White paper

HP 3D High Reusability PA 12 W for the HP Jet Fusion 5420W 3D Printing Solution

Dimensional capability

Data Courtesy of Ed Lighting

Introduction

At HP, we are committed to providing part designers and part manufacturers with the technical information and resources needed to enable them to unlock the full potential of 3D printing and prepare them for the future era of digital manufacturing.

The aim of this white paper is to provide you with information on the dimensional capabilities that can be achieved with the HP Jet Fusion 5420W 3D Printing Solution with HP 3D High Reusability (HR)[1] PA 12 W.

In this white paper, you will find:

- Tolerances in XY and Z for nominal dimensions ranging from 0 mm to 80 mm that can be achieved with the HP Jet Fusion 5420W 3D Printing Solution, according to a process capability index
- A detailed explanation of the test conditions under which these values were obtained
- Additional information on the concept of process capability and dimensional tolerancing, and a glossary of key terms used

Data Courtesy of Castomade

Dimensional profiles

The HP Jet Fusion 5420W 3D Printing Solution has an in-printer feature that provides the capability to apply dimensional profiles. This feature helps streamline the workflow and provide an enhanced experience while helping achieve manufacturing-level accuracy and repeatability.

The HP Jet Fusion 3D Printing process involves selectively melting plastic powder. Once melted, the material cools down until it solidifies, changing its internal structure. During solidification, the melted volume suffers from shrinkage. Dimensional profiles are used to compensate the variation of this effect along the printing volume, automatically applying geometrical transformations to each part being printed.

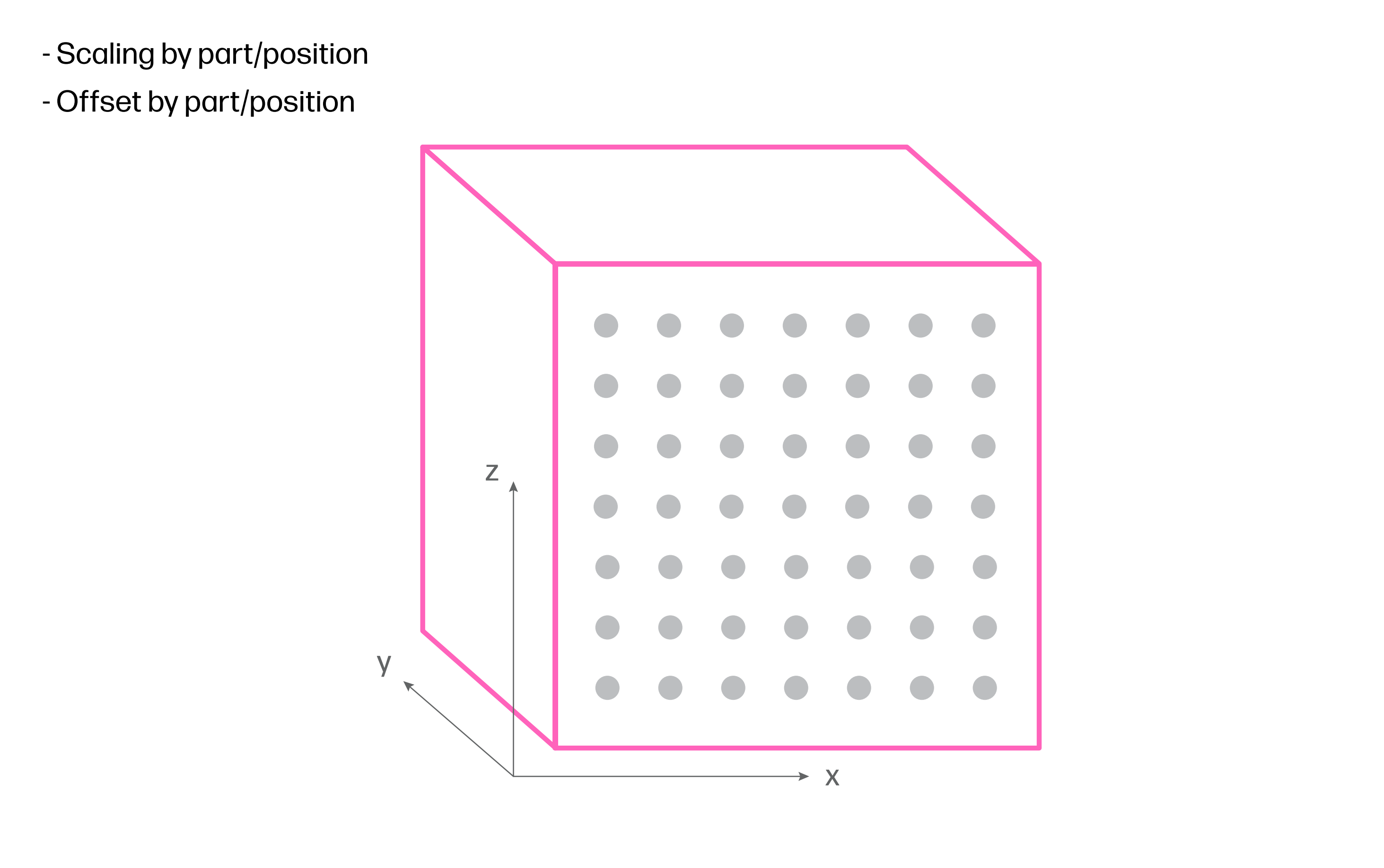


Figure 1. Representation of conceptually geometrical transformations

Geometrical transformations are applied independently in each axis, ensuring optimal results for every part orientation. For example, non-uniform scaling is used to compensate for shrinkage during the solidification process. In addition to the volumetric compensations, dimensional profiles can act on the surface of the parts with axis-dependent 3D morphology.

By default, the HP Jet Fusion 5420W 3D Printing Solution comes with general dimensional profiles. General profiles are a unique type of dimensional profile that optimize part geometry based on the average behavior of a wide-sample population of HP Jet Fusion 3D printers. Each print profile is associated to a general dimensional profile.

Figure 2 illustrates the geometries and jobs used to build the mathematical models.

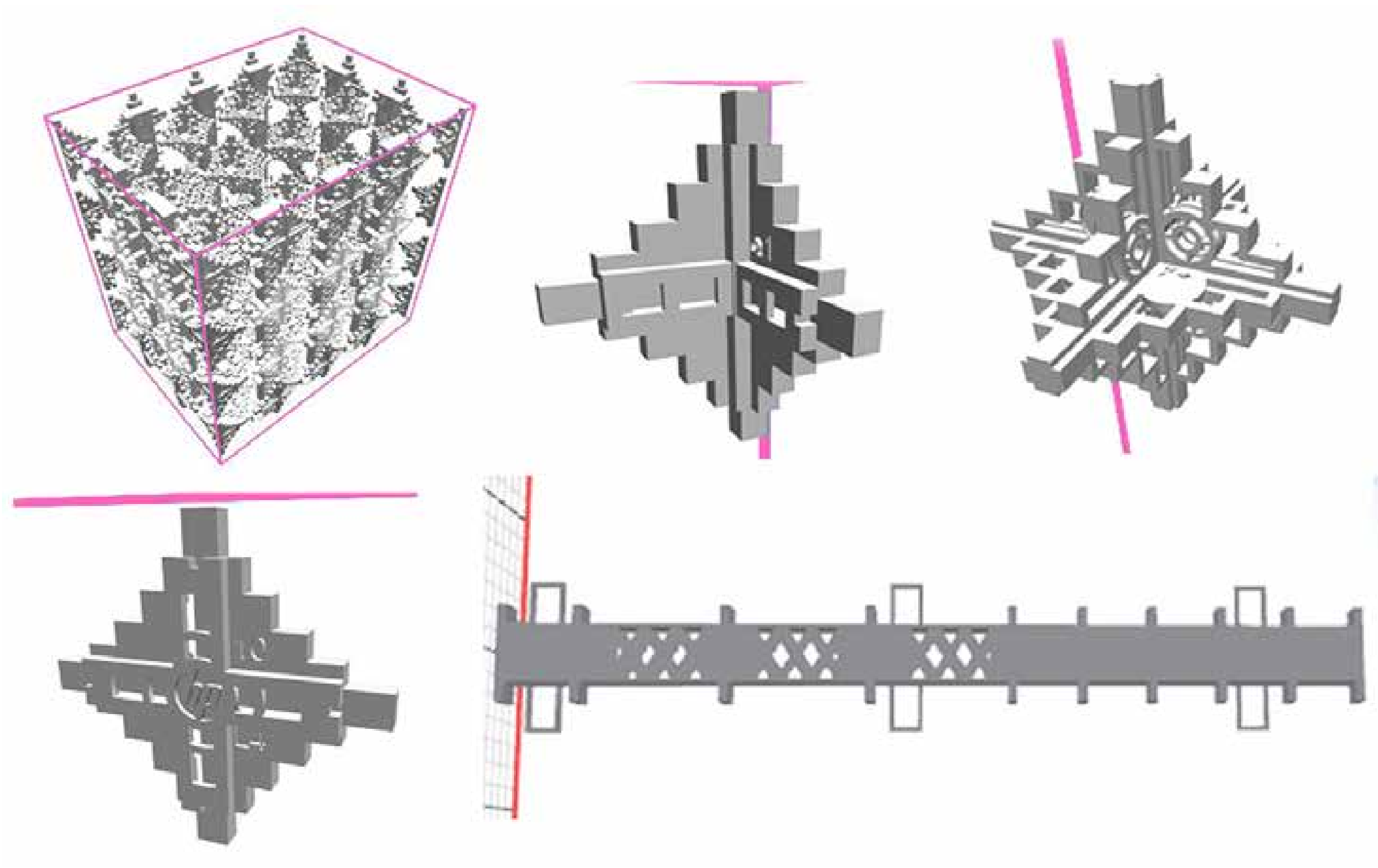


Figure 2. Part geometries & job configurations used in the calibration of dimensional profiles

Each of these parts has different critical dimensions that are measured in each print. For example, some of the critical dimensions collected for a specific part included in one of the jobs are shown in Figure 3.

	Name	Nominal/mm
1	Height-1	8
2	Height-2	18
3	Height-3	30
4	Height-4	45
5	Height-5	60
6	Height-6	80

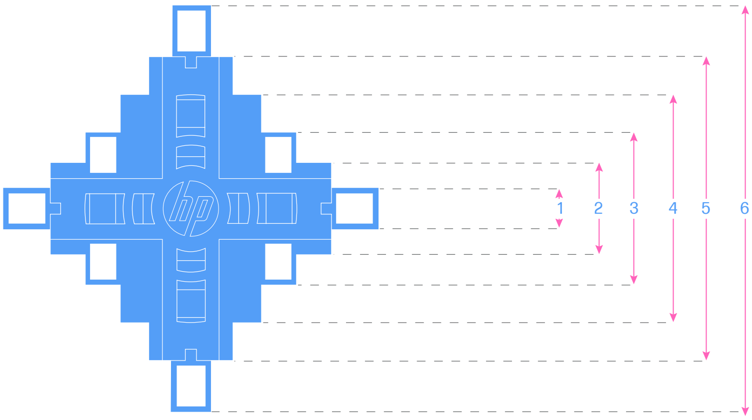


Figure 3. Diagnostic part critical dimensions

To generate the general dimensional profile, the machine-learning model produces the correction, based on the average of all the printers that provide data. For the hardware-specific dimensional profile, the data collected from the specific device are compared with the data from the overall population, and the correction is generated, based on the average measurement from printers with a similar configuration.

Table 1 shows the statistics of the overall data used by the machine learning process to improve the profile generation.

	All data collected
Critical dimensions	8,000
Printers	4
Jobs printed	8

Table 1. Data collected to generate profiles

HP Jet Fusion 5420W 3D Printing Solution dimensional capability performance

Test job

The dimensional capability performance of the HP Jet Fusion 5420W 3D Printing Solution with HP 3D HR PA 12 W was characterized using the HP dimensional capability characterization job (Figure 4), which contained 122 diagnostic parts distributed throughout the printable volume. The job included three different types of diagnostic parts and a total of 1,524 dimensions.

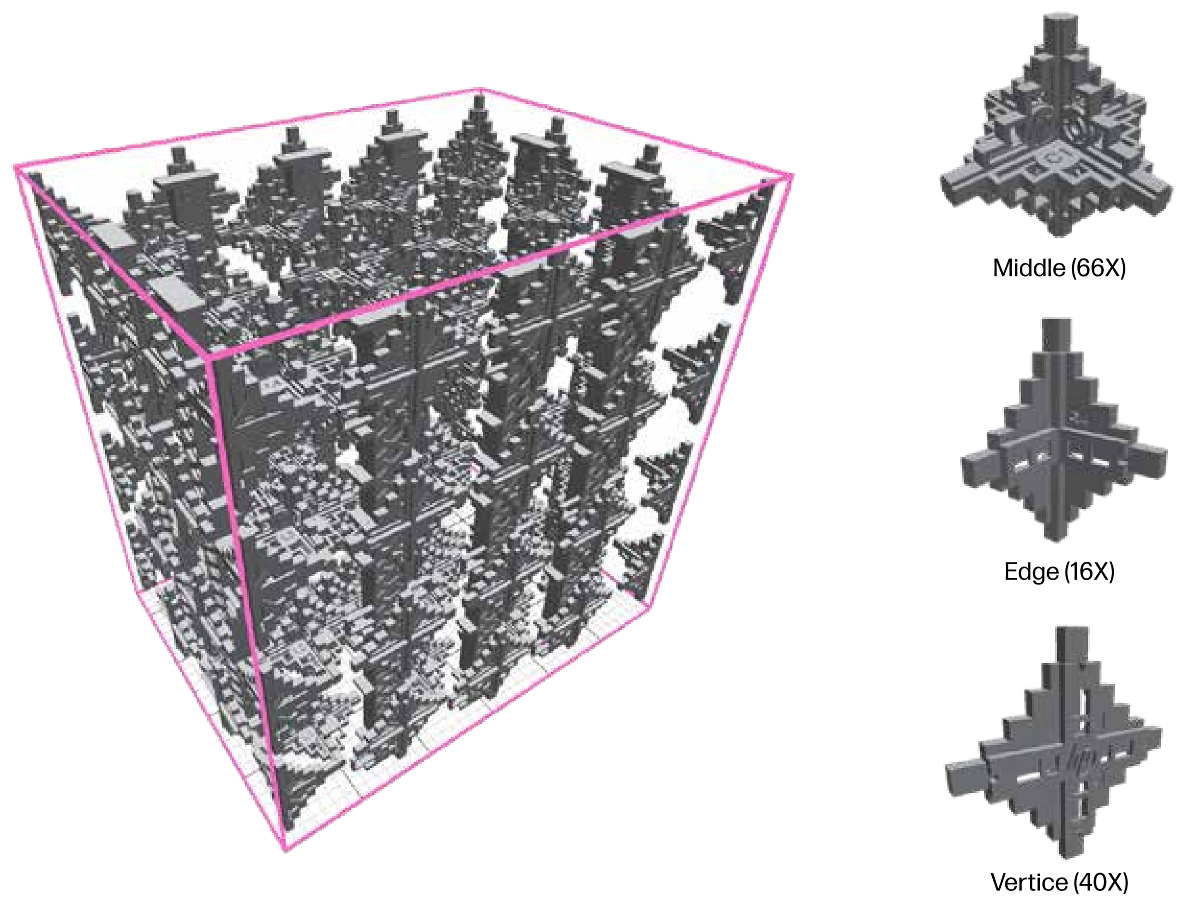


Figure 4. HP dimensional capability characterization job

Performance results for HP 3D HR PA 12 W (Balanced print mode)

Testing was performed for HP 3D HR PA 12 W with a 25% refresh ratio using the Balanced print profile, natural cooling, and measured after bead-blasting with glass beads at 5-6 bars.

Table 2 shows the dimensional tolerances obtained during the characterization for a target process capability[2] of C_{pk} = 1.33 (4 sigma)*.

Tolerances for C_{pk} = 1.33[1, 2, 3] (in mm)	Nominal dimension					
	0 - 30 mm		30 - 50 mm		50 - 80 mm	
	XY	Z	XY	Z	XY	Z
With the general dimensional profile for the HP Jet Fusion 5420W 3D Printing Solution	±0.20	±0.42	±0.25	±0.50	±0.30	±0.67

1. Based on internal testing and measured using the HP dimensional capability characterization job. Results may vary with other jobs and geometries.
2. Using HP 3D HR PA 12 W material, 25% refresh ratio, Balanced W print profile, natural cooling, and measured after bead-blasting with glass beads at 5-6 bars.
3. Following all HP-recommended printer setup and adjustment processes and printheads aligned using semi-automatic procedure.

Table 2. Dimensional capabilities for HP 3D HR PA 12 W. Target process capability of C_{pk} = 1.33*.

Table 3 shows the dimensional tolerances if the process capability target is set to C_{pk} = 1.00 (3 sigma)*.

Tolerances for C_{pk} = 1.00[1, 2, 3] (in mm)	Nominal dimension					
	0 - 30 mm		30 - 50 mm		50 - 80 mm	
	XY	Z	XY	Z	XY	Z
With the general dimensional profile for the HP Jet Fusion 5420W 3D Printing Solution	±0.18	±0.34	±0.20	±0.40	±0.26	± 0.52

1. Based on internal testing and measured using the HP dimensional capability characterization job. Results may vary with other jobs and geometries.
2. Using HP 3D HR PA 12 W material, 25% refresh ratio, Balanced W print profile, natural cooling, and measured after bead-blasting with glass beads at 5-6 bars..
3. Following all HP-recommended printer setup and adjustment processes and printheads aligned using semi-automatic procedure

Table 3. Dimensional capabilities for HP 3D HR PA 12 W. Target process capability of C_{pk} = 1.00*.

* Data from 8 jobs on 3 printers (job: Dimensional_profiler_EH_V5, firmware: different versions of BD0, IDs: MR_006_1074, MR_006_1078, MR_006_1085, MR_146_309, MR_146_317, MR_294_631, MR_294_632, MR_294_638).

Appendix 1: Understanding process capabilities

Process capability determines whether a process meets a specification. The process capability index or process capability ratio (C_{pk}) is a statistical measure of process capability. It quantifies the ability of a process to produce output within specification limits.

When talking about a dimensional specification, the C_{pk} measures the statistical probability that a certain process produces a dimension within its tolerance range. The higher the C_{pk} value the better, meaning more measurements will be within the tolerance range.

For a process to be capable, it needs to be both repeatable and accurate.

Repeatability is how close multiple measurements are to each other (also called precision).

Accuracy is how close a measurement value is to the specified nominal.

The capability of a process is then a function of two parameters:

- How repeatable it is, compared to the width of the specification limits, measured by the C_p
- How accurate it is, measured by the bias

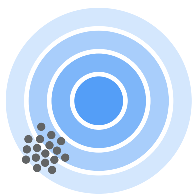
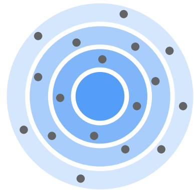
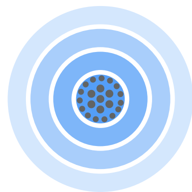
Capability = C_{pk} = C_p * (1-2*bias)		
 Repeatable, but not accurate	 Accurate, but not repeatable	 Both, repeatable and accurate
Good C_p (low variability) but high bias	Good bias (low) but high variability	Low bias and good C_p so C_{pk} is good

Figure 5: Relationship between bias and variability

This concept only holds meaning for processes that are in a state of statistical control with an output that is approximately normally distributed.

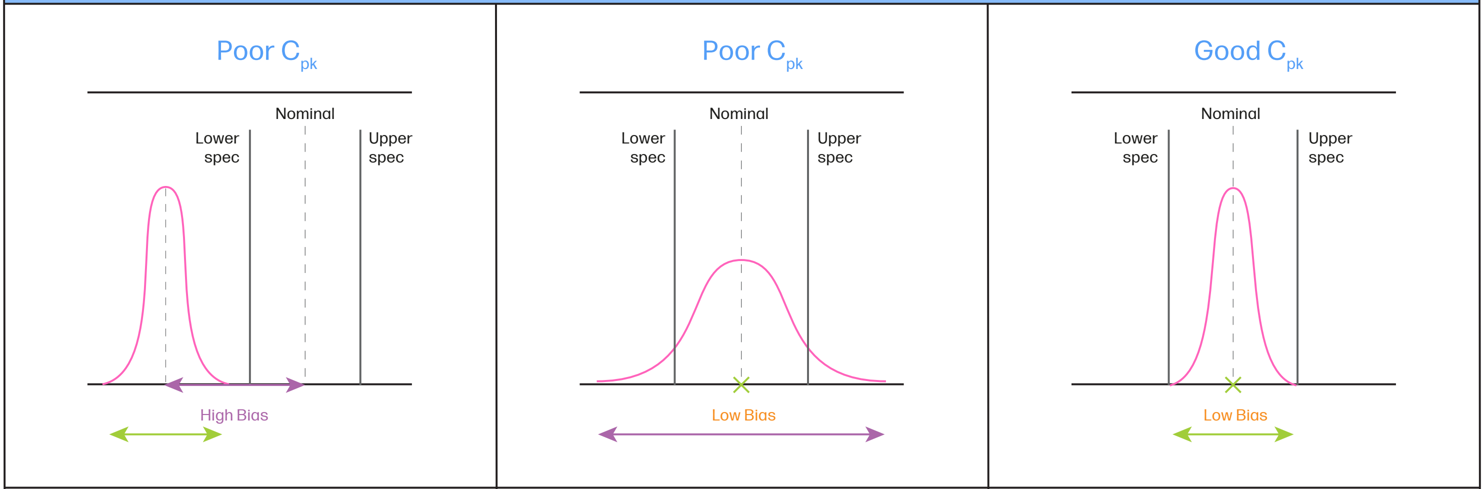
Both conditions happen when dealing with the dimensional quality control of HP MJF-produced parts where the output is the dimensional value of the different geometrical features of a part.

Dimensional quality control processes define an Upper Specification Limit (USL) and Lower Specification Limit (LSL), also called the “tolerance range” of the process. The target of the process is the center of this range, typically the nominal dimension value.

The objective to have a well-controlled dimensional process is to have its normal distributed population of measurements:

- With a variability (calculated as standard deviation) that 'fits' in the tolerance range. C_p measures how well the variability fits within the tolerance range.
- With a mean (average) as close as possible to the target. The deviation is measured by the bias.

Only if both conditions are met, process capability measured by C_{pk} is considered good



Low variability, fits in tolerance range, high C_p	High variability, does not fit in tolerance range, low C_p	Low variability, fits in tolerance range, high C_p

Figure 6. Process capability C_{pk} scenarios

The mathematical calculation of these parameters is as follows:

$$C_p = \frac{\text{Specification width}}{\text{Process width}} = \frac{(USL - LSL)}{6\sigma}$$

Standard deviation estimates the sigma and quantifies the variability and dispersion of the process.

C_p should always be greater than 1.00 for the variability to fit within the tolerance range.

$$C_{pk} = \min \left\{ \frac{[USL - \mu]}{3 \cdot \sigma}, \frac{[\mu - LSL]}{3 \cdot \sigma} \right\}$$

The statistical mean estimates the mu (μ).

Therefore:

- C_{pk} 'measures' the distance of the mean to the closer specification limit, which could be the upper or the lower limit.
- C_{pk} takes into account how centered the process is ($C_{pk} \leq C_p$).
- For a perfectly centered process, $C_p = C_{pk}$.
- If $C_p > C_{pk}$, it is possible to increase the C_{pk} by readjusting the mean of the process.

Table 4 displays the relevant C_{pk} values and their correlation with process yields.

	C_{pk}	Sigma level	Dimensions within specs (%)	Dimensions out of specs (units per million)	Part yield for a part with 10 dimension (%)	
100% inspection	0.33	1	68.27	317,300	2.20	
	0.67	2	95.45	45,500	62.77	
	1.00	3	99.73	2,700	97.33	
Statistical process control	1.33	4	99.9937	63	99.94	Desired
	1.50	5	99.99966	3.4	100	
	1.67	6	99.99997	0.6	100	

Table 4. C_{pk} and process yield correlation

For a part to be considered good, all the specified dimensions need to be within tolerances. Therefore, the part yield is a metric that can be calculated as the statistical sum of the single dimension success rate. In Table 4, an example for a part with 10 dimensions is shown in the right column.

For C_{pk} values below 1.00, the yield is such that the best quality control method is 100% inspection, and the general fabrication process is to over-produce and send only the parts that meet the tolerance requirements. This is a costly but reasonable process, especially for low-volume production.

For C_{pk} values above 1.00 (3 sigma), the dimensional success rate and the yield begin to approach each other, and statistical process control starts to become a viable option. This means that after the process has demonstrated that it is statistically and consistently achieving Cpk above 1.00 for all dimensions, random parts could be audited for each lot of parts.

Generally, a C_{pk} of 1.33 (4 sigma) is desired to ensure enough of a margin for statistical process control, especially when dealing with multi-part complex mechanisms.

Appendix 2: Key terms

- Process capability: Statistical measurement of a process's ability to produce parts within specified limits on a consistent basis.
- International Tolerance grade (IT grade): Grade used to identify the tolerances a given industrial process can produce for a given dimension.
- Repeatability: Ability of a process to consistently produce the same output; in this case, the same part dimensions.
- Bias: Difference between the average of the population for a given dimension and the target value of that dimension.
- Cp: Process capability index that measures of the ability of a process to produce consistent results – the ratio between the permissible spread and the actual spread of a process. This does not take into account how well the output is centered on the target (nominal) value.
- Cpk: Process capability index that estimates what the process is capable of producing, considering that the process mean may not be centered between the specification limits. Cpk < 0 if the process mean falls outside of the specification limits.
- Dimensional profile: Specific configuration used to compensate for variations in printed geometry along the printing volume. Through the dimensional profile, geometrical transformations are applied automatically on each axis to ensures optimal results for every part feature.
- General dimensional profile: Default dimensional profile available for each print profile in the HP Jet Fusion 5420W 3D Printing Solution, based on the average behavior of a wide sample population of HP Jet Fusion 3D printers.
- Hardware-specific dimensional profile: Dimensional profile specifically configured to compensate for possible variations in a specific printer to achieve the nominal value of the calibration job.

1. HP Jet Fusion 3D Printing Solutions using HP 3D High Reusability PA 12 W provide up to 75% powder reusability ratio, producing functional parts batch after batch. For testing, material is aged in real printing conditions and powder is tracked by generations (worst case for reusability). Parts are then made from each generation and tested for mechanical properties and accuracy.

2. For more information on process capabilities, see Appendix 1: Understanding process capabilities.

4AA8-2744EEW, April 2023