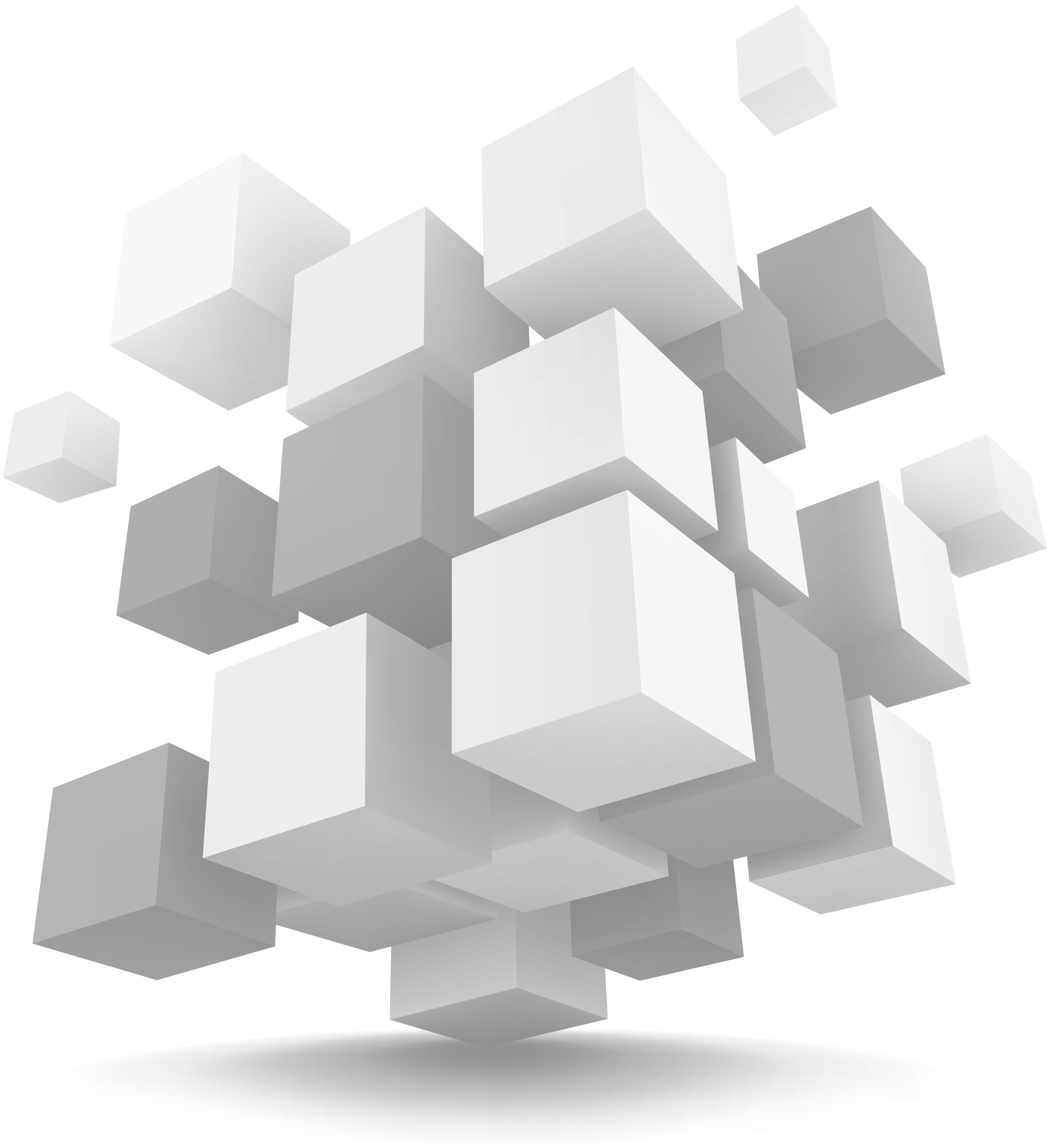
# HP Multi Jet Fusion Handbook

Special edition



# Transforming Design and Manufacturing

## Technology introduction

### 3D Printing transformation

Until the introduction of the Industrial Revolution, hand-crafted one-off design and manufacturing was the norm. Blacksmiths were both designer and manufacturer; each pair of horseshoes they crafted was unique, even when made for the same horse! Production was slow and products were made to order. Save for a few high value items like coffee, tea, and spices, products were rarely, if ever, made in advance, inventoried, and ready for sale. Supply chains for manufactured goods were nonexistent.

But this changed in the 18th century with the rise of the machine and the first Industrial Revolution. Textiles went from handspun wool to cotton woven with a spinning wheel and loom, leading to faster production time with lower material costs. The introductions of the weaving loom, cotton gin, steam engine, and factories for assembling products changed the very nature of how things were made.

Over a period of roughly 75 years—late 1700s to the mid-1800s—production became increasingly standardized, and each task from design to manufacturing and assembly was broken down into discrete functions. Henry Ford's Model T took things to a new level at the start of the 20th century, gaining speed and efficiency with the introduction of mass production and factories. New materials and methodologies from metal casting to Injection Molding have helped to produce most of the products in the world today. With refined workforce and manufacturing practices and the computer automation of previously manual labor-intensive tasks throughout the last century, production rates have accelerated, resulting in the ability to produce in larger quantities. Those who failed to adopt were left behind.

Despite all of this forward movement, the basic design and manufacturing process hasn't fundamentally changed over the past 100+ years. In fact, not only have the processes not improved but they've also put a substantial strain on our natural resources, pushed production farther and farther from the consumer, and constrained design flexibility and customization.

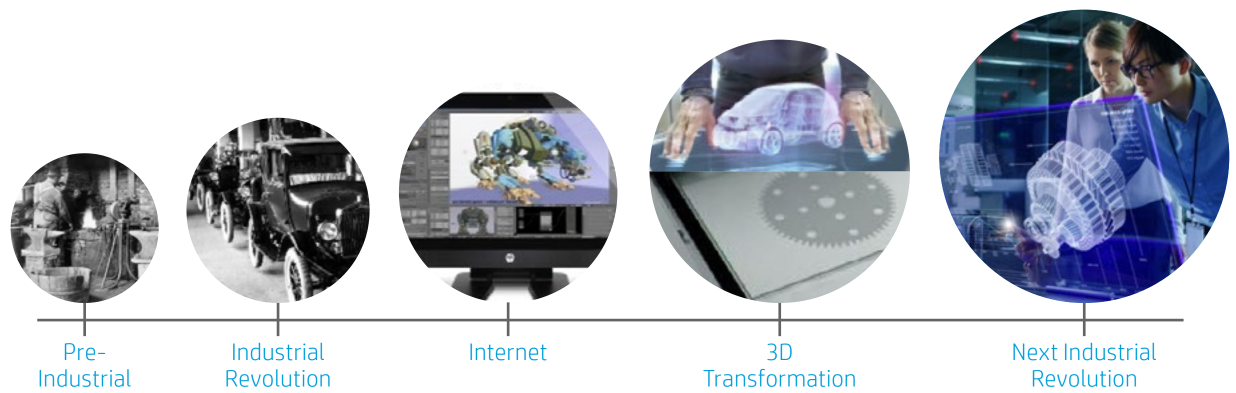



*Figure 1: Driving the next Industrial Revolution through the democratization of design and ubiquitous production*

## Why consider 3D printing as a final part fabrication process?

During the next 10 to 15 years, socioeconomic forces, advanced design and production innovation, and highly automated printing processes will intersect to create a massive transformation of manufacturing as we know it today.

There has been a lot of talk about innovative part designs, designs that could not be fabricated by any of the historical analog processes. This begins now. Unique geometric designs can be made and printed even today. Improvements in function and aesthetics can be realized and in a much shorter development time than was ever possible. Eventually, design tools and printers will evolve to enable voxel-by-voxel differentiation, providing even more product competitiveness.

*Figure 2: Real-time medical and prosthesis design. Orthotic helmet image courtesy of Invent Medical.*

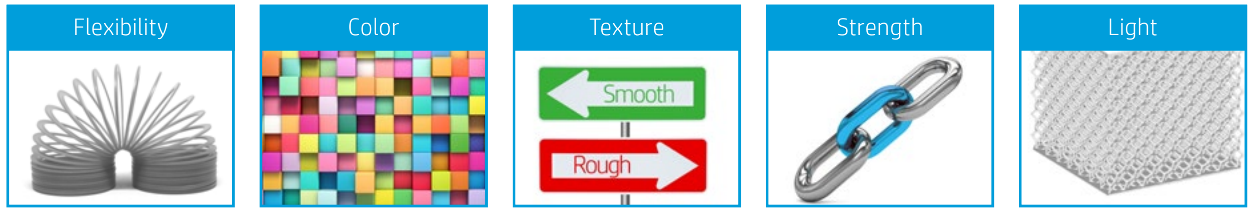



*Figure 3: Designers can create customized, flexible, strong, and light 3D printed products.*

Further, even if designs were not going to become more complex, there are some fundamental advantages to adopting processes that enable faster and less-expensive product development cycles. To illustrate, a typical return on investment graphic is shown in Figure 1.

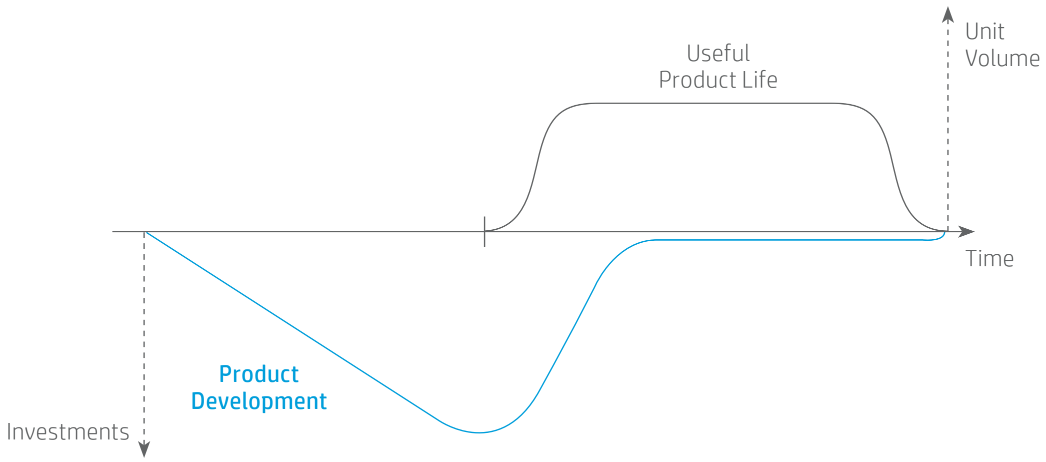



*Figure 4: Illustration of return on investment for new hardware product development*





The challenge with new hardware product development delays, until now, is two-fold. If you delay for a month, for example, not only do you continue to invest at peak levels for an additional month, but you also reduce the useful competitive life of the product by a month, missing a whole month of stable revenues. If you were to recalculate the return on investment from beginning to end, you might find that the investment no longer makes sense. This is illustrated in Figure 2.

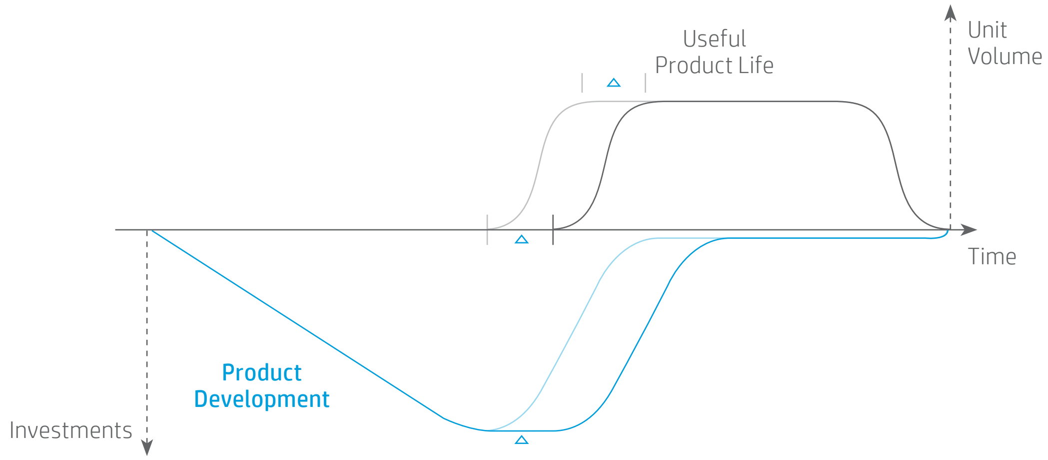



*Figure 5: Illustration of a recalculated return on investment for new hardware product development*

It is normal to consider the money spent as sunk costs and convince yourself that it still makes sense to move forward. But what if you did not need to delay? What if you had a process that would prevent you from tooling unstable part designs and allow you to begin manufacturing on time? If you had a 3D printer with equal quality and reasonable capacity, this would be possible. You may eventually tool these parts, but you use 3D printing to hold schedule. Applying this strategy—known as bridge manufacturing—it is possible to iterate more frequently on these unstable designs, and the product quality could actually improve.

If you had a 3D printer that had equal quality, the necessary long-term capacity, and a competitive cost, even at high volumes, you may not ever have to invest in tools for certain parts.

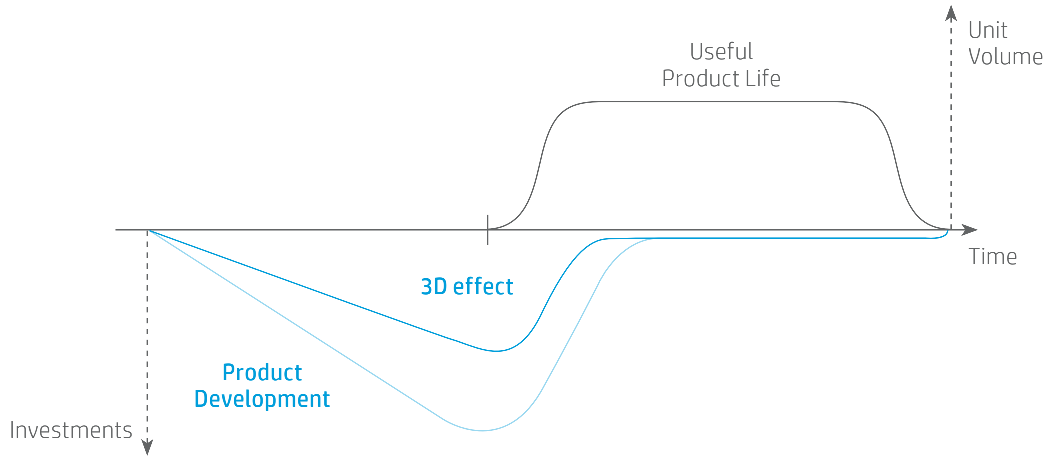



*Figure 6: Illustration of the 3D printing effect on investment in new hardware product development*

While complex products require parts from several different processes, eventually all parts could be 3D printed, and you could not only develop new hardware products for less investment, you could also introduce them sooner or, effectively, with higher frequency, allowing you to keep your competitive edge.

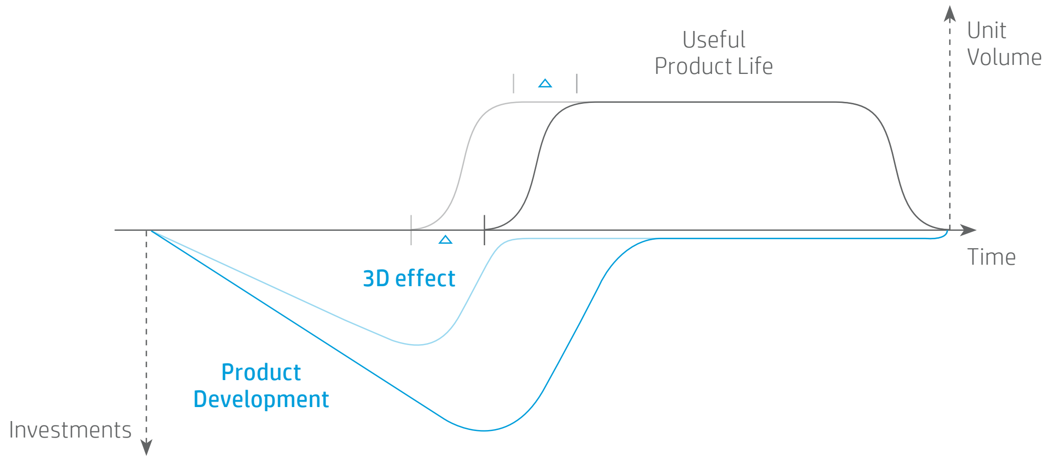



*Figure 7: Illustration of the 3D printing effect on product life in new hardware product development*

With the introduction of the HP Jet Fusion 3D Printing Solutions, based on a disruptive HP Multi Jet Fusion technology, new levels of 3D printing production speed can be achieved, at reduced operating cost, for parts which offer an unprecedented combination of both fine detail and end part strength. The product development cycle can now be disrupted.

## Cost and quality: Former barriers to adoption

In choosing which process to use for final part manufacturing of a specific part, it's important to consider which may be the least expensive combination of process and material that meets the design requirements. Until now, the two main barriers to adopting 3D printing—cost and quality—were factors in making this decision.

The first barrier to adoption has been the effective cost per part and the ability for 3D printing processes to compete head on against Injection Molding. For years, the cost per part for the 3D printing digital processes has been considered a flat line, and the first part can cost the same as the 1,000th part, which would cost the same as the 10,000th part (shown in figure 5). This simplified view leads to a few negative assumptions.

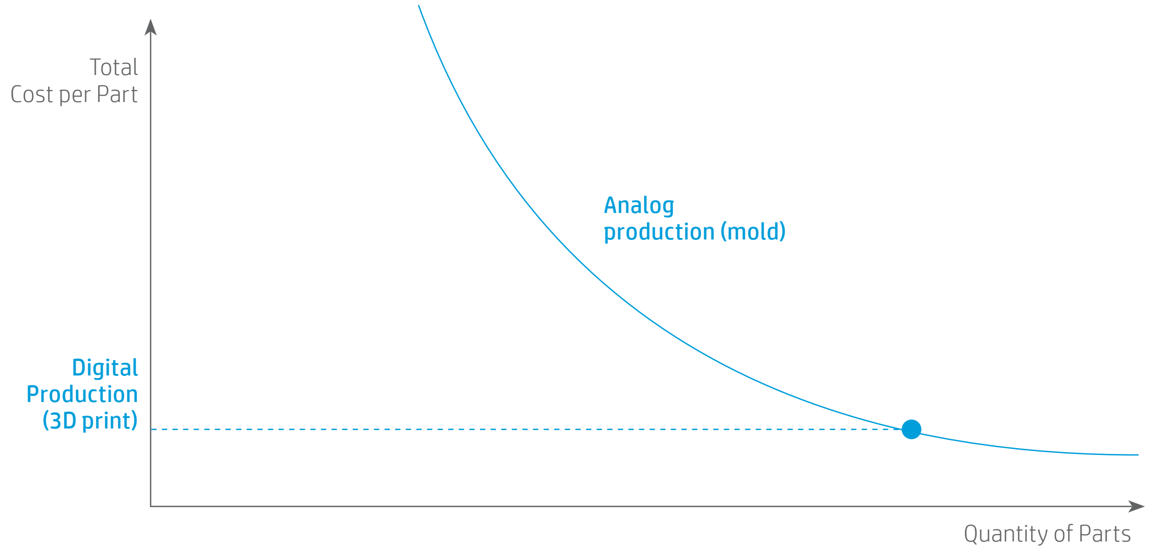



*Figure 8: Breakeven curve assuming a productive 3D printer and no set-up costs or development time*



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Until the introduction of HP Multi Jet Fusion technology, the first negative assumption of 3D printing has been that the printers have reasonable capacity to meet a company's manufacturing forecasts. The fact is, however, that paying hundreds of thousands of dollars for a system that can only fabricate a couple of hundred parts per year results in a flat line that is really a step function (as shown in figure 6). With the high productivity of HP Multi Jet Fusion technology, the step can be tens of thousands of parts instead of hundreds (depending on the part size).

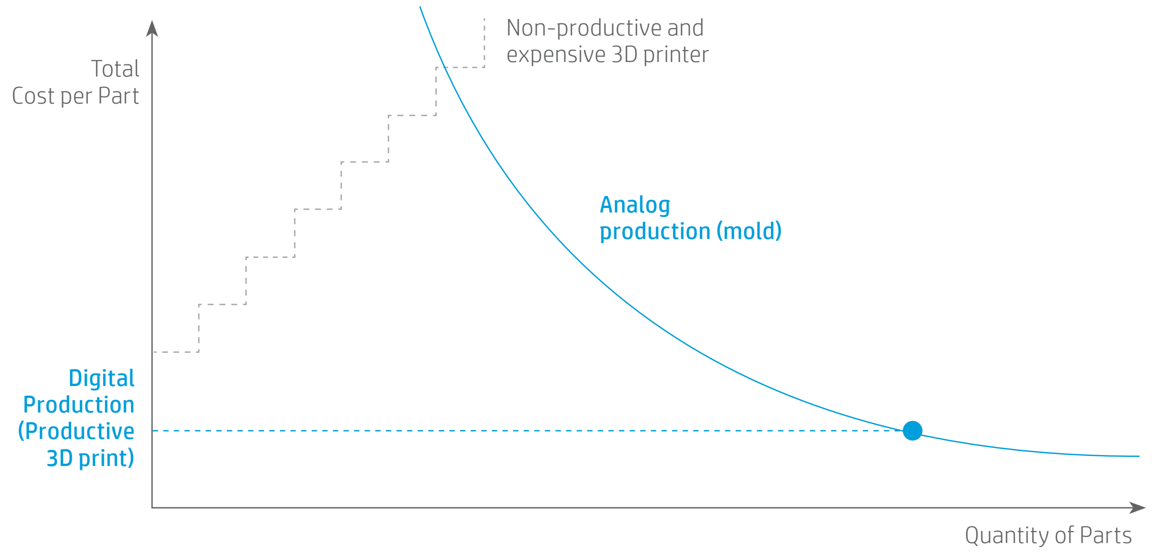


*Figure 9: Breakeven curve for a non-productive 3D printer and no set-up costs or development time*

The second negative assumption of 3D printing in that flat-line curve is that you can go from design to manufacturing without any development or set-up costs. The truth is that any process will need some sort of development phase in order to meet the quality requirements of the design. During this development phase, both the design and process will always require some tuning. The designer tunes the design to the final fabrication process, and the process engineer tunes the process to the design and its requirements. The beauty of this tuning in 3D printing, or digital fabrication, is that the tuning can be done digitally, and no expensive tooling, with expensive reworks, needs to be included.

There are several layers to optimizing and tuning a design to HP Multi Jet Fusion.

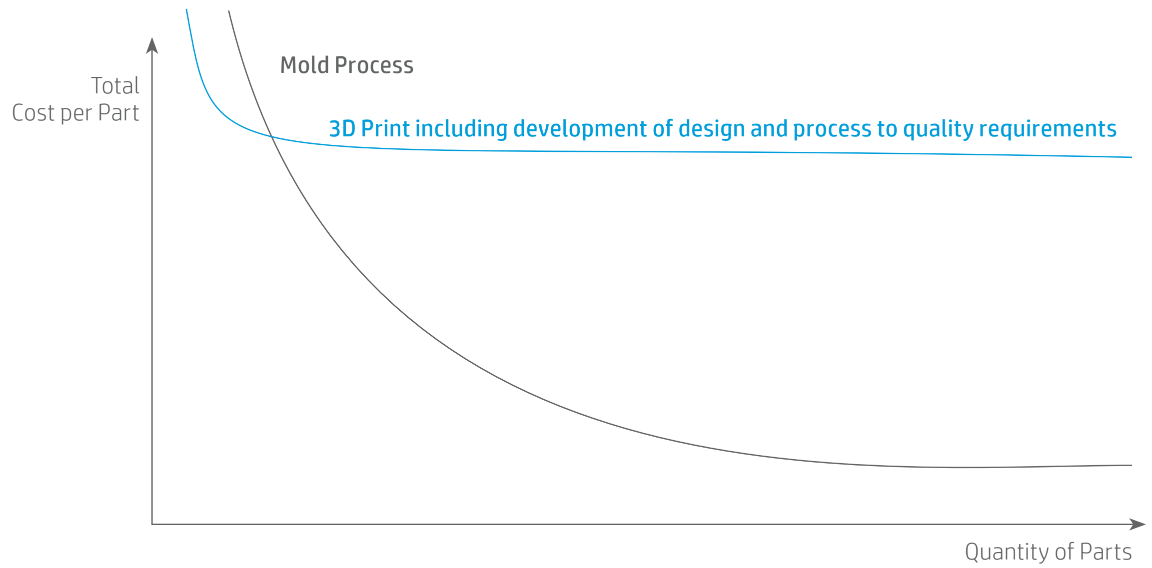


*Figure 10: Breakeven curve for 3D printing including development of design and process to quality requirements*

The first layer involves following the fundamental guidelines for the fabrication process. All processes have fundamental design guidelines as driven by the physics of the process itself. HP Multi Jet Fusion has such guidelines, like recommended wall thickness. If you choose to follow the guidelines, you will have improved quality and yield, and your effective cost per part will decrease.

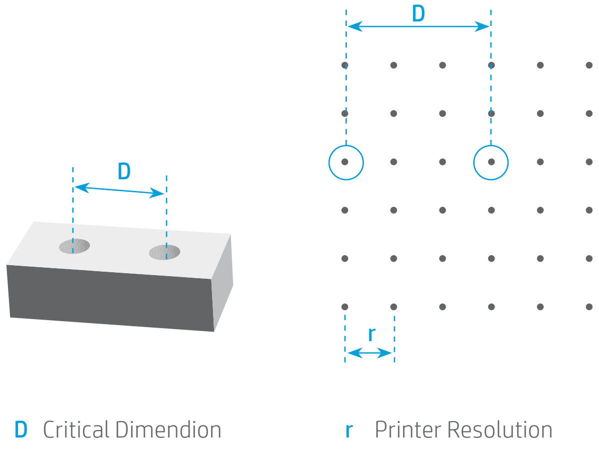


*Figure 11: Example guideline: To attain maximum accuracy, critical dimensions should be an integral number of the printer resolution*

The next level in optimization involves making slight changes to the design that allow for more efficient use of material or more efficient space management of the build volume. If less material can be used for the part and/or more parts can fit into the same build volume, the effective cost per part will decrease even further.


*Figure 12: Optimized material use*

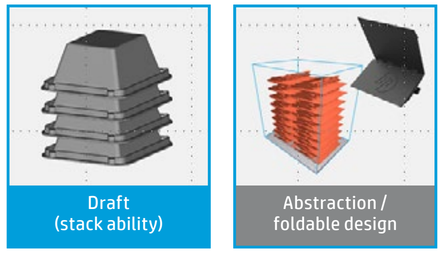


*Figure 13: Optimized use of the build volume*

The final design optimization for 3D printing is maintaining the third dimension and combining parts. When a mechanical designer takes a system function and breaks this into parts that can be easily Injection Molded, the resulting parts are largely 2.5-dimensional, meaning that they tend to have two larger dimensions and one smaller dimension. This is because molds must open and close easily. If you intend to 3D print the parts, the parts can remain integrated, and then the breakeven curve becomes a comparison of one part versus several parts from several molds.

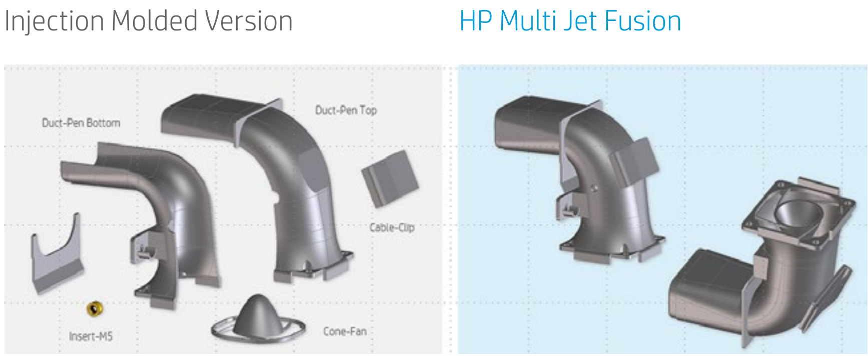


*Figure 14: Maintain the integration of the functional design intent*





## What is the proposed solution?

In the mid-term, HP Jet Fusion 3D Solution will complete the portfolio to best accompany our customers in the journey of adopting 3D printing technologies, from assessment on where to start, how to design to how to maximize of your HP Jet Fusion 3D Printing Solution.

Software can be developed to help designers tune their designs to HP Multi Jet Fusion or allow process engineers to tune the HP Multi Jet Fusion process to the design. But domain knowledge must come first.

This HP Multi Jet Fusion handbook is a vehicle for capturing the domain knowledge around HP Multi Jet Fusion and sharing it with the world so that it can be applied immediately.

This handbook includes a design chapter to help designers understand the unique design guidelines for HP Multi Jet Fusion that should be followed to obtain optimal quality. Further, the design chapter will eventually provide additional guidelines on how to optimize designs for cost when fabricating with HP Multi Jet Fusion.

In future revisions, this handbook will also include chapters on process optimization to help process engineers select the right parameters for quality and cost, such as orientation or spacing of parts in a build.

Additional future chapters will include HP Multi Jet Fusion material selection, quality control, and other helpful knowledge for facilitating the adoption of HP Multi Jet Fusion into your library of possible processes for fabricating final parts.

## Approaching the perfect storm

When cost and quality can be achieved, the true potential of 3D printing can be realized. Future design tools will enable designers to develop more and more differential products through unique designs that cannot be fabricated by analog processes. The seamlessness of the interface between design tools and 3D printers will become even more important as future printers enable multiple properties within one object, enabling changing colors, textures, transparency, strength, elasticity, and more.

What we design, as well as how and where we design, sell, and manufacture products will continue to become both hyper-global and hyper-competitive. To stay successful through this transformation, companies will need to either adopt or be left behind.

Along this journey, this handbook will help guide the transformation, with updates posted online at hp.com/go/MJFHandbook. In the meantime, welcome to the future of part fabrication.

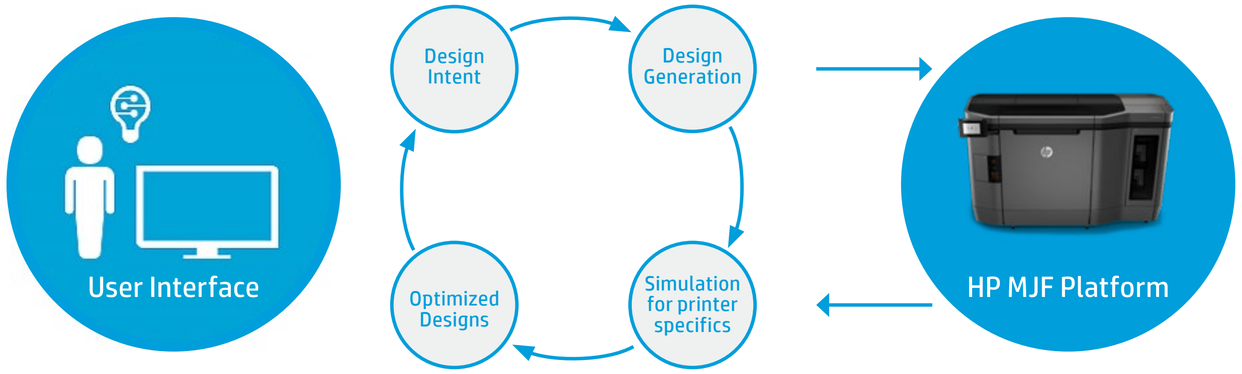


*Figure 15: Designers can create customized predictable 3D printed products when printer capability is communicated upstream*

# Snap-fits
## Design for HP MJF: Union joints design

### Introduction

A snap-fit is an efficient assembly method used to attach plastic parts via a protruding feature on one part (e.g., a hook), which deflects during assembly to be inserted into a groove or a slot in the second part. After the assembly, the protruding feature returns to its initial position.

Snap-fits provide a simple and economical way to assemble plastic parts by drastically reducing assembly time. The way a snap-fit is designed determines whether it can be disassembled and reassembled several times and the force required to do so. This assembly method is suited to thermoplastic materials for their flexibility, high elongation, and ability to be printed into complex shapes.

HP Multi Jet Fusion technology allows for the designing and printing of parts with specific design features integrated, such as snap-fits, in order to connect them.

### Types of snap-fits

The various types of snap-fits are listed below.

#### Cantilever snap-fit

The cantilever snap-fit is the most commonly used type of snap-fit. It consists of a cantilever beam with an overhang at the end. In this type of snap-fit there is a direct relationship between the robustness of the assembly and the strength of the snap-fit.

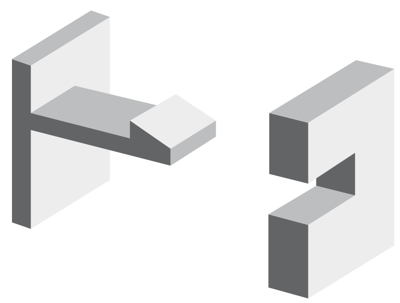

*Figure 1. Cantilever snap-fit*

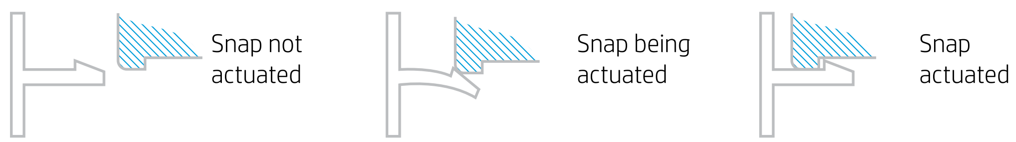


*Figure 2. Cantilever snap-fit assembly operation*

## L-shaped snap-fit

When it is not possible to design a cantilever snap-fit without compromising the robustness of the assembly and the strength of the snap-fit due to material or geometrical constraints, an L-shaped snap-fit can be an alternative. Adding a groove to the base of the snap-fit increases its flexibility while reducing the strain on the beam, compared with a cantilever snap-fit.

*Figure 3. L-shaped snap-fit*

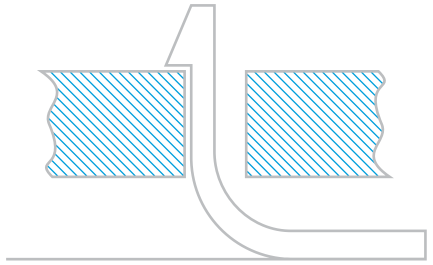

*Figure 4. L-shaped snap-fit assembly operation*

## U-shaped snap-fit

The U-shaped snap-fit is another alternative to the cantilever snap-fit when it is necessary to increase the snap-fit flexibility within a reduced space. This U-shaped alternative is extremely flexible, and thus easier to remove. This type of snap-fit is usually used in cases where the parts need to be pulled apart repeatedly or when two parts don't require a lot of force to stay in position (e.g., in a battery compartment lid).

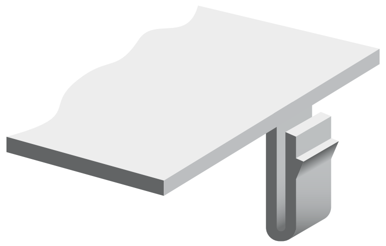

*Figure 5. U-shaped snap-fit*

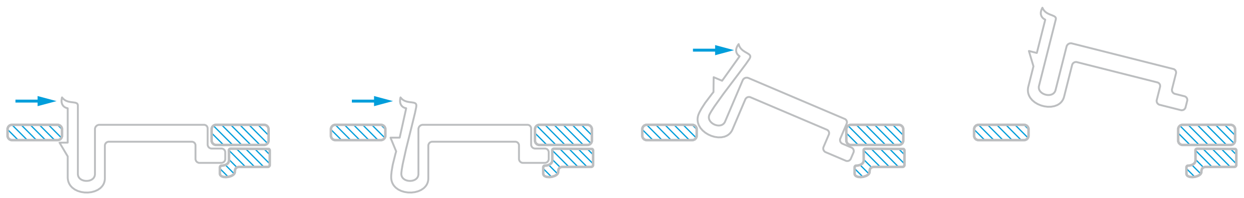

*Figure 6. U-shaped snap-fit assembly operation*





## Annular snap-fit

The annular snap-fit is an assembly method usually used between two cylindrical or ring-shaped parts or between two rotationally symmetric parts, where the deformation required to assemble or disassemble the snap-fit is made in a 360º direction at the same time.

With this assembly method, one part is designed with an undercut and the other is designed with a mating lip. The joint occurs through the interference between both parts during the assembly operation.

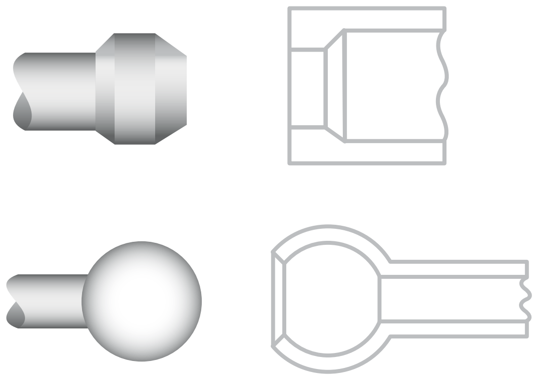

*Figure 7. Annular snap-fit*

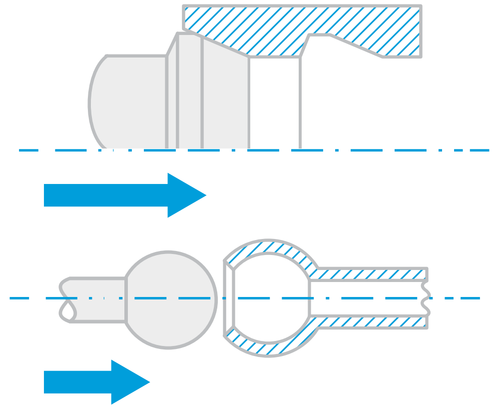

*Figure 8. Annular snap-fit assembly operation*

## Torsional snap-fit

The torsional snap-fit is an assembly method where the flexible point is in a torsional bar instead of the self–snap-fit body. When the torsional bar is pushed down, it turns slightly and opens the joint.

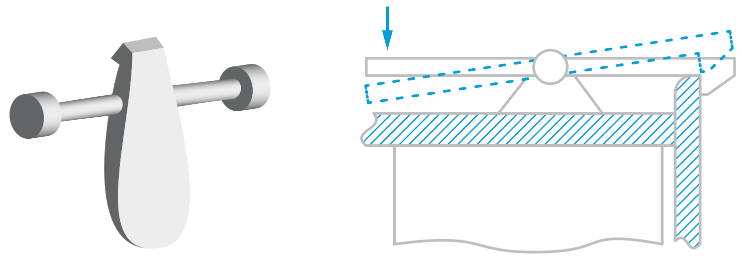

*Figure 9. Torsional snap-fit*

# Design considerations

As mentioned previously, the most commonly used type of snap-fit is the cantilever snap-fit. When designing this type of snap-fit, it is important to design a balanced solution between the robustness of the assembly and the strength of the snap-fit cantilever beam.

This type of snap-fit can be approximated using a simplification of the general beam bending theory, which allows for the inspection of the snap-fit design feasibility. This approach models the cantilever snap-fit by a fixed-free beam with a point-applied end load:


*Figure 10. Cantilever beam with a point-applied end load*

### Mating force and beam stress

The robustness of the assembly will be defined by the force (P) required to assemble and disassemble it. A weak force required to deflect the snap-fit beam will lead to a weak assembly that is unable to maintain the connection between both parts. Otherwise, a strong force will lead to an extremely robust assembly, which will be difficult to assemble and disassemble when required.

Moreover, the design of the snap-fit must be strong enough to resist the stress (σ) suffered by the beam when it deflects due to the mating force (P) applied, without compromising the snap-fit integrity and performance.

For this reason, the mating force (P) and the beam stress (σ) must be the main considerations when designing a cantilever snap-fit, and according to the beam bending theory, they are dependent upon the snap-fit geometry and the material used to make it.

### Material and geometry dependence

Because of their direct relationship with the assembly robustness and snap-fit strength, the snap-fit material and geometry are considered the most critical design parameters, and they are often dependent upon the available design space.

**For this reason, geometry and material choice are usually the first steps when designing a snap-fit.**

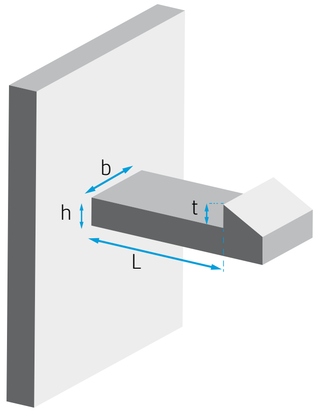


*Figure 11. Snap-fit geometry*

When choosing the snap-fit material and geometry (h, b, L, t), other dependent factors are clearly defined:

- Choosing the snap-fit cross-section geometry (h, b) allows the designer to calculate its moment of inertia (I), which, for a cantilever beam with a rectangular cross-section, is as follows:

$$I = \frac{b \cdot h^3}{12}$$

- Once the printing material is selected, the modulus of elasticity (E) is made clear since it is often provided in the material datasheet.

The product of the moment of inertia (I) and the modulus of elasticity (E) is known as the beam flexural rigidity (EI).

According to the beam bending theory, these dependent parameters, along with the snap-fit material and geometry, have a direct relationship with the required mating force (P) and the beam stress (σ), as shown below:



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- Deflection (y) at the end of a cantilever beam with a point-applied end load:

$$y = \frac{P \cdot L^3}{3 \cdot E \cdot I} \quad (1)$$

- Maximum stress (σ) in a cantilever beam with a uniform rectangular cross-section:

$$\sigma = \frac{P \cdot L \cdot h}{2 \cdot I} \quad (2)$$

The minimum amount of deflection (y) at the end of the cantilever beam required to assemble and disassemble the snap-fit is usually a known parameter dependent upon the geometric constraints and the available design space. In fact, it is defined by the depth (t) of the snap-fit overhang:

- The minimum amount of deflection (y) must be at least equal to the depth (t) of the snap-fit overhang to allow a proper assembly and disassembly operation.

$$y \geq t$$

- A deeper overhang will lead to a strong assembly, but it will mean that the beam must deflect further and, as a consequence, it will require a greater matting force (P)—as shown in equation (1) —and the beam stress (σ) will also increase—as shown in equation (2)-.

## Design calculations

The first step in checking the snap-fit design feasibility is to calculate the resultant mating force (P) and to check whether it is suitable. This calculation can be done by solving the equation (1) for P:

$$P = \frac{3 \cdot E \cdot I \cdot y}{L^3} \quad (3)$$

Based on the equation (3), the force (P) is dependent upon how much farther the snap-fit beam must deflect (y), but it also will depend on the material resistance against the bending deformation, which is known as beam bending stiffness (k), and its function of the beam flexural rigidity (EI), the length (L) of the beam, and beam boundary condition:

$$P = k \cdot y \quad (4)$$

The suitable mating force (P) value should not be greater than 50N to 100N, which is considered an ergonomic value for an estimated finger strength average.

Once the mating force (P) has been calculated and it results in a suitable value, the second step to check the snap-fit feasibility is to calculate the stress (σ) in the cantilever beam based on the equation (2).

If the beam stress (σ) is above the yield strength of the material, the snap-fit will deform, and some part of the deformation will be permanent and non-reversible, thus compromising the snap-fit performance and strength up to rupture.

$$\text{Beam stress } (\sigma) < \text{Material yield strength} \quad (5)$$

Considering that the yield strength is not a common property specified in technical datasheets when producing plastic parts, the best option to calculate the snap-fit strength is to use the material allowable strain (ε) and modulus of elasticity (E):

$$\text{Beam stress } (\sigma) < E \cdot \varepsilon \quad (6)$$

In order to obtain the allowable strain (ε) value, designers can refer to usual recommendations for other plastic manufacturing processes such as Injection Molding:

$$\text{Allowable strain } (\varepsilon) < \frac{1}{3} \cdot \text{Material elongation at yield} \quad (7)$$

All design considerations are shown in the following flowchart:

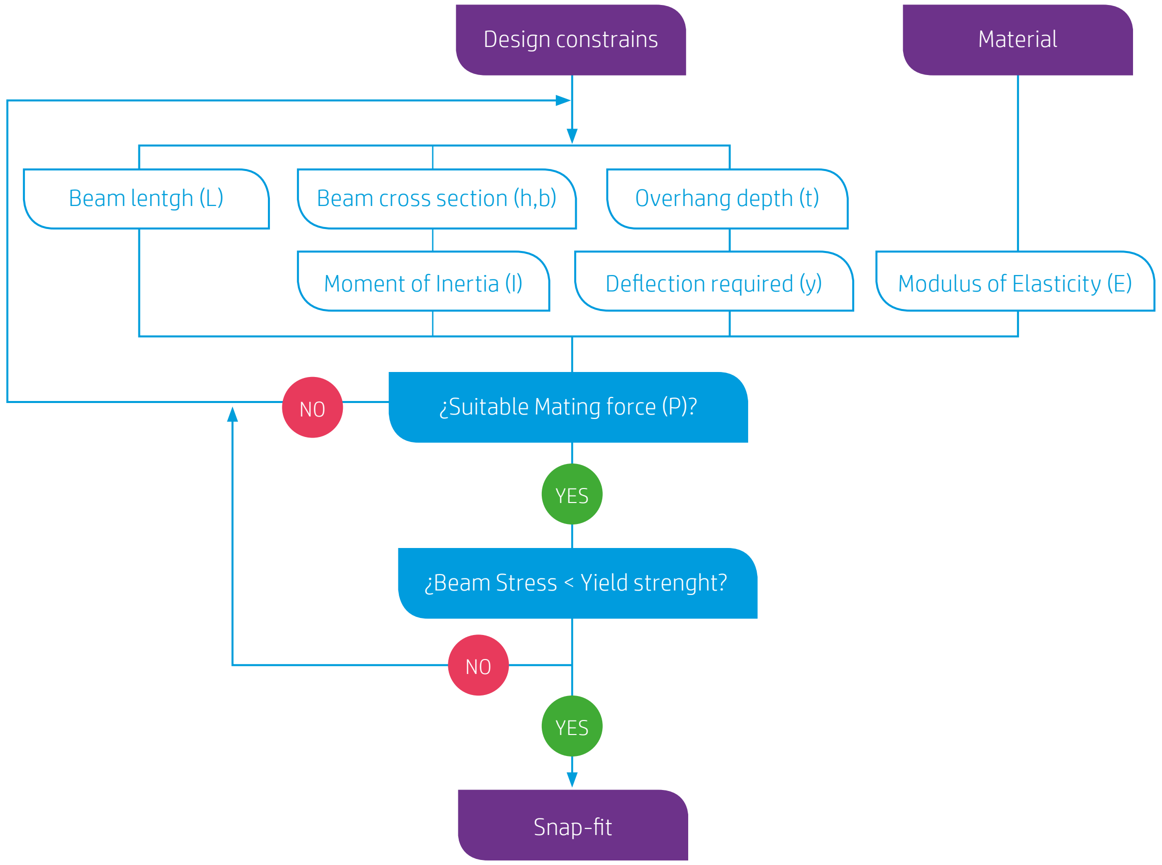



*Figure 12. Design snap-fit flowchart*

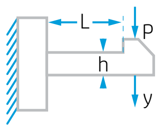
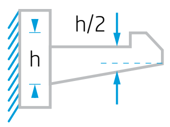
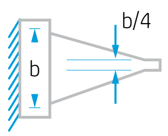
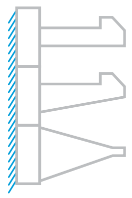
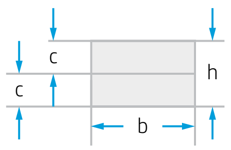
| | (Permissible) deflection | | | Deflection force |
|---|---|---|---|---|
| Type of design |  |  |  |  |
| Shape of the cross section | | | | |
|  Rectangle | $y = 0.67 \cdot \frac{\varepsilon \cdot L^2}{h}$ | $y = 1.09 \cdot \frac{\varepsilon \cdot L^2}{h}$ | $y = 0.86 \cdot \frac{\varepsilon \cdot L^2}{h}$ | $P = \frac{bh^2}{6} \cdot \frac{E\,\varepsilon}{L}$ |

*Figure 13. Snap-fit calculation equations**

**Note 1: Beam deflection (y) expressed in terms of allowable strain (ε), based on equations (1), (2)*
**Note 2: Mating or deflection force (P) expressed in terms of allowable strain (ε), based on equation (2)*





## Design guidelines

There are several design recommendations when designing snap-fits with HP Multi Jet Fusion:

### Minimum thickness (h)

The minimum recommended thickness at the base of the cantilever is 1 mm.

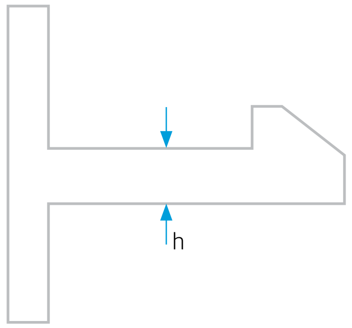



*Figure 14. Minimum thickness at the base of the cantilever*

### Minimum overhang depth (t)

The minimum overhang depth (t) should be at least 1 mm.

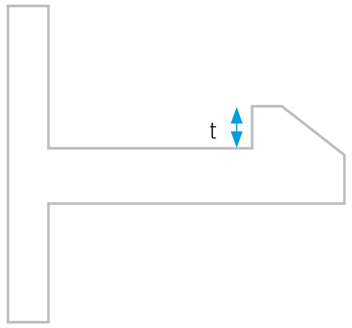



*Figure 15. Minimum overhang depth (t)*

### Recommended common radius

It is recommended to add a common radius at the base of the cantilever to avoid sharp corners and reduce the stress concentration. This common radius should be at least half of the thickness (h) of the base of the cantilever.

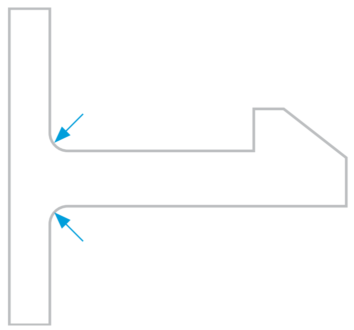


*Figure 16. Common radius*

### Snap-fit overhang

It is recommended to avoid sharp edges at the end of the snap-fit overhang, adding a small chamfer to prevent breaking during the assembly operation.

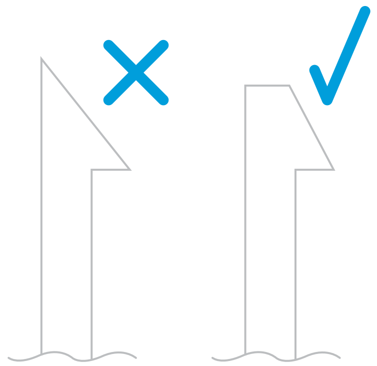


*Figure 17. Snap-fit overhang*

### Assembly angle (α)

As mentioned previously, the snap-fit overhang usually has a gentle chamfer to facilitate the assembly operation. The inclination of this chamfer angle (α) directly affects the mating force (P). If the angle (α) is reduced, the mating force (P) will also reduce. The recommended assembly angle value should be between 35º and 40º.

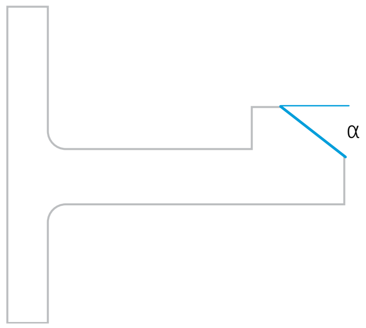



*Figure 18. Assembly angle*

### Disassembly angle (β)

The way the overhang is designed determines whether the snap-fit can be disassembled and reassembled several times. The disassembly angle (β) affects the ease of joint disassembly. For example, a 90º angle (β) can never be disassembled. However, a snap-fit with a disassembly angle (β) equal to the assembly angle (α) will need the same mating force (P) for both operations.

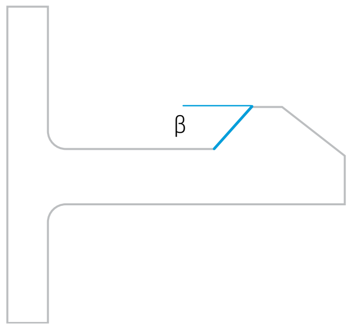



*Figure 19. Disassembly angle*





### Tolerances between parts

When designing a snap-fit, there must be a gap between the protruding feature and the groove to ensure a proper performance, even including the worst tolerance case as shown in the following figure:

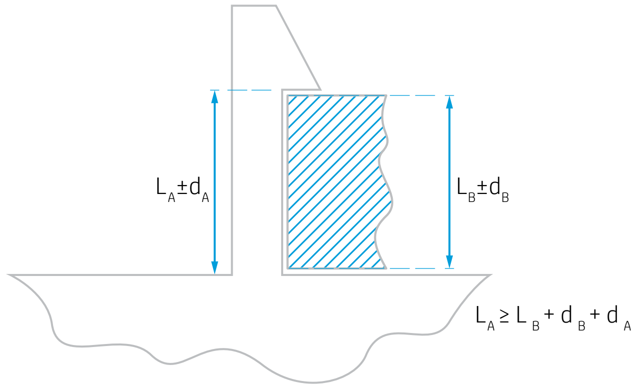



*Figure 20. Tolerances between parts*

### Modifying the mating force (P)

Sometimes, after choosing the snap-fit material and geometry, the resulting mating force (P) is a non-desirable value. Based on the equation (3) and bearing in mind that when designing a snap-fit, the most common restrictive tolerances are the length (L) of the beam and the depth (t) of the overhang, the most common solution when modifying the mating force (P) is needed is to change the cantilever cross-section (h, b).

Reducing the mating force (P) will also reduce the beam stress (σ).

### Tapered beam

One of the most recommended changes in the snap-fit cross-section is to design a tapered beam. While a snap-fit beam with a uniform cross-section has an uneven distribution of strain and concentrates the stress at its base, a tapered beam uses less material and results in a more even distribution of strain throughout the cantilever, thus reducing stress (σ) concentration and the assembly and disassembly force (P).

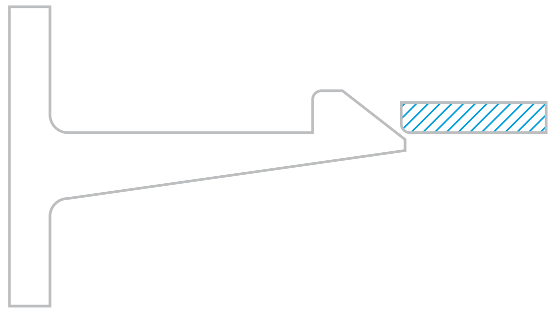


*Figure 21. Tapered beam*

## Printing orientation

There are some recommended orientations when printing a snap-fit regarding its accuracy and proper performance.

### For tight snap-fits

When printing tight snap-fits where the length of the beam (L) is critical, the XY plane orientation is recommended to achieve the best accuracy and, thus, a better performance.

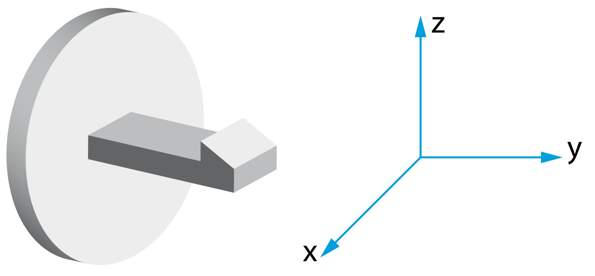



*Figure 22. XY plane orientation*

When the width of the snap-fit (b) is critical, the XZ or YZ plane orientation is recommended to achieve the best accuracy and to avoid excessive clearances on the XY plane, which can lead to noise and vibrations.

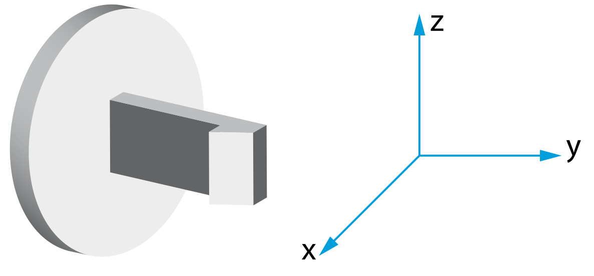



*Figure 23. XZ or YZ plane orientation*

### To reduce printing issues

Printing the snap-fit inclined slightly in the X, Y, and Z axes can reduce the likelihood of typical printing issues.

## Post-processing recommendations

HP MJF technology allows for different post-processing methods that can affect the finishing of the printed part. Although most of the post-processing methods should not affect a 3D printed snap-fit, there can be some automatic post-processes that affect it, such as the tumbler post-process.

The tumbler post-process involves hitting the 3D printed part with small abrasive pellets in order to reduce its roughness. In return, some dimensions and/or small features can be affected by the process.

In the case of the snap-fits, a tumbler process can reduce the mating force (P) of the assembly and even break it depending on the snap-fit geometry.

For this reason, if automatic post-processes are required, it is recommended to protect the part with a sinter box to prevent damage.





## Calculation example

The following figure illustrates the calculation needed when designing a cantilever snap-fit.

In this particular case, a clipping system for an optical sensor must be designed as follows:

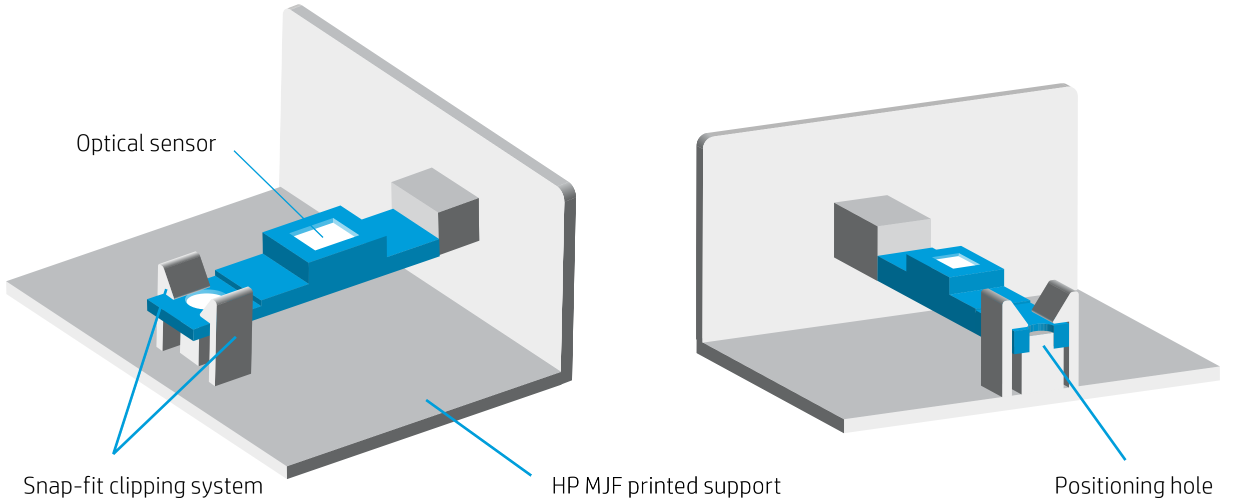



*Figure 24. Optical sensor clipping system*

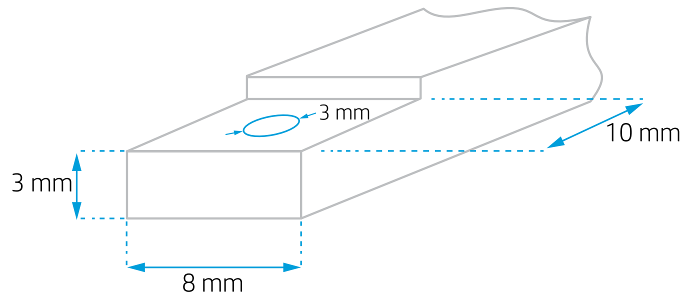



*Figure 25. Optical sensor dimensions*

The design requirements are listed below:

- The material used to print the part is HP 3D HR PA 12, with an elastic modulus of elasticity (E) of 1800 MPa.
- Due to optical requirements, the sensor must lay 5 mm above the base. Thus, the snap-fit total length must consider the worst-case tolerances and the optical requirements:

$$L = 3\ mm + 0.1\ mm + 5\ mm + 0.2\ mm + 0.2\ mm = 8.5\ mm$$

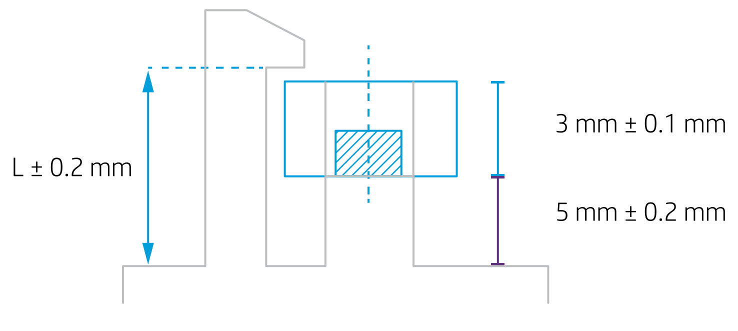



*Figure 26. Snap-fit length calculation*

- Due to constructive constraints, the snap-fit cannot overlap the positioning hole, which means that the overhang depth (t) must be between 1 mm—the minimum recommended value—and 2.5 mm—the maximum allowable distance to avoid contact between the snap-fit overhang and the sensor positioning hole:

$$\textit{Overhang depth } (t) = y = 1\ mm$$

- The width must be smaller than 10 mm due to geometrical constraints:

$$b = 9.5\ mm$$

Once the snap-fit material and geometry (h, b, L, t) are clearly defined, the resulting mating force (P) must be calculated to check whether it is suitable. This calculation can be done using the equation (3):

$$P = \frac{3 \cdot E \cdot I \cdot y}{L^3} = \frac{3 \cdot E \cdot (b \cdot h^3) \cdot y}{12 \cdot L^3} = \frac{3 \cdot 1800MPa \cdot 9.5\ mm \cdot (1.5\ mm)^3 \cdot 1\ mm}{12 \cdot (8.5\ mm)^3} = 23.49N$$

The calculated mating force (P) value is inside the ergonomic range. Therefore, based on the equation (2) and (6), the next step is to check the strength of the snap-fit calculating the allowable strain (ε):

$$\sigma = \frac{P \cdot L \cdot h}{2 \cdot I} = E \cdot \varepsilon$$

$$\varepsilon = \frac{P \cdot L \cdot h}{2 \cdot I \cdot E} = \frac{12 \cdot P \cdot L \cdot h}{2 \cdot (b \cdot h^3) \cdot E} = \frac{12 \cdot P \cdot L}{2 \cdot (b \cdot h^2) \cdot E} = \frac{12 \cdot 23.49N \cdot 8.5\ mm}{2 \cdot (9.5\ mm \cdot (1.5\ mm)^2\ ) \cdot 1800\ MPa} = 0.03 = 3\%$$

The calculated allowable strain (ε) shows that the snap-fit does not deform when it deflects due to the mating force (P) applied, without compromising its integrity and performance.

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