Design Challenge 1 – Minimum Feature Size & Self-Supporting Angles

Initial Benchmark Design

For my design I choose to test Minimum Feature Size and Self-Supporting Angles. The independent and dependent variables cam be seen in Table 1 on the right. As for my failing criteria I choose. The CAD model designed for Minimum Feature Size and Self-Supporting Angles can be seen in Figure 1 and Figure 2 respectively.

	Minimum Feature Size	Self-Supporting Angles
Independent Variables	Geometry (Square & Circles)	Thickness (1mm & 2mm)
Dependent Variables	Print Speed (40mm/s & 60 mm/s)	Print Speed (40mm/s & 60 mm/s)

Table 1: Selection of Independent and Dependant Variables for Minimum Feature Size And Self-Supporting Angles

Square (Side-Length)	Circle (Diameter
3	0.35
2.5	0.5
2	0.75
1.5	1
1	1.5
0.75	2
0.5	2.5
0.35	3

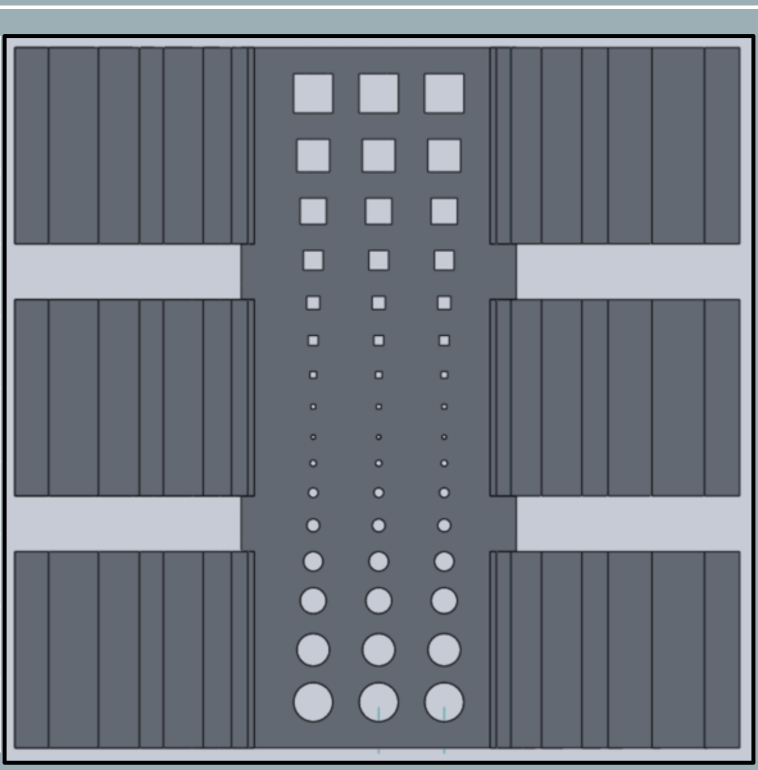


Figure 1: Top View of Test Specimen showing varying Square and Box Sizes
Table 2: Recorded variances of Square side-length and Circle diameter in the order it in seen in Figure 1 (Top to Bottom)

Design Criteria (Minimum Feature Size)

To test the restrictions related to Minimum Feature Size in the XY plane, the size of the square's side-length and the circles diameter was varied. This was repeated 3 times within the same part to avoid multiple prints. This variation is can be seen in Figure 1 on the left and is recorded in Table 2 on the left in the order it is seen (Top to Bottom). Lastly, the criteria for failure of Minimum Feature Size of the printed Holes and Squares will be a deviation greater than 0.5mm of the diameter and side-length respectively

Design Criteria (Self-Supporting Angles)

To test the restrictions related to Self-Supporting Angles, a curved beam was sketched using straight lines at progressively varying angles. For this design, the thickness of the curved beam was varied from 1mm (left) to 2mm (right), seen in figure 2, to analyze its combined effect with print speed. Moreover, this was repeated 3 times along the edges of the specimen to avoid multiple prints. Lastly, the criteria for failure of printed Self-Supporting Angles will be a deviation greater than 0.5mm in the thickness of the beam. This method is used to determine overhang.

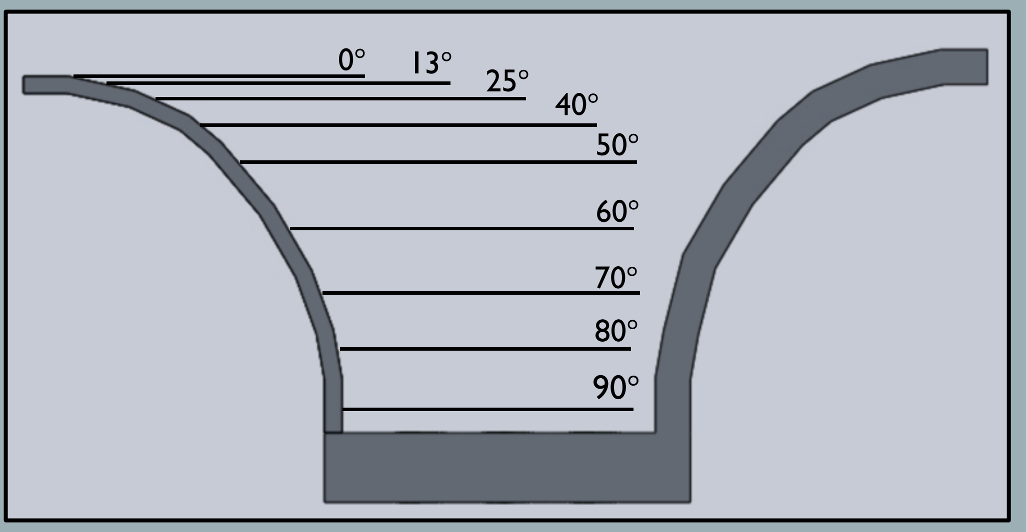


Figure 2: Side View of Test Specimen showing varying Self-Supporting Angles at different thicknesses, 1mm (left) and 2mm (right)

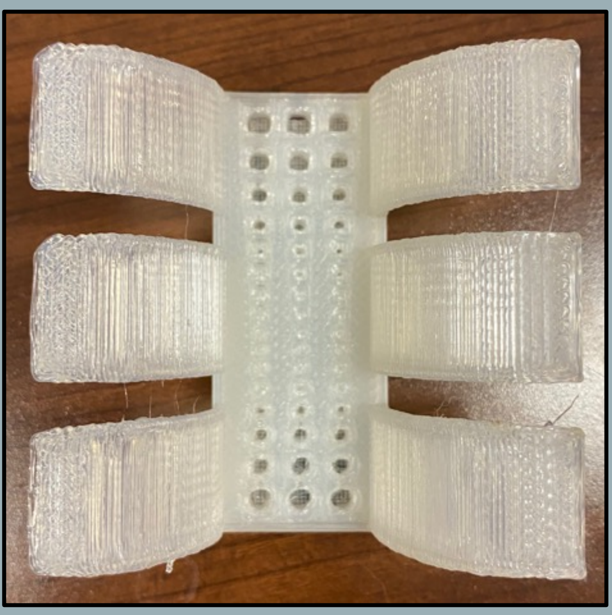
Experimental Parameters

Printer	LulzBot TAZ 6 (Single Extruder)
Material	PLA (Verbatim)
Profile	Standard (0.250mm)
Temperature	205 °C
Print Speed	40 mm/s & 60 mm/s
# of Specimens	One @ 40 mm/s & One @ 60 mm/s
Print Time	01h 14min (40 mm/s) & 01h 07min (60 mm/s)
Material	15g / Specimen

Accurate/Failure Printed Feature Sizes & Angles

Print Speed	Circle Diameter	Square Side-Length	Overhang Angle (1mm)	Overhang Angle (2mm)
40 mm/s	1.5 mm	1 mm	50°	40°
60 mm/s	1.5 mm	1 mm	60°	50°
40 mm/s FAILURE	1 mm	0.75 mm	40°	25°
60 mm/s FAILURE	1 mm	0.75 mm	50°	40°

Table 3: Most accurate and failure feature sizes for varying geometries & angles for self-support (above)
Table 4: Summary of experimental parameters taken into consideration (left)



Analysis of Minimum Feature Size

A set of Vernier Calipers using the minimum feature size tool were used to measure the diameters and side-lengths of the circles and squares respectively. To obtain the most accurate results, the average of 3 readings were taken for each feature size. Next, the failure values were inputted into Minitab 18 for an ANOVA analysis of the data using Print Speed and Geometry. The results seen in table 5 indicate P-Values > 5% (0.05) which means that our null-hypothesis is taken into consideration. This means that Print Speed and Geometry have no effect on the minimum feature size in our experiment. However, it was noticed that our apparatus used was capable of printing square features more accurately than circles. I believe these results were achieved since the difference in print speeds was not nig enough.

Figure 3: Sample of the test specimen at 60 mm/s indicating minimum feature size restrictions

Analysis of Self-Supporting Angles

A set of Vernier Calipers were used to measure the thickness of the different thickness beams printed at the two print speed (40mm/s and 60mm/s). To obtain the most accurate results, the average of 3 readings were taken for each thickness and print speed. Next, the failure values were inputted into Minitab 18 for an ANOVA analysis of the data using Thickness and Print Speed. The results seen in table 5 indicate P-Values < 5% (0.05) which means our null-hypothesis is rejected and both print speed and thickness had a significant effect on self-supporting angles in our experiment. It was noticed that as the print speed got faster, the printers capability to print accurate self-supporting angles without overhang got worse. Moreover, as the thickness of the curved beam increased, the ability of the printer to print self-supporting angles without overhang got better. These results make sense, since as print speed increases, the filament has less time to cool down; hence, more overhang will be noticed. Moreover, as the thickness increases, the printer will have a larger surface area to deposit the filament making it less likely to notice overhang at smaller angles.

Source	P-Value	Significance
Geometry	0.166	Insignificant
Print Speed	0.113	Insignificant
Geometry + Print Speed	0.240	Insignificant
Thickness	0.000	Significant
Print Speed	0.000	Significant
Thickness + Print Speed	0.003	Significant

Table 5: ANOVA analysis of data using Minitab 18

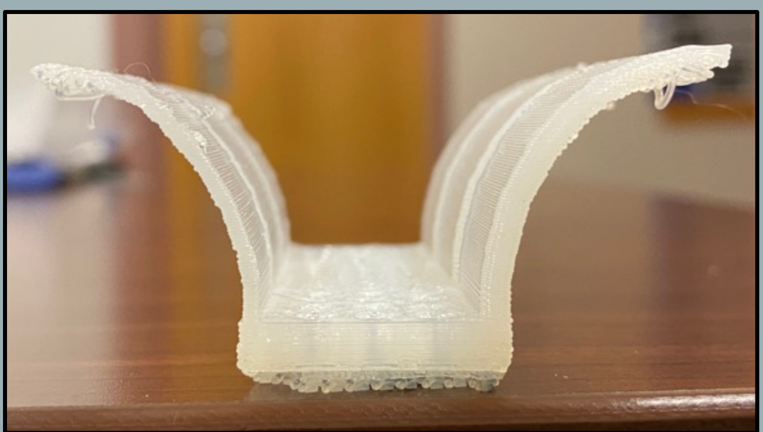


Figure 5: Sample of test specimen printed at 60 mm/s indicating self-supporting angle restrictions