White paper

How to complement CNC production with HP Multi Jet Fusion 3D printing

CNC machining

CNC is a subtractive manufacturing technology typically used in industries such as aerospace or automotive engineering and machinery/equipment manufacturing. It is well-suited for low-volume part manufacturing in a variety of materials, including metals and plastics. Accuracy is one of its main advantages—machined parts can be produced with tolerances of up to up to +/-0.025mm, which cannot be achieved with injection molding, for example.

However, some geometries—for example, internal corners with small radii, cavities with complex geometries and undercuts or thin walls—can be difficult or sometimes impossible to manufacture with CNC.

CNC equipment usually requires qualified operators, as setting up and maintaining the equipment can be complex and the cutting program to produce parts needs to be created in advance in specific CAM software. Before starting to manufacture a part, certain set-up operations are required for CNC machining. A cutting program that directs the cutting tool must be created, and the proper cutting tool and raw material fixtures must be placed in the machine as well. For these reasons, parts are normally produced sequentially in batches, one part at a time.

How 3D printing can complement CNC machining

HP Multi Jet Fusion technology is a relatively new 3D printing technology that powers HP's Jet Fusion 3D Printers, which can offer disruptive cost[1], speed[2] and quality[3] benefits compared to other 3D printing technologies.

It can complement and enhance CNC machining and production workflows by enabling:

Design freedom and weight reduction

3D printing enables the production of complex geometries that were not possible before, enabling lighter parts with enhanced performance, thanks to lattice structures or topology optimization. Moreover, 3D printing materials are much lighter than aluminum or steel.

With HP Multi Jet Fusion, a part's weight can be reduced while still maintaining the required robustness. Moreover, HP MJF can produce parts that have nearly the same mechanical properties[3] for the XY axes compared to the Z axis—therefore, in the design process there is no need to factor in mechanical behavior.

The example on the left shows an internal part from an HP Large Format printer, originally produced with CNC (the part on the left), that has been redesigned for HP MJF (the part on the right), enabling a 50% cost reduction, 93% weight reduction and 95x carbon footprint reduction[4].

Assembly consolidation

3D printing can reduce lead times, because complex multicomponent assemblies can be consolidated into single parts. This also reduces the risk of errors and other issues during the assembly process, as well as labor costs.

Cost

When assessing costs, CNC machining is a suitable production process for parts with simple designs. However, parts with more complex geometries often require more manufacturing time with CNC which can drive up the final part cost.

With HP Multi Jet Fusion, complex geometries do not increase production time or cost, as this technology allows a higher throughput independent of part complexity.

As mentioned before, HP Multi Jet Fusion technology can produce parts that have been redesigned (hollowed or topologically optimized) to reduce the quantity of material required to manufacture them, resulting in further cost savings.

In comparison to other 3D printing technologies, HP Multi Jet Fusion can produce quality parts at the lowest cost[1], thanks to HP 3D High Reusability Materials that offer up to 80% surplus powder reusability[5].

Plus, the ease of use, ease of cleaning and predictability of HP MJF technology reduces operator time and the operator skill-set required. Skilled labor required to set-up and maintain complex and expensive CNC equipment can also impact overall costs. This can be reduced with HP Multi Jet Fusion, as once the design of a 3D part is completed, the file is sent electronically to the printer, and the part can be produced with little human intervention.

Productivity & time

Time is critical when a manufacturing aid or prototype is needed. Usually, several iterations are required in order to achieve the perfect design for an application. Machining complex metal geometries takes significant planning and highly skilled CAM designers and machine operators. With HP Multi Jet Fusion, besides not needing CAM, lead times can be reduced as several design iterations can be done in parallel, as multiple parts with different designs can be produced in a single production batch.

HP Multi Jet Fusion produces parts up to 10 times faster[2] than other 3D printing technologies. With these levels of productivity and speed, you can drastically reduce lead times: from several days to just one.

Inventory reduction

3D printing enables on-demand production, which in turn can reduce or even eliminate manufactured part inventory.

Materials inventory can also be reduced with 3D printing. Whilst CNC shops usually need to have several sizes of material blocks readily available, in order to be able to work efficiently, with 3D printing, powder is used directly from the materials cartridge, regardless of the part geometries or sizes that will be produced.

Waste material

HP Multi Jet Fusion production environment

CNC machining, as a subtractive technology, removes material from an original raw block and therefore, inherently produces waste, for which recycling, especially for plastics, is difficult, costly and time consuming. HP Multi Jet Fusion minimizes material (powder) waste in the printing process when using standard packing densities with a powder reusability ratio of up to 80%[5].

What type of parts can I print with HP Multi Jet Fusion?

HP Multi Jet Fusion is a 3D manufacturing technology that can complement CNC machining. The table below showcases the best fit for both technologies versus several key applications and requirements:

Applications	CNC	MJF
Prototypes	Sequential production	Several iterations can be produced at the same time
Jigs&fixtures	Current technology used	Lightweight Low cost Assemblies unification
Fluid vessels	Geometry limitations	Low cost & fast time to part Flow optimization
Grippers / end effectors	Current technology used	Lightweight Low cost Assemblies unification
Brackets / supports	Current technology used together with sheet metal for low volume	Low cost Assemblies unification
Part requirements		
Complex geometries	High cost	Low cost & fast time to part Assembly unification
Thin walls	Difficult or not doable	Walls up to 0.5mm
Parts with high accuracy	Accuracy up to 0.025mm	Machining specific features with accuracy lower than +/-0.2mm/0.008 inches on XY for hollow parts below 100 mm/3.94 inches and ±0.2% for hollow parts over 100 mm/3.94 inches
Part with cosmetic requirements	Roughness (Ra) around 1 μm after machining	Post-processes available: tumbling, chemical polishing, dyeing, painting
Strength	>50 MPa tensile strength Metals	Up to 48 MPa tensile strength Redesigns to reinforce
Flame retardant requirements	UL94 HB to UL94 V0 (material dependant)	UL94 HB (for HP 3D HR PA 12 and PA 12 GB)
Stiffness	>2800 MPa tensile modulus Metals	Up to 2800 Mpa tensile modulus with HP 3D HR PA 12 GB Redesigns to reinforce

Excellent fit | Good fit | Possible fit

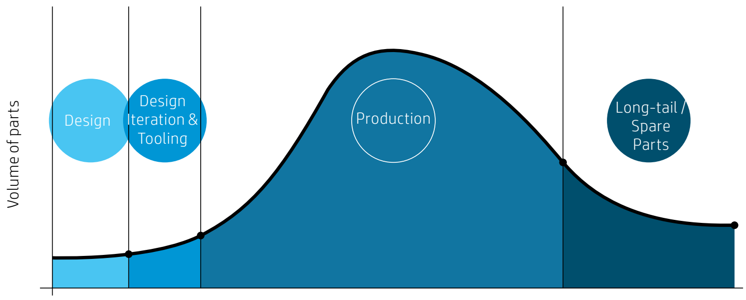
CNC machining and HP MJF for different applications and requirements

3D printing and Product Life Cycles

Traditionally, 3D printing technologies have been used to validate designs and reiterate them during the early stages of product development. The volume of parts during this phase tend to be low compared to what is needed today for final or spare parts.

With HP Multi Jet Fusion, you can rapidly produce truly functional parts, at low cost, which can not only be used in prototyping, but also as final parts, in all the different phases of a Product Life Cycle (PLC). The introduction of HP Multi Jet Fusion parts in production can save costs compared to traditional technologies depending on the part and the production volume and adds additional value to the design process. One example of value-add is to allow new geometries and shapes that weren't possible before.

This also opens up interesting opportunities for spare parts, as the use of 3D printed parts can optimize supply chains and logistics in the last stages of a PLC.



Volume of 3D parts in each step of the PLC

The main applications where HP Multi Jet Fusion could offer an enhanced value versus CNC machining include:

1. Prototypes

A prototype is a preliminary design of a part or a product that is used in the development cycle to iterate and validate a concept until the final design is achieved. Functional prototyping allows for the testing of a concept early in the product design cycle before moving into production.

Data courtesy of NACAR

Design iterations of a doorknob

Design iterations of a speaker cover

HP Multi Jet Fusion benefits for prototypes:

- Low cost[1]
- Several parts with different design iterations can be printed at the same time
- Fast[2] time to part

2. Interior parts

For some low-volume products or machinery, manufacturing a mold does not make economic sense–therefore, some parts are manufactured with machining or sheet metal instead of injection molding. In these situations, there are different types of plastic parts–such as brackets or supports (e.g. sensor supports) that withstand small loads–that can be manufactured with HP Multi Jet Fusion instead of other traditional manufacturing technologies.

HP Multi Jet Fusion benefits for interior parts:

- Low cost[1]
- Assemblies can be optimized and redesigned to be unified
- Fast[2] time to part

3. Grippers/end effectors

An end effector or gripper is the device located at the end of a robotic arm, designed to interact with the environment. Depending on the yearly volume, geometry and mechanical requirements, grippers can be made with metal (CNC machining or in sheet metal) or plastic (machining or injection molding).

HP Multi Jet Fusion benefits for grippers/end effectors

- Parts can be produced with lower weight, which enhances precision and faster movements, especially when the robotic arm is moving, as inertia is reduced and the center of gravity is closer to the arm.
- Low cost[1]
- Assemblies can be optimized and redesigned to be unified

Here are some examples of types of grippers that can be produced with HP MJF:

Automotive Gripper: This gripper has 4 pneumatic suction cups; however, the larger frame has also been customized in order to contribute to the general stability of the gripper. The 4 suction cups are directly connected to independent fluid vessels, designed and 3D printed, then integrated into the overall part, bringing more shape versatility and optimization to the whole design and part.

Automotive gripper
Data courtesy of IAM 3D HUB

Pneumatic gripper
Data courtesy of IAM 3D HUB

Pneumatic gripper: This pneumatic gripper has been prototyped and developed specifically to customer requirements. One of these requirements is to ensure that the gripper's lifespan test passes one million cycles. Its design has been improved by strengthening some of its typical failure areas and by adding small and precise mechanisms to achieve better symmetric movements and grip stability.

The spiral shape of the pneumatic system has been designed not only by using typical splines but also mathematical growth functions in order to create the perfect spiral. When the spiral is filled with pressurized air, the gripper closes. When the air is released, the gripper opens again, allowing relatively fast opening and closing of the gripper by regulating the air input and output frequency. Design for 3D printing has made it possible to produce this gripper as one single part. With traditional manufacturing methods, it would have had to have been produced as multiple parts and then assembled.

4. Fluid ducts

Fluid ducts are parts—pipes, tubes or canals - used to convey fluid inside a system. Normally, ducts are produced by extrusion, but some smaller ones are made with CNC machining. The material used to produce the fluid vessels needs to be chemically compatible with the fluid. The porosity of the material can affect the fluid-tightness.

HP Multi Jet Fusion duct example

HP Multi Jet Fusion benefits for fluid ducts

- Fluid-tightness can be achieved without post-processing
- Unification of different ducts or parts improve performance (reducing leakage)
- Flow efficiency improvement
- HP 3D High Reusability PA 12 material[6] has high chemical compatibility[7] with several fluids, including water, brake fluid and alcohols

5. Manufacturing aids

Manufacturing aids are any kind of tool that is used in the production process to control quality or aid in manufacturing. They provide repeatability, accuracy, productivity and interchangeability in the process.

3D printing and CNC machining are already used to produce manufacturing aids in production lines, but the solutions that were available until now were very costly.

HP Multi Jet Fusion offers breakthrough productivity[2] compared to other 3D printing technologies and can significantly reduce the lead time to produce manufacturing aids. This increases flexibility during the manufacturing process, enabling faster reaction when changes (for example, changes to part designs) are required.

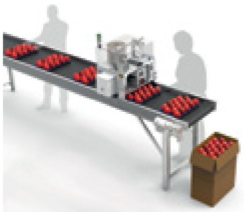
HP Multi Jet Fusion benefits for manufacturing aids

- Low cost[1]
- Weight reduction through lattice structures or topology optimization
- Freedom of design and higher flexibility
- Ability to unify separate assemblies

HP Multi Jet Fusion use cases

SIGMADESIGN vacuum applicator fitting

SIGMADESIGN is a product development services company, that offers solutions that help clients take their products from concept to production and beyond. Among other services, SIGMADESIGN provides industrial design, quality assurance and testing, and engineering support, in addition to end product manufacturing.



SIGMADESIGN fruit labeling machine

One of SIGMADESIGN's clients makes a fruit labeling machine. It is a high-value, low-volume machine that applies thousands of labels per hour, yet also requires precision to ensure that no fruit is damaged.

SIGMADESIGN was tasked with saving costs as well as improving the design of certain parts for this machine.

They identified several parts that could be enhanced with HP Multi Jet Fusion technology, including:

A vacuum applicator fitting—a part of the gripper of the arm that places the labels on the apples.

Vacuum applicator fitting

The original assembly is machined in aluminum. It operates at a vacuum pressure between -2 to -3 psi. The expected lifespan is that of the lifespan of the machine, which is in the range of tens of millions of cycles.

This part needed to be accurate enough to allow threaded inserts to be heat-staked into each of the upper holes. It was important for these holes to be produced within a specific tolerance to retain maximum strength between the threaded fitting and the part after the heat-staking process.

SIGMADESIGN solved the challenge by designing the part for 3D printing with HP Multi Jet Fusion.

Original CNC machined part | HP MJF part | Cross-section

Design optimization with HP Multi Jet Fusion

HP Multi Jet Fusion enabled SIGMADESIGN to:

- Print continuous airflow channels within the part, that were just not possible with CNC machining processes, reducing air leakage and improving part performance
- Optimize the part's geometry—previously constrained due to CNC production—to work within a defined space, preventing collisions with other moving parts
- Reduce the cost of the part by 68%[8] versus the original design

HP Inc. Drill extraction shoe

HP Inc. is a consumer electronics company that produces 3D & 2D printers, PCs and peripherals. HP is pioneering the use of HP Multi Jet Fusion technology to streamline processes throughout its supply chain and has identified myriad opportunities where HP Multi Jet Fusion can replace traditional manufacturing methods. Just one example is a tool in HP's printhead manufacturing line—a drill extraction shoe.

The nozzles of HP printheads are manufactured with a laser-cutting process. This process uses water to prevent overheating of the laser and the silicon plates. The drill extraction shoe is used during cutting to remove the silicon sludge and water that continuously appears, enabling a more efficient laser-drilling process.

Sufficient extraction pressure (~3 to 4.5 kPa) and a clean extraction shoe are needed for proper laser drilling. The tool must withstand a certain amount of heat caused by stray laser pulses during the drilling process.

As can be seen in the picture on the right, the original CNC machined tool on the left is made of 7 sub-parts, most of them mechanized from an aluminium block and two of them extruded from aluminium. The HP MJF redesigned part is on the right, and has been consolidated into a single part.

HP Multi Jet Fusion enabled:

- The water-tightness required for manufacturing aids that contain pressurized fluids, without needing to post-process or coat the parts
- The design to be optimized to reduce turbulence in the part using finite element analysis. The shape of the end of the pipe has been modified to optimize the flow during the section transition
- Cost reduction of 95% versus the original part[9]
- Weight reduction of 90% versus the original part[10] thanks to topology optimization and material reduction
- Lead-time reduction from 3-5 days with CNC machining to just 24 hours with HP MJF
- Assembly reduction by consolidating seven sub-parts into one single part

Learn more about HP Multi Jet Fusion technology at hp.com/go/3DPrint

Connect with an HP 3D Printing expert or sign up for the latest news about HP Jet Fusion 3D Printing: hp.com/go/3Dcontactus

1. Based on internal testing and public data, HP Jet Fusion 3D 4210 Printing Solution average printing cost-per-part is 65% lower versus the average cost of comparable fused deposition modeling (FDM) and selective laser sintering (SLS) printer solutions from $100,000 USD to $300,000 USD on market as of April, 2016 and is 50% lower versus the average cost of comparable SLS printer solutions for $300,000 USD to $450,000 USD. Cost analysis based on: standard solution configuration price, supplies price, and maintenance costs recommended by manufacturer. Cost criteria: printing 1.4 full build chambers of parts per day/5 days per week over 1 year of 30 cm^3 parts at 10% packing density on fast print mode using HP 3D High Reusability PA 12 material, and the powder reusability ratio recommended by manufacturer.
2. Based on internal testing and simulation, HP Jet Fusion 3D average printing time is up to 10 times faster than average printing time of comparable fused deposition modeling (FDM) and selective laser sintering (SLS) printer solutions from $100,000 USD to $300,000 USD on market as of April, 2016. Testing variables for the HP Jet Fusion 4210/4200 Printing Solutions: Part quantity: 1 full build chamber of parts from HP Jet Fusion 3D at 20% of packing density versus same number of parts on above-mentioned competitive devices; Part size: 30 cm^3; Layer thickness: 0.08 mm/0.003 inches.
3. Based on HP's unique Multi-Agent printing process. Excellent dimensional accuracy and fine detail within allowable margin of error. Based on dimensional accuracy of ±0.2 mm/0.008 inches on XY for hollow parts below 100 mm/3.94 inches and ±0.2% for hollow parts over 100 mm/3.94 inches, using HP 3D High Reusability PA 12 material, measured after sandblasting. See hp.com/go/3Dmaterials for more information on materials specifications. Based on the following mechanical properties: Tensile strength at 48 MPa (XYZ), Modulus at 1700 -1800 MPa (XYZ). ASTM standard tests with HP 3D High Reusability PA 12 material. See hp.com/go/3Dmaterials for more information on materials specifications.
4. Cost reduction calculated based on: Aluminium machined part = $22, MJF part = $11. Weight reduction calculated based on: Aluminium machined part = 355g, MJF part = 23g. Carbon footprint reduction calculated based on: Aluminium machined part carbon footprint: 19.7 kg CO_2 eq. MJF part carbon footprint: 0.97 kg CO_2 eq.
5. HP Jet Fusion 3D printing solutions using HP 3D High Reusability PA 12 provide 80% post-production surplus powder reusability, producing functional parts batch after batch. For testing, material is aged in real printing conditions and powder is tracked by generations (worst case for recyclability). Parts are then made from each generation and tested for mechanical properties and accuracy.
6. Industry-leading surplus powder reusability based on using HP 3D High Reusability PA 12 at recommended packing densities and compared to selective laser sintering (SLS) technology, offers excellent reusability without sacrificing mechanical performance. Tested according to ASTM D638, ASTM D256, ASTM D790, and ASTM D648 and using a 3D scanner for dimensional accuracy. Testing monitored using statistical process controls. Liters refers to the materials container size and not the actual materials volume. Materials are measured in kilograms.
7. Tested with diluted alkalies, concentrated alkalies, chlorine salts, alcohol, ester, ethers, ketones, aliphatic hydrocarbons, unleaded petrol, motor oil, aromatic hydrocarbons, toluene, and DOT 3 brake fluid.
8. Cost reduction data according to SIGMADESIGN: Cost per part: CNC machined $90. HP MJF $28.75.
9. Cost reduction data according to HP: Cost per part: CNC machined $450. HP MJF $18.
10. Weight reduction data according to HP: CNC machined part weight 575g. HP MJF part weight 52g.

References:

[1] Y. Altintas, Manufacturing automation. Second edition, New York: Cambridge University Press, 2012.

[2] Modern Machine Shop magazine. Sponsored by IMTS 2018 and AMT, "Modern Machine Shop. 2017 Executive Summary," Modern Machine Shop, Cincinnati, August 2017.

[3] J. P. P. Davim, Surface integrity in Machining, London: Springer, 2010.

[4] A. B. Varotsis, "3D Hubs," [Online]. Available: Alkaios Bournias Varotsis. [Accessed January 2018].

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