

# DESIGN FOR ADDITIVE MANUFACTURING

## Restrictive DfAM Benchmark Artifact

### DESCRIPTION & HYPOTHESIS

The two design elements of restrictive DFAM being evaluated as shown in Figure 1 are **minimum feature size** and **minimum assembly clearance**.

The assumptions being tested out in this experiment are due to the following:

1. High print speed could cause material not to have enough time to fully adhere to the previous layer, leading to under extrusion, poor bonding and gaps that could affect the final part. A relatively lower/normal print speed allows for a more precise deposition, improving the accuracy of intricate features like small holes due to more heat being retained per layer.

2. Many real-world assemblies involve cylindrical fits like pins and holes, hence testing these features would help understand how clearances behave in rotational fits, sliding fits or press fits. It also helps in knowing what best tolerances to give based on what. Different shapes also interact with different layered printing as some shapes are more prone to thermal deformation or anisotropic shrinkage. Circles tend to print slightly elliptical due to material expansion, making clearance testing essential. Other shapes like squares test sharp edge retention and feature accuracy in AM processes.



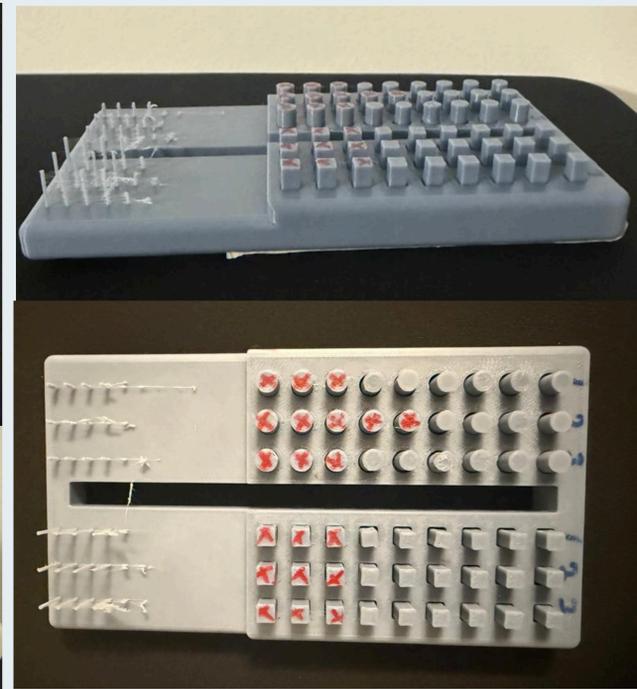
### DESIGN

To test minimum feature size, pins of varying diameter ranging from 0.2mm – 1.1mm were used. The DfAM independent variables selected were print speed set to a standard 100% and fast 400% and for feature height, a height of 5mm and one for 10mm.

For testing assembly clearance, the independent variables selected were print speed set to a standard 100% and fast 400% and geometric shapes namely: square and circle pins with sides and diameter ranging from 5.1mm – 5.9mm respectively with same hole size of 6mm for all pins.

For this benchmark test, the pass/fail criteria for minimum feature size was to measure the height of the pins if they crossed a threshold value of >80% of the required value i.e.  $\geq 4\text{mm}$  for the 5mm expected height and  $\geq 8\text{mm}$  for the 10mm expected height. This is mainly because of the lack of precision measuring tools like digital calipers. Using a ruler could help give measurements close enough to draw our needed conclusions on the experiment.

For minimum assembly clearance, the pass/fail criteria was to put a standard weight on the pins to see if they fell out of the holes or not.



### Minimum Assembly Clearance

Feature Shape

Print Speed	Circle	Square
	Fast	Fast
Slow	Circle	Square
	Slow	Slow

### Minimum Feature Size

Feature Height

Print Speed	Tall	Short
	Fast	Fast
Slow	Tall	Short
	Slow	Slow

Each of the combinations for both variables was printed three times in one part to cover possible inefficiencies that could have arose from the print process. They were tested at two levels, a low and a high with a full factorial combination mainly with the intent of figuring out the effect of the combination of each different factor. It printed two different specimens one for each print speed, with each consuming 75g of filament and 4hrs of print time.

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### EXPERIMENTATION

For this experiment, it was expected that the print speed and varying geometries could affect the smallest allowable gap between mating parts in an assembly which could be aimed at ensuing proper fit, function, and/or manufacturability.

It was also expected that varying print speed and feature heights could also affect the smallest dimension or detail that could be reliably printed or manufactured using DfAM techniques, in this case, PLA 3D printing.

Also it was expected that minimum feature sizes from 0.2 and 0.3mm will clearly fail since the nozzle size was 0.4mm. However, the intent was to find out how the printer attempts to print that.

For minimum assembly clearance it was also expected that tolerance values less than 5.3 will also fail.

Minimum Feature Size						
5mm feature height, 100% Print Speed				10 mm feature height, 100% Print Speed		
Pin size (mm)	Pass/Fail Criteria			Pin size (mm)	Pass/Fail Criteria	
1.1	Pass	Pass	Pass	1.1	Pass	Pass
1	Pass	Pass	Pass	1	Pass	Pass
0.9	Pass	Fail	Pass	0.9	Pass	Pass
0.8	Pass	Fail	Pass	0.8	Pass	Pass
0.7	Fail	Fail	Fail	0.7	Fail	Fail
0.6	Fail	Fail	Fail	0.6	Fail	Fail
0.5	Fail	Fail	Fail	0.5	Fail	Fail
0.4	Fail	Fail	Fail	0.4	Fail	Fail
0.3	Fail	Fail	Fail	0.3	Fail	Fail
0.2	Fail	Fail	Fail	0.2	Fail	Fail

Minimum Feature Size						
5mm feature height, 400% Print Speed				10 mm feature height, 400% Print Speed		
Pin size (mm)	Pass/Fail Criteria			Pin size (mm)	Pass/Fail Criteria	
1.1	Pass	Fail	Pass	1.1	Pass	Pass
1	Pass	Pass	Pass	1	Pass	Pass
0.9	Pass	Fail	Pass	0.9	Pass	Pass
0.8	Pass	Pass	Pass	0.8	Pass	Pass
0.7	Fail	Fail	Fail	0.7	Fail	Fail
0.6	Fail	Fail	Fail	0.6	Fail	Fail
0.5	Fail	Fail	Fail	0.5	Fail	Fail
0.4	Fail	Fail	Fail	0.4	Fail	Fail
0.3	Fail	Fail	Fail	0.3	Fail	Fail
0.2	Fail	Fail	Fail	0.2	Fail	Fail

Minimum Assembly Clearance						
Feature shape - Square, 100% Print Speed				Feature shape - Circle, 100% Print Speed		
Peg size (mm)	Pass/Fail Criteria			Peg size (mm)	Pass/Fail Criteria	
5.9	Pass	Pass	Pass	5.9	Pass	Pass
5.8	Pass	Pass	Pass	5.8	Pass	Pass
5.7	Pass	Pass	Pass	5.7	Pass	Pass
5.6	Fail	Fail	Fail	5.6	Fail	Fail
5.5	Fail	Fail	Fail	5.5	Fail	Fail
5.4	Fail	Fail	Fail	5.4	Fail	Fail
5.3	Fail	Fail	Fail	5.3	Fail	Fail
5.2	Fail	Fail	Fail	5.2	Fail	Fail
5.1	Fail	Fail	Fail	5.1	Fail	Fail

*NB: Constant hole size*

Minimum Assembly Clearance						
Feature shape - Square, 400% Print Speed				Feature shape - Circle, 400% Print Speed		
Peg size (mm)	Pass/Fail Criteria			Peg size (mm)	Pass/Fail Criteria	
5.9	Pass	Pass	Pass	5.9	Pass	Pass
5.8	Pass	Pass	Pass	5.8	Pass	Pass
5.7	Pass	Pass	Pass	5.7	Pass	Pass
5.6	Fail	Fail	Fail	5.6	Fail	Fail
5.5	Fail	Fail	Fail	5.5	Fail	Fail
5.4	Fail	Fail	Fail	5.4	Fail	Fail
5.3	Fail	Fail	Fail	5.3	Fail	Fail
5.2	Fail	Fail	Fail	5.2	Fail	Fail
5.1	Fail	Fail	Fail	5.1	Fail	Fail

*NB: Constant hole size*

### RESULTS

#### Minimum Assembly Clearance

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Sample (Print Speed)	0.013333	1	0.013333	3.2	0.111434	5.317655072
Columns (Shapes)	0	1	0	0	1	5.317655072
Interaction	0.013333	1	0.013333	3.2	0.111434	5.317655072
Within	0.033333	8	0.004167			
Total	0.06	11				

Based on the ANOVA table for minimum assembly clearance, the following deduction can be made. There is no statistically significant difference between the varying print speeds nor varying different shapes nor their interactions as the P-Values are all greater than .05

#### Minimum Feature Size

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Sample	0	1	0	0	1	5.317655072
Columns	0.013333333	1	0.01333	2	0.19502	5.317655072
Interaction	6.93889E-18	1	6.9E-18	1.04E-15	1	5.317655072
Within	0.053333333	8	0.00667			
Total	0.066666667	11				

Based on the ANOVA table for minimum feature size, the following deductions can be made. For minimum feature size, there is no statistically significant difference between the varying print speeds nor varying heights of features nor their interactions as the P-Values are all greater than .05

### CONCLUSION

From the experiment conducted, the results could have been so because the different feature lengths still lie in the sweet region of the printer, hence, not enough to cause any significant changes in the features printed. Also, the printer speed which was increased from 100% – 400% might also not be significant enough to impact the print. To further establish the findings from the experiment, other print speeds could be experimented to see point of failures.