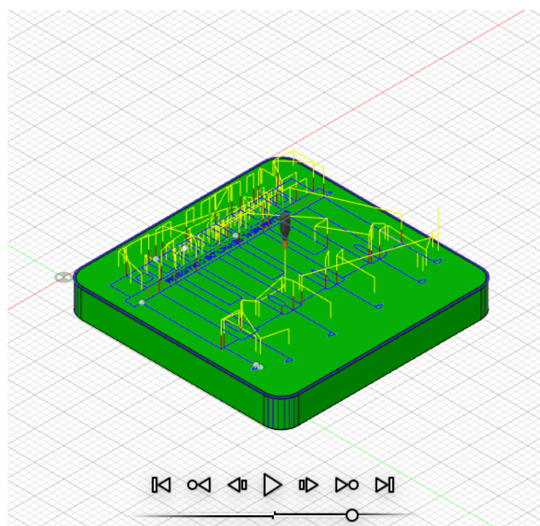
  

Second Machining- To begin the second part of machining on the bottom view, place the part inside the second CNC vice jaws. The loading steps and securing properly are held the same here as well. With the part being upside down, we first ran a face program on the back side using a 2.5” face mill (Tool 1) to remove all the remaining stock. Then, with a tool change to grab our 1/16” engraving mill (Tool 10), traced the entire Reynolds Coliseum. Lastly, using another tool change to Tool 5, chamfer the outside edge to smooth for proper individual handling using the ⅜” chamfer mill. Remove any access chips from the part by blowing air, loosen the jaws off of aluminum, and pick up the part for final inspection. See images below for the opposite side and final operation.

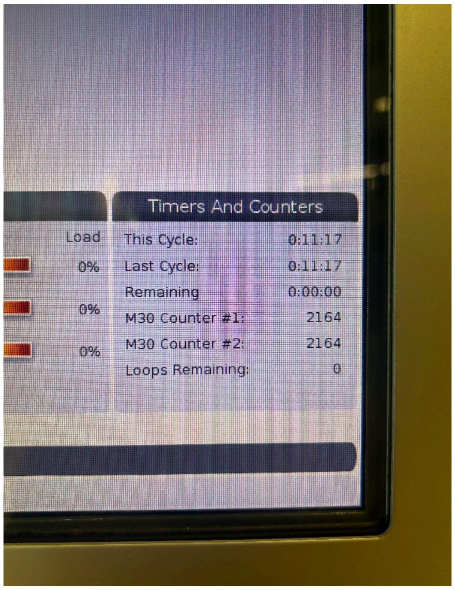




Here are a few screenshots taken from our second side of machining based on Fusion 360 for the Face Mill and Trace program.

Final steps: Check and make sure the acrylic is not smudged. If so, use WD-40 to clean off fingerprints or stains from machining. After booking our second session, we were able to run both machines with each group member doing a specific part for our next four coasters we machined to keep for ourselves. One person was in charge of manning and operating the first CNC machine for the top view, the second person was in charge of taking off paper for acrylic from Glowforge, and lastly, the third person was in charge of the second machine to run the bottom program. Each of us would rotate through different parts to make sure we got to work with different stations. Overall, the machine time for the half-cycle front view was 14 minutes and 59 seconds. For the second half cycle of the bottom view was 11 minutes and 17 seconds. See below for a few different pictures taken during each of these steps, the machining time for half cycle, and the final part completed with acrylic.



3. PRODUCT INSPECTION PLAN AND DATA

Our main goal of the product inspection was to ensure the accuracy of our dimensions for both pockets that made out the baseball field for the acrylic inserts to fit inside each pocket and be secured tightly without any room for movement. This was to ensure the consistency across all four coasters that were made. To measure the proper distance of the pocket, we used a digital caliper due to its high precision and reliability, especially since we were measuring small distances for both pockets. Our goal for the pitcher's mound was for the pocket to have a diameter of and a tolerance of .004”. For the larger pocket, the size was determined based on the difference in the width of the pocket from home to first base side and the third to home base side. The target width across the first base side was with a tolerance of. As for the third base side, the target width was with a tolerance of. To ensure that the coaster was dimensioned correctly before acrylic insertion, we measured twice at all three notable pocket spots before inserting the acrylic.

To make sure that the acrylic insert would fit inside the pockets, for the pitcher’s mound, we measured the diameter of the pocket to ensure that the width was consistent. For the acrylic insert, we took the average width that was measured as the diameter that was used on the acrylic. As for the baseball field, between the home plate and first base, and between third base and home plate, we measured multiple times up and down the narrow pocket to see what the dimensions were, since they are not consistent between the bases. Once we found the dimensions for both stretches between the different bases, we were able to use the smallest width for each side, respectively, to create the width needed for those widths in between the bases. This ensured that when the acrylic was inserted, there was no area where it was too big and would not fit without cracking. The tables shown below show the data that was collected when measuring each area of the baseball field pocket and the pitcher's mound pocket, and as to if those measurements were accurate within the tolerance given.

Pocket Diameter Pitcher's Mound			
Coaster #	1st Measurement	2nd Measurement	Average Dimension
1	.271	.272	.2715
2	.270	.271	.2705
3	.270	.270	.270
4	.269	.270	.2695
5	.270	.271	.2705

Pocket Width Dimension Baseball Field Home to 1st Base			
Coaster #	1st Measurement	2nd Measurement	Smallest Dimension
1	.150	.151	.150
2	.149	.152	.149
3	.151	.150	.150
4	.150	.150	.150
5	.151	.150	.150

Pocket Width Dimension Baseball Field 3rd to Home Base			
Coaster #	1st Measurement	2nd Measurement	Smallest Dimension
1	.150	.150	.150
2	.151	.152	.151
3	.149	.150	.149
4	.150	.150	.150
5	.150	.151	.150

From the inspection table above, it can be seen that all the dimensions that were measured out for both the pitcher's mound pocket and baseball field pocket were within the range given for the tolerance. With each coaster being measured twice for the pitchers mound and that average being taken, and the smallest dimension being used for the baseball field pocket, there was an indication that the machining process that took place on those pockets were fairly consistent and effective providing that our coaster was of high quality and reliability in its standards.

With all the coasters having met the tolerances and specifications that were defined, we were able to confidently say that the acrylic insert would go into the pocket. When inserting the acrylic in the pitcher's mound, there would be little difficulty in securing that piece. For the baseball field, it would be a bigger task since there was a hole in the middle of the acrylic where some of the coasters would fit in. Using a rubber mallet, light tabbing starting around the bases would need to be done to ensure that the small acrylic widths went in before the larger widths, to make sure that cracking did not occur.

Through our entire inspection process, our final results show that the manufacturing and design process that we created was executed extremely well. Across all the coasters we made, the consistency was shown through our acrylic pieces fitting tightly in the pockets so that they did not crack when inserting, but also were not loose. Our process was systematically controlled the entire time, which can lead to a future ramp-up of production since we know the system is reliable. For a faster process of knowing whether the pockets are good for acrylic insertion, we can use the go no-go gauges to determine the suitability of the pitcher's mound pocket and the width of the baseball field between the 1st, 3rd, and home base.

4. PRODUCT MANUFACTURING ECONOMICS

Using the production cost equation Cp = Cm + Cmo(Tp) + (Cpt/Np) + (Cot/Nt), we can make assumptions to calculate the cost to produce one hundred thousand parts. Using the information provided in the chapter 7 Economics of Manufacturing slides, we can begin to fill in the information needed to analyze the total production expenses in the U.S.A. and Mexico.

Given the information provided in the chapter 7 slides (slide 16 table), we can see that the average machinist's hourly pay in the U.S.A. is $35.67. Additionally, we can see that the hourly wage for a machinist in Mexico is $6.36. This information shows us how drastically the production cost can change depending on where we are producing our product. The raw material cost of aluminum stock is $1/piece, and the cost per acrylic insert is $0.50/piece. At 100,000 total parts, this puts our cost of raw materials at $150,000, or a Cm of 150,000

The total time of production (Tp) for our part is 26 minutes and 16 seconds. By using the $/kWh table also provided in the slide 16 table, along with information on the HAAS VF-2 and GlowForge kW usage from their respective websites we can determine the cost of electricity to power both HAAS machines and the GlowForge for one hour to be $1.65 in Mexico and $1.98 in the U.S.A putting our total costs to operate in the U.S.A at $37.65/hr ($0.63/min) and $8.01/hr ($0.13/min) in Mexico.

Next, to calculate the perishable tooling costs, we need to figure out how many pieces can be produced per tool. Using the equation (VT^n=C), we can find out that the tool life for a 2.5" Face Mill (tool #1), we determined the lifespan to be approximately 517 parts before tool failure, and we will use this assumption for all perishable tools used. Additionally, using the prices listed on their website, we find the price of the two HAAS machines to be $119,690.50 and the Glow Forge to be $5,999.00 for a total one-time cost of $125,689.50. Furthermore, we used the provided website McMaster-Carr (not all tools are exact, but we used the closest alternatives)

Results:

Cp(U.S.A) = 150,000 +0.63(26.267) + (300/517 + 10.23/517 + 26.96/517 + 90.10/517 + 38.40/517) + 1.2569 = $150,018.71

Cp(Mexico) = 150,000 +0.13(26.267) + (300/517 + 10.23/517 + 26.96/517 + 90.10/517 + 38.40/517) + 1.2569 = $150,005.57

Now, to calculate the cost per part to manufacture, we take the $0.63 that it costs per minute to operate the equipment and pay a machinist, multiply it by twenty-six (we round down since you are not able to produce a full part in the remaining sixteen seconds) to get a cost of $16.38 to machine a single part in the U.S.A., and do the same for the $0.13 in Mexico to get a production cost of $3.38 per part.

5. CONCLUSIONS

Throughout this project, our group encountered multiple challenges that allowed us to incorporate different ideas and angles to complete our final design. One of our unique issues that arose was the inability to add acrylic to the outside edge of the outfield. Our group initially thought this would be a great idea and would add more color to the top of our part, but it was not applicable with the size dimension of the outer edge being within a 1/20". In reality, the CNC machine was able to produce such tolerances to cut, but the Glowforge program was unable to laser cut that specific dimension we would need. As a result, our group decided to take an alternate approach and simply expand the base width and pocket dimensions for easy insertion of acrylic within the infield.

Another area of struggles and lessons learned was when we first were laser cutting with the Glowforge. The width between the pocket and the bases of the acrylic would not give enough space for the Glowforge to laser, causing an error. With the help of our instructor and TA, we were able to adjust these bases and set the laser to cut around the entire pocket rather than go in between the pitcher mound and bases. For the rest of the CNC machining we did not have many issues except when trying to insert the acrylic piece, which we needed to burr with a metal ruler to shave down the sides enough for it to fit tightly.

Overall, this project allowed our group to design, manufacture, and create an NC State-themed coaster set. It also allowed us to have hands-on experience within NC State's lab using HAAS-VF2, Glowforge, and even Inkspace when we initially created our SVG files. This project highlighted the importance of making sure individuals and machinists know their CNC limitations when manufacturing a product. For the future, our group would spend more time exploring different approaches in initial designs that might better set us up for success within the Glowforge and CNC programs. Additionally, we would like to outline throughout each lab's encounters with issues the TA or professor might encounter to better prepare ourselves for future machining projects within NC State and how to develop a proper solution.

With the mass production of 100,000 units in quantity, it is important to consistently improve efficiency and machining time to produce the most parts per day, using the least amount of energy while also improving tool life. For example, if we had a simpler pocket design and insertion, that would have allowed a much quicker machining and hammering time for the few times we struggled with initial testing. Also, a better standardization throughout the production run would simplify inspection processes and also enhance our ability to produce multiple parts on a larger scale.

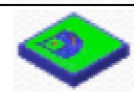
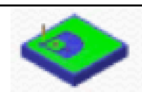
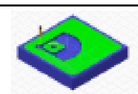
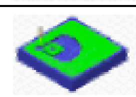
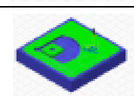
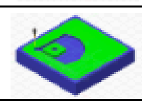
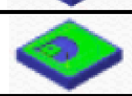
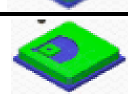
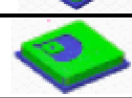
Regarding the high costs of tools and CNC machines, outsourcing the production to an established factory would help reduce initial investment costs when starting a large-scale production. Also, it is worth considering production in Mexico, as their labor costs and materials are much cheaper to purchase. If that is the case, it is important to note the import/transportation costs when your mass production is being outsourced to a different factory. Overall, we each greatly enjoyed working with one another and attending the consistent lab sessions for proper instruction and analysis of what a typical mass production machinist might encounter.

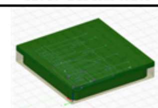
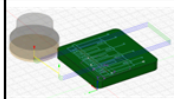
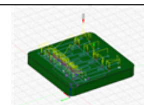
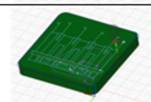
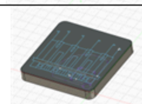
APPENDIX A - Tool Life and Tool Costs

Tool Used	Tool Life	Tool Cost
2.5" Face Mill (VF-2 #2) (Tool 1)	13604.89 min	~$300
1/2" Bullnose Endmill (Tool 2)	44.19168 min	$90.10
1/8" TiCN Endmill (Tool 4)	11313.07 min	$10.23
3/8" Chamfer Mill (Tool 5)	139.6675 min	$38.40
1/16" Engraving Mill (Tool 10)	186919.17 min	$26.96

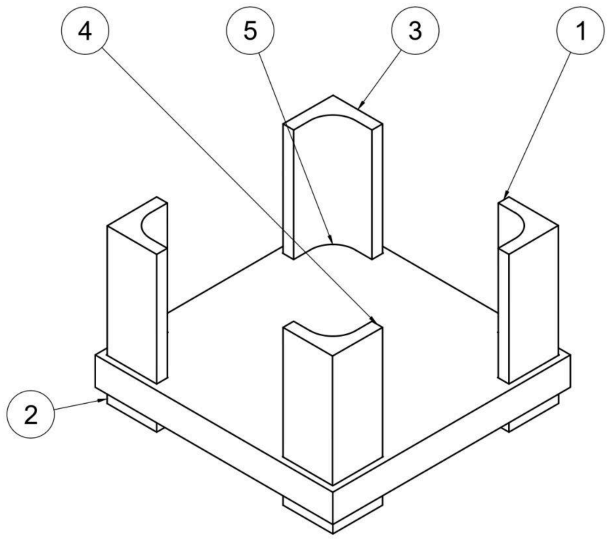
(All tool prices were taken from McMaster-Carr and are listed in the references. Exact tools were not found for all tools, but very close alternatives were used instead.)

APPENDIX B - Process Plan

		PROCESS PLAN		NCSU-ISE INC.				
	Part #:							
	Part Name:	Coaster Top		Material:				
	Prepared by:	Group 6	Date: 4/14/25	Revision #:	1.0			
	Approved by:		Date:	Revision Date:	3/1/21			
OP. #	OPERATION DESCRIPTION	WORKSTATION/MACHINE	SETUP DESCRIPTION	TOOL	SPEED	FEED	DEPTH OF CUT	OP. TIME
10	Load and clamp blank into the vice or fixture	CNC Machine 1		N/a	N/a	N/a	N/a	0.5 min
20	Face Mill top .02 inches deep in 1 passes	CNC Machine 1		1	3000 Ft/min	4.583 ft/min	0.02 in	.283 min
30	2D Pocket Roughing .1 inches deep, 2 passes	CNC Machine 1		4	262 ft/min	30 in/min	0.100 in	3.26 min
40	2D Pocket Finishing .005 inches deep, 1 pass	CNC Machine 1		4	262 ft/min	30 in/min	0.005 in	3.1 min
50	2D Contour max roughing stepdown .07, 2 passes	CNC Machine 1		4	262 ft/min	18 in/min	0.1 in	1.37 min
60	2D Contour max finishing stepdown .07, 2 passes	CNC Machine 1		4	262 ft/min	18 in/min	0.1 in	.45 min
70	Trace NC State logo using 1/16" Engraving 1 pass	CNC Machine 1		10	130 ft/min	25 in/min	0.001 in	2.283 min
80	Trace NC State Wolfpack Words using 1/16" Engraving 1 pass	CNC Machine 1		10	130 ft/min	25 in/min	0.001 in	.47 min
90	Trace outside field edge using 1/16" Engraving 1 pass	CNC Machine 1		10	130 ft/min	25 in/min	0.001 in	1.13 min
100	2D Contour max stepdown .1, 5 passes	CNC Machine 1		2	1047.2 ft/min	84 in/min	.1 in	1.00 min
110	2D Chamfer top edge of part width .05 inches, 1 pass	CNC Machine 1		5	785.3 ft/min	24 in/min	0.025 in	.62 min
120	Unload and Visually inspect finished work piece	CNC Machine 1		N/a	N/a	N/a	N/a	0.5 min

			PROCESS PLAN			NCSU-ISE INC.			
	Part #:								
	Part Name:					Material:			
	Prepared by:		Date:			Revision #:	1.0		
	Approved by:		Date:			Revision Date:	3/1/2021		
OP. #	OPERATION DESCRIPTION	WORKSTATION/MACHINE	SETUP DESCRIPTION	TOOL	SPEED	FEED	DEPTH OF CUT	OP. TIME	
10	Take the part out of the clamp and flip it over to back side, load clamp part into CNC Machine 2	CNC Machine 2		N/a	N/a	N/a	N/a	N/a	
20	Face the bottom 0.1'' in 3 passes	CNC Machine 2		1	3000 ft/min	4.583 ft/min	0.1''	0.867 min	
30	Trace Reynolds Colosseum onto the back of the part at .001 depth	CNC Machine 2		10	130.9 ft/min	8.00 ft/min	0.001''	8.82 min	
40	Chamfer bottom edge 0.025''	CNC Machine 2		5	785.398 ft/min	8.00 ft/min	0.025''	0.633 min	
50	Unload part for inspection	CNC Machine 2		N/a	N/a	N/a	N/a	N/a	

Appendix C - Engineering Drawings

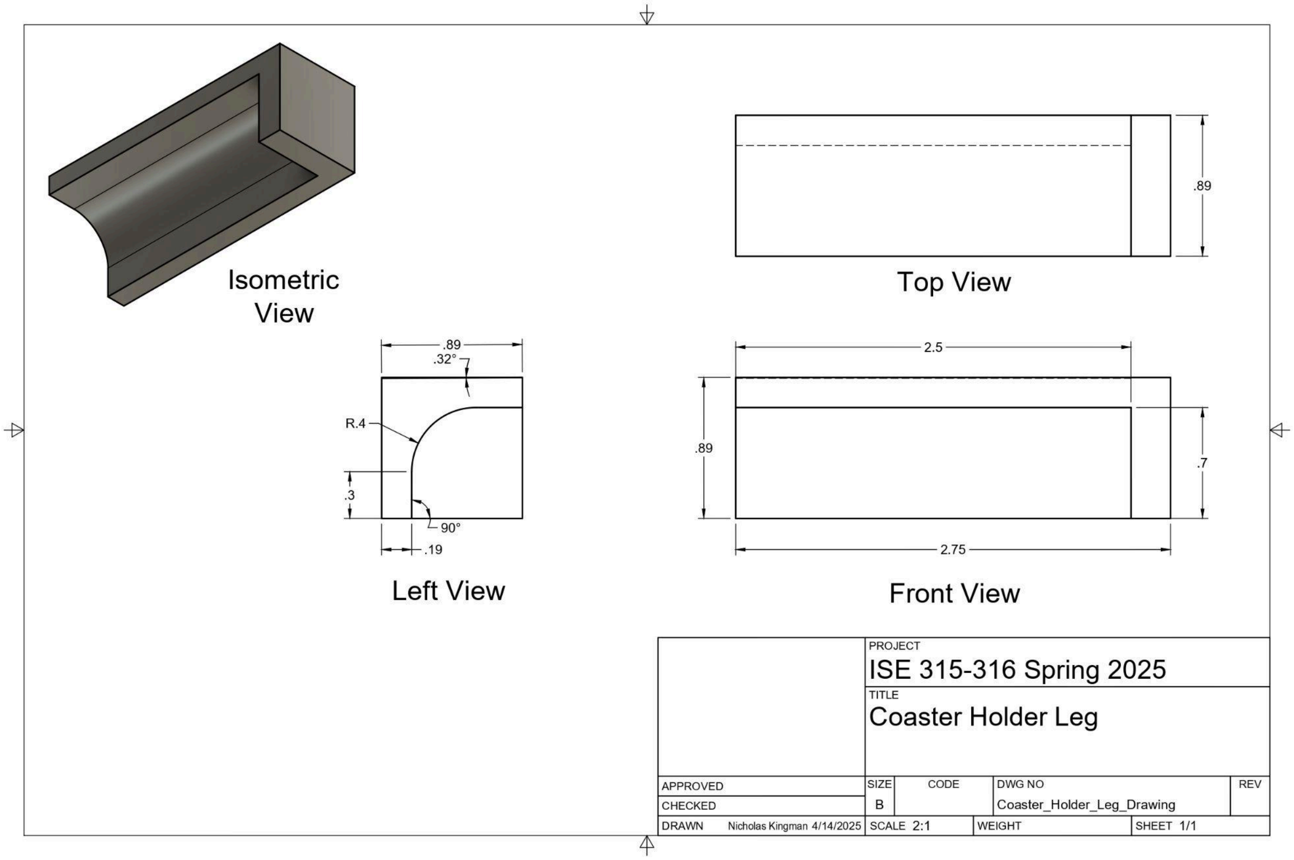


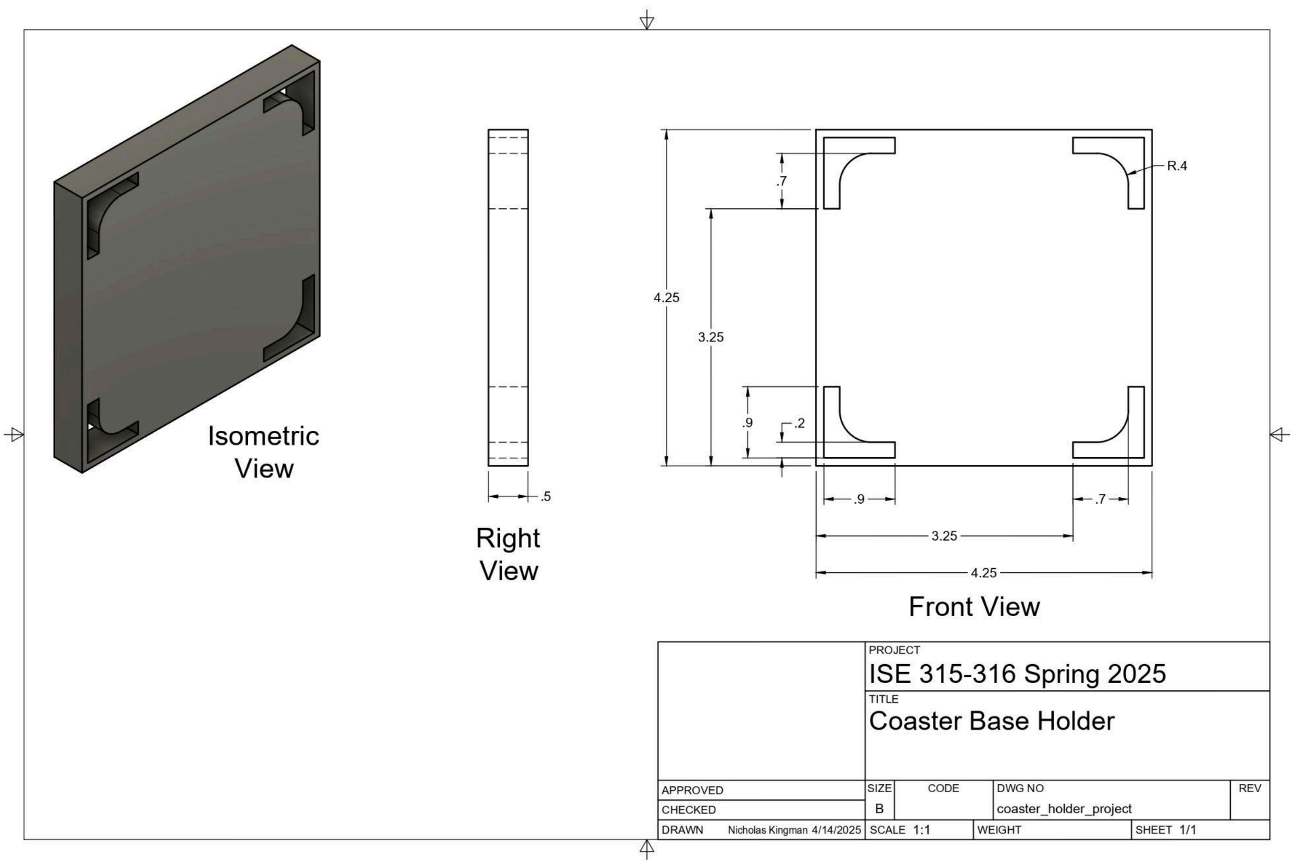
Isometric View

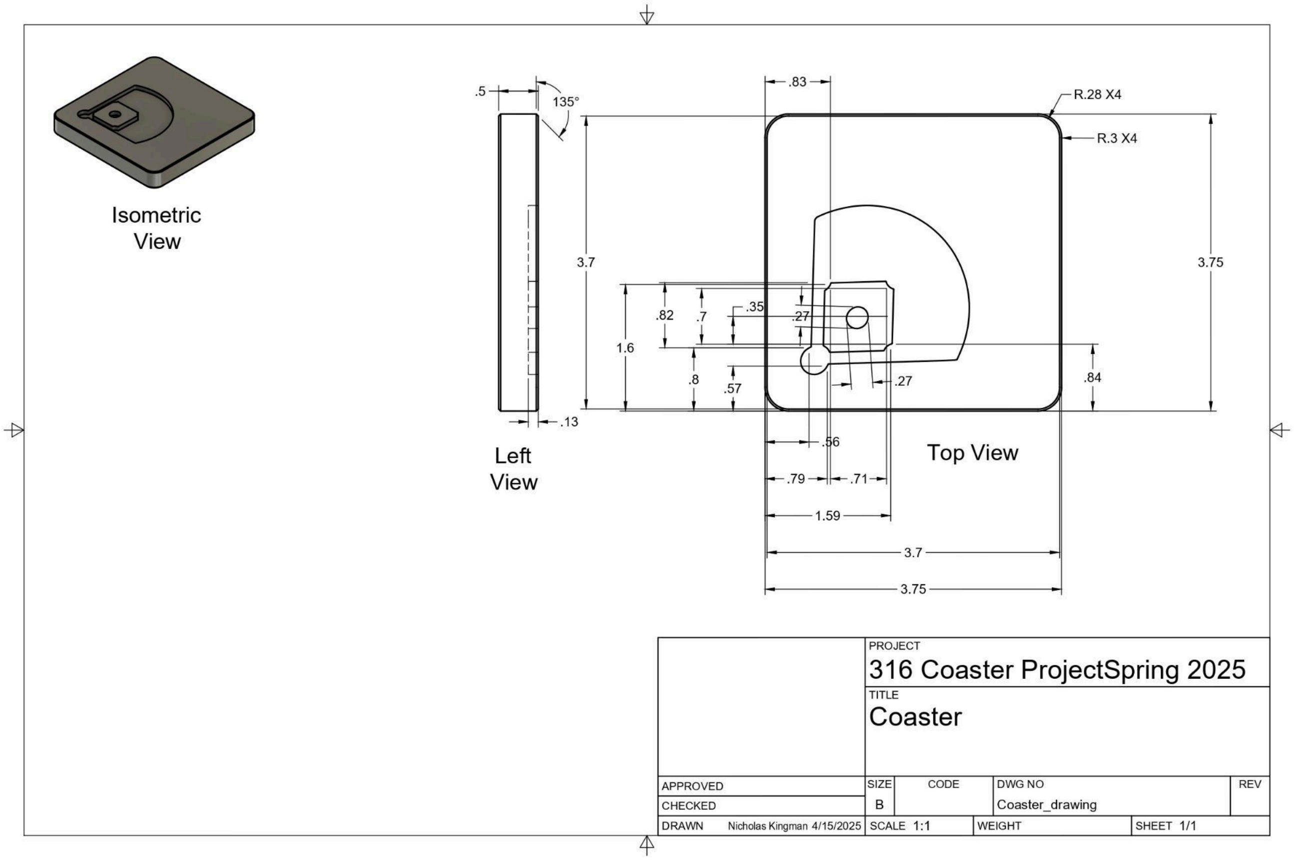
PARTS LIST

ITEM	QTY	PART NUMBER
1	1	COASTER HOLDER LEG 1
2	1	COASTER HOLDER LEG 2
3	1	COASTER HOLDER LEG 3
4	1	COASTER HOLDER LEG 4
5	1	COASTER HOLDER

	PROJECT ISE 316 Spring 2025		
	TITLE Coaster Holder Assembly		
APPROVED	SIZE B	CODE	DWG NO Assembly_Coaster_Project / REV
CHECKED			
DRAWN Nicholas Kingman 4/14/2025	SCALE 1:1	WEIGHT	SHEET 1/7


Isometric View
Top View
.89
2.5
.89
.32°
R.4
.3
90°
.19
.89
.7
2.75
Left View
Front View
PROJECT
ISE 315-316 Spring 2025
TITLE
Coaster Holder Leg
APPROVED
CHECKED
DRAWN Nicholas Kingman 4/14/2025
SIZE B
CODE
DWG NO Coaster_Holder_Leg_Drawing
REV
SCALE 2:1
WEIGHT
SHEET 1/1


Isometric View
Right View
.5
.7
R.4
4.25
3.25
.9
.2
.9
.7
3.25
4.25
Front View
PROJECT
ISE 315-316 Spring 2025
TITLE
Coaster Base Holder
APPROVED
CHECKED
DRAWN Nicholas Kingman 4/14/2025
SIZE B
CODE
DWG NO coaster_holder_project
REV
SCALE 1:1
WEIGHT
SHEET 1/1


Isometric View
Left View
Top View
.5
135°
.13
3.7
.83
R.28 X4
R.3 X4
3.75
.82
.7
.35
.27
1.6
.8
.57
.27
.84
.56
.79
.71
1.59
3.7
3.75
PROJECT
316 Coaster ProjectSpring 2025
TITLE
Coaster
APPROVED
CHECKED
DRAWN Nicholas Kingman 4/15/2025
SIZE B
CODE
DWG NO Coaster_drawing
REV
SCALE 1:1
WEIGHT
SHEET 1/1

Appendix D - Product Inspection Plan and Data

Pitchers Mound Pocket

MMC = .266

UL = .0004

LL = 0.0

X-Go =.266 +0.004

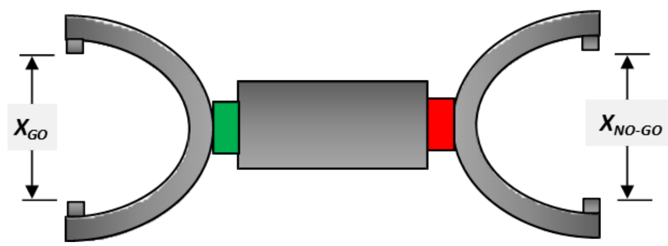
LMC = .274

UL = 0.0

LL = .0004

X-No-Go =.274 -0.004

Pocket Inbetween 1st, 3rd and Home Base



MMC = .146

UL = .0004

LL = 0.0

X-Go =.146 +0.004

LMC = .154

UL = 0.0

LL = .0004

X-No-Go =.154 -0.004

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“Glowforge Pro 3D Laser Printer.” MatterHackers, www.matterhackers.com/store/l/glowforge-pro-3d-laser-printer/sk/MT13CGMV?rcode=PMAX_GENPOPLASERS&gad_source=1&gclid=CjwKCAiA9bq6BhAKEiwAH6bqoMpj1lWIk7y4gVwD1PtzcDhG5Hr8Dd-g5UcM9fOxo4fpJ4p2bs2nRhoCOkYQAvD_BwE. Accessed 30 Nov. 2024.