

Design guide

Direct Metal Printing



Contents

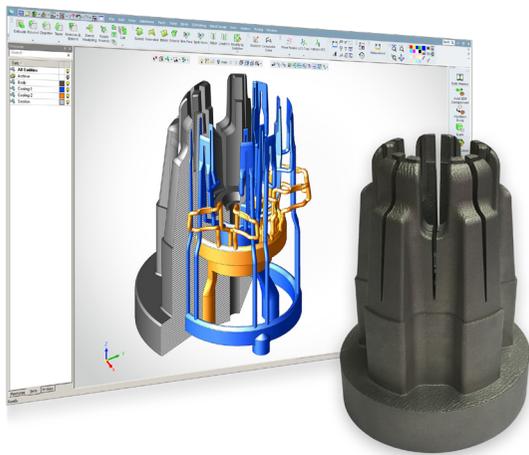
- 03 Why Direct Metal Printing
- 04 The Direct Metal Printing (DMP) Process
- 05 Basic Principles of DMP
- 13 Part Orientation Guidelines
- 19 Design Constraints
- 22 Design Guidelines
- 32 Post Processing



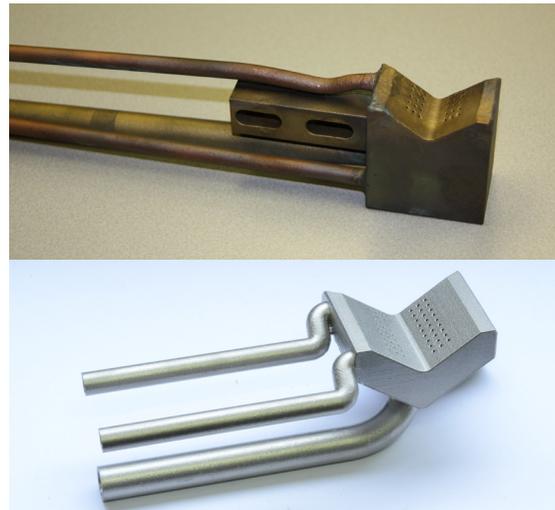
Why Direct Metal Printing

Direct Metal Printing (DMP) is an additive manufacturing technique that produces parts in a broad variety of metal alloys.

Starting from metal powder the product will be manufactured layer by layer. Each layer is then melted on to the previous one creating a strong and dense part (up to 99.9%) comparable with conventional manufacturing techniques (milling, casting). In this process almost no waste material is created and complex geometries can be built that could not be manufactured otherwise.



Manufacturing “freeform” internal complex features (e.g. conformal cooling channels) is ideally suited for dmp



Combining multiple parts into one single product, eliminates the weakness of assembly processes e.g. welding, thereby adding functionality

BENEFITS OF DIRECT METAL PRINTING

Weight Reduction

e.g through lattice structure or topology optimization



Customized products

e.g internal structures such as complex cooling channels, that otherwise could not be produced



Increased functionality of parts

e.g thermal, flow, structural functionality, or integration of various functions into one part



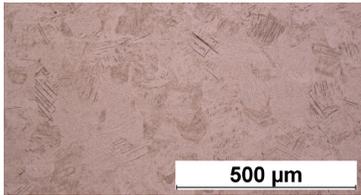
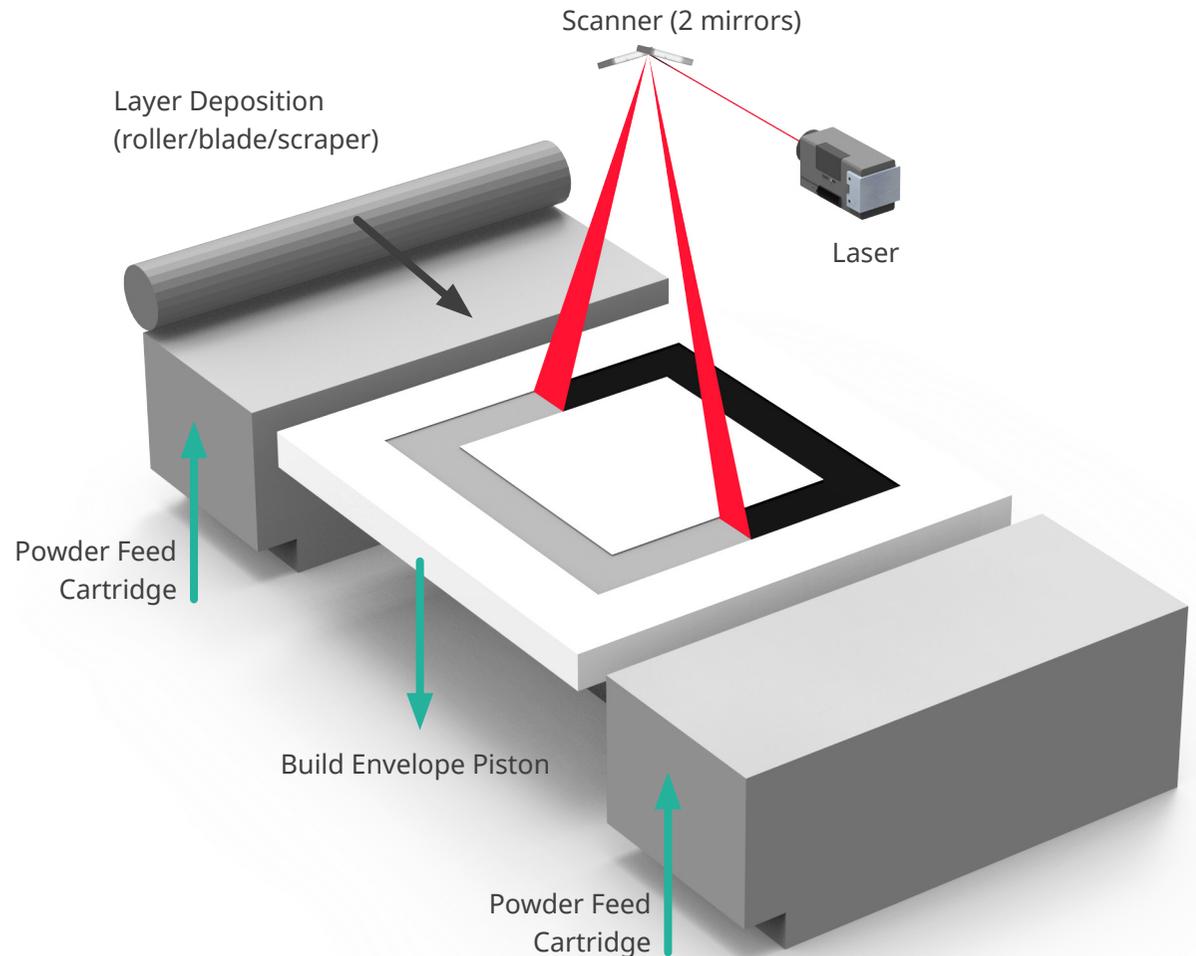
Fast production

no tools or extensive programming are required



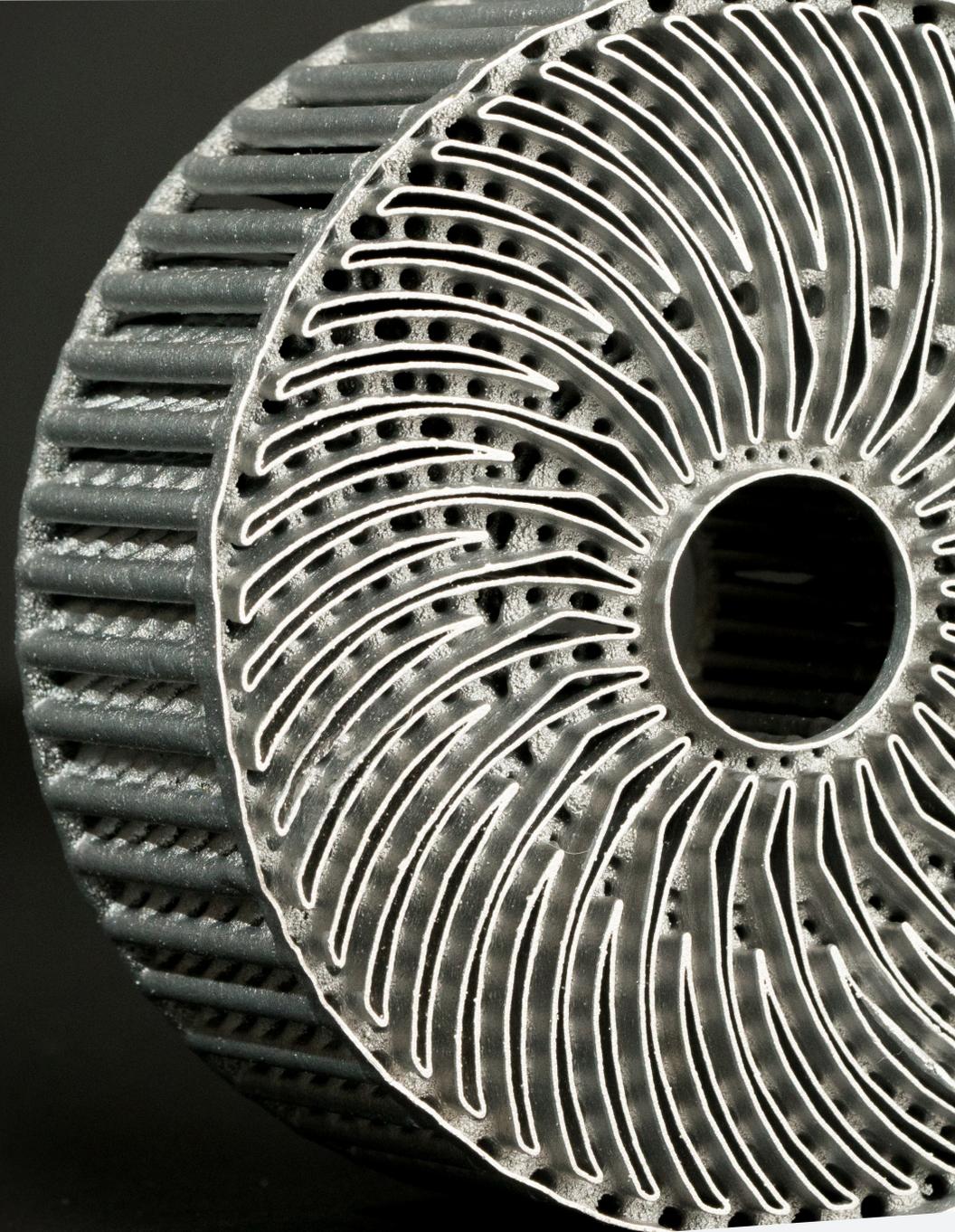
The Direct Metal Printing (DMP) Process

- No binders, no additives
- High Power laser -> fully dense parts (up to > 99,9%)
- High accuracy (down to 10µm layers)
- Process physics with extremely rapid cool down
- Unique super fine microstructure
- Excellent mechanical properties
- Print directly from CAD-model



Microstructure of LaserForm Ti Gr5 (A) as built in DMP process without additional stress relief or heat treatments that further improve the structure

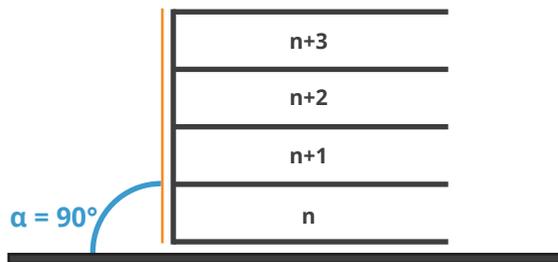
Basic Principles of DMP



Surfaces

Basic terminology

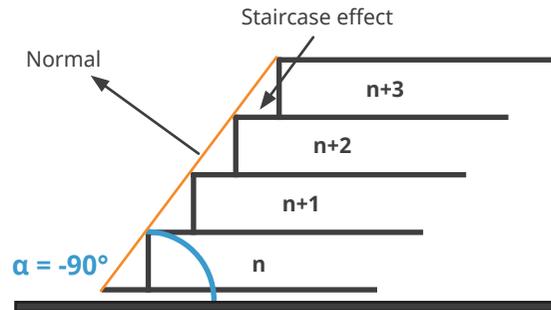
MIDDLE SURFACES



$\alpha = 90^\circ$

α = angle between horizontal build platform and tangent line of the object surface

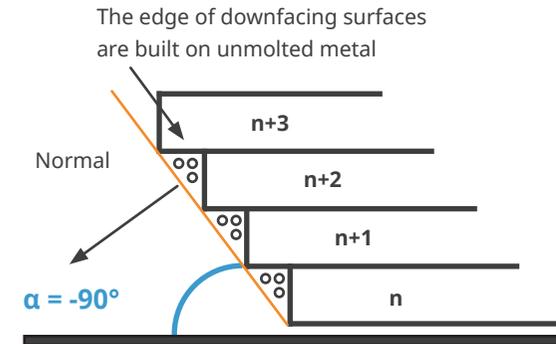
UPFACING SURFACES



$\alpha = -90^\circ$

Upfacing surfaces are characterized by the normal of the object pointing away from the build platform

DOWNFACING SURFACES



$\alpha = -90^\circ$

Downfacing surfaces are characterised by the normal of the object pointing towards the build platform.



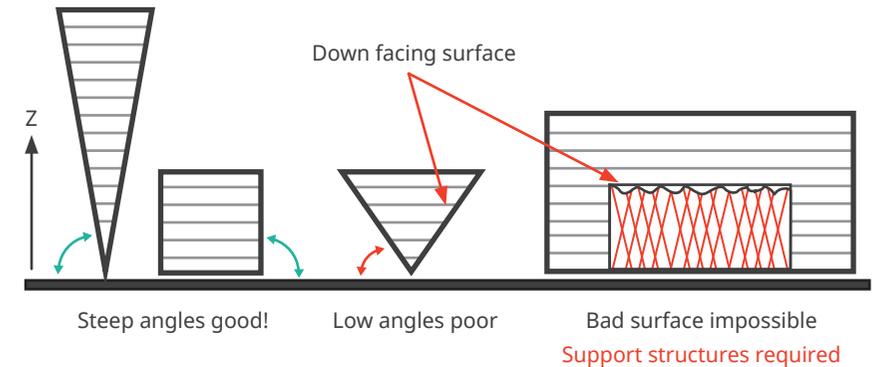
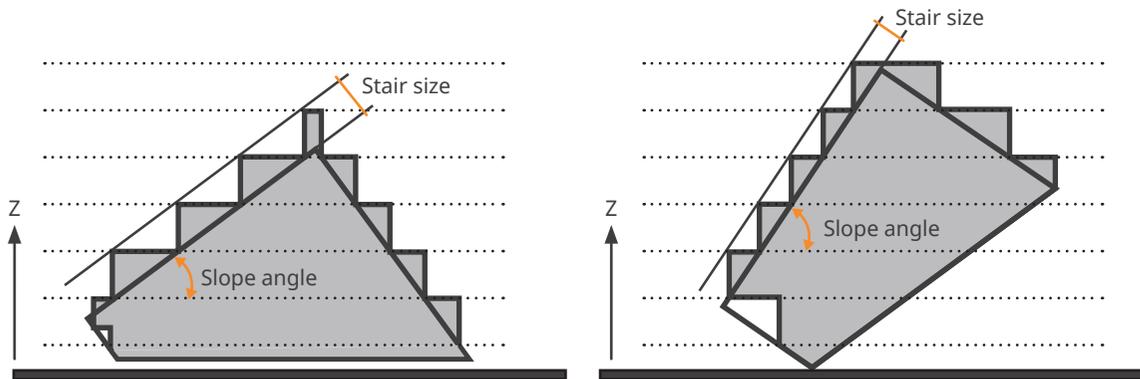
Example of **upfacing surfaces** in different angles ranging from: 0° (left) to 90° (right) with steps of 15°



Example of **downfacing surfaces** in different angles ranging from: 75° (left) to 0° (right) with steps of 15°

Surfaces

Influences on quality



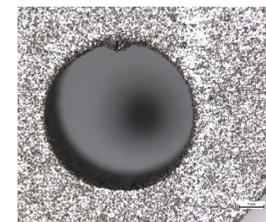
Surface quality in DMP is dependent on the orientation of the surface

The stair stepping effect that is intrinsic to all additive layer manufacturing technologies can be reduced by building more vertically or completely horizontally oriented surfaces.

On upfacing surfaces this effect is clearly visible and important.

On down facing areas, the dross formation effect is in most cases bigger than the stair stepping effect. Dross is the undesired amount of molten material and particles as a consequence of melting on loose powder.

- The lower the angle, the more dross formation you have, resulting in worse surface quality
- Low angles need support structure
- Supported faces have worse quality



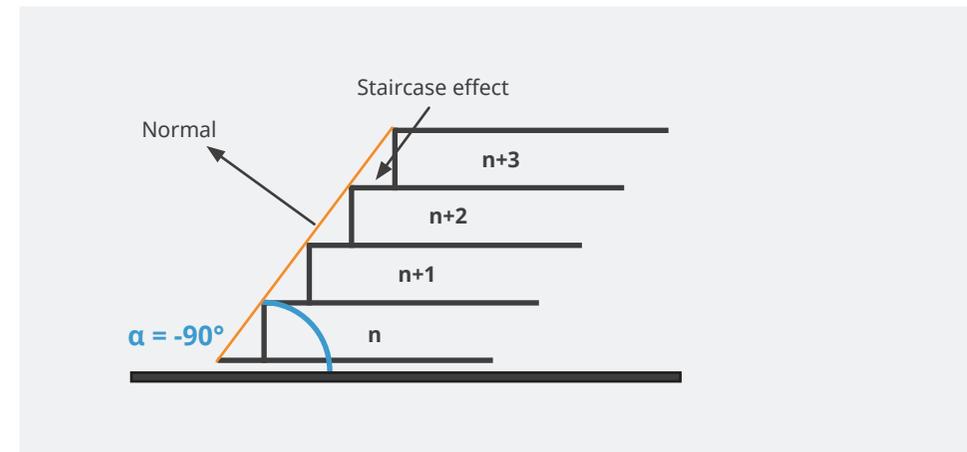
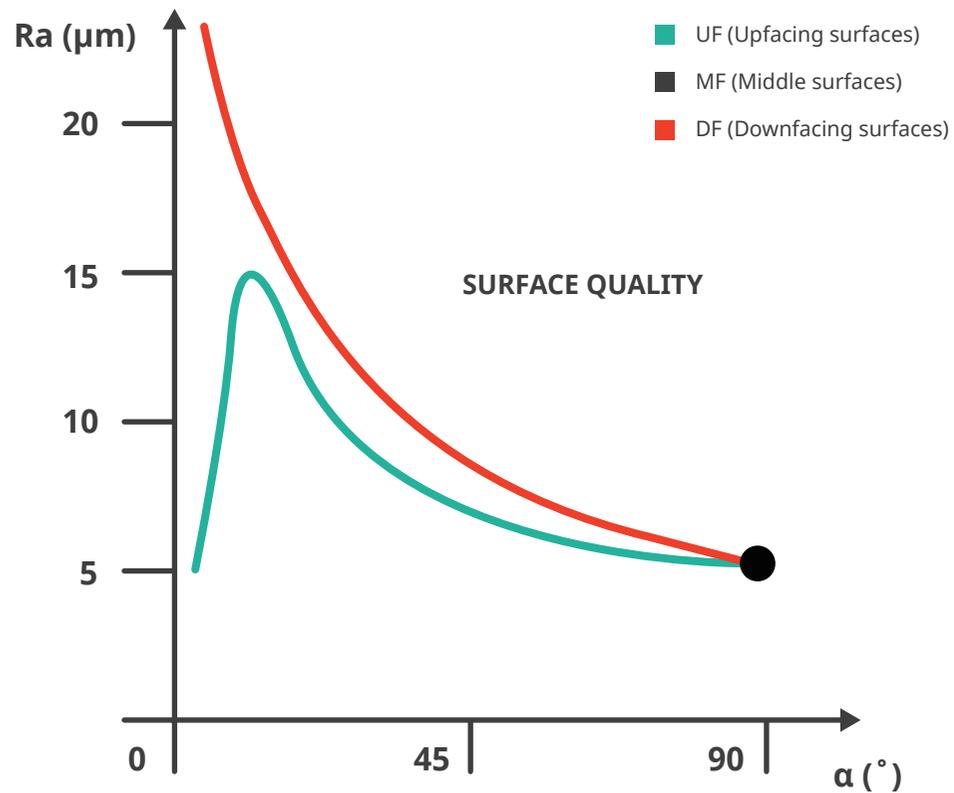
Dross formation:

In downfacing surfaces the melted layer sags through the loose powder underneath, resulting in dross formation.

Surfaces

Influences on quality

Surface quality depending on type of surface and angle



Thermal Stresses

Basic principles

Why do we have thermal stress in the part?

- High melting temperatures
e.g. Titanium: 1650°C; Stainless steel: 1200°C
- Fast cooling rates (< 1ms – 100°C)
- Stresses accumulate throughout layers, because in each layer the top layers are heated and cooled down again. Expansion and shrinking, blocked by already solidified layers causes residual stresses
- Deformation behavior is material specific

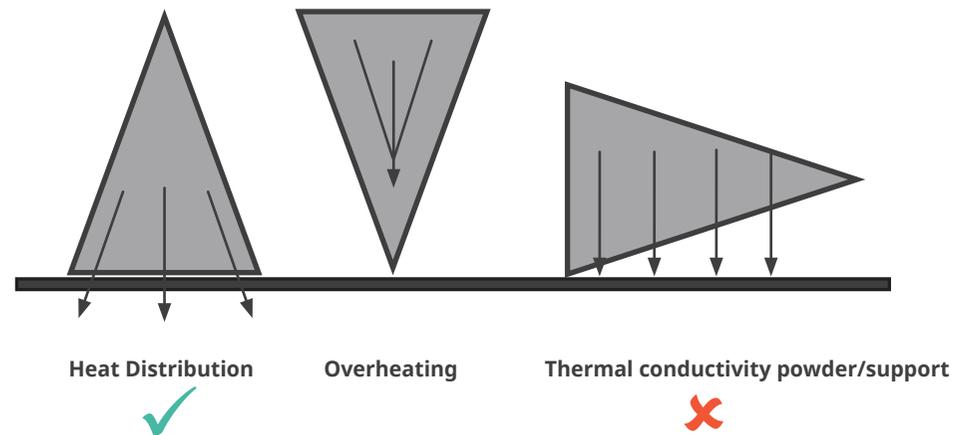
Important influences on those stresses

$\sigma T \sim A$ Thermal tension is proportionate to the melted surface area. To mitigate this:

- Reduce area to be melted per layer
- Ensure longest direction of part along Z-axis
- High number of small sections is better than one big section

$\sigma T \sim \Delta T$ Thermal tension is proportionate to the temperature drop during solidification

Make sure you have good heat transfer to the baseplate and machine. The better the heat is transferred, the less a part will warp.



Thermal Stresses

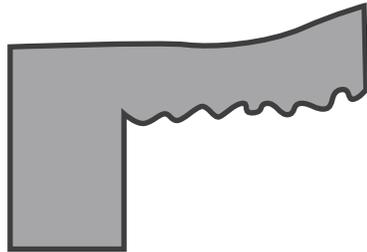
How to deal with them

How to handle thermal stresses

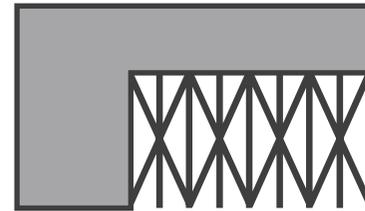
- Residual stresses result in parts that want to warp
- Support structure is needed to avoid warping and keep part in position
- Stresses remain in the part after building – if support is immediately removed, the part will still deform to the wanted position.
- Heat treatment is required after powder removal, prior to platform and support removal, to release the stresses.



DESIGNED MODEL



WARP AND DROOP FORMATION

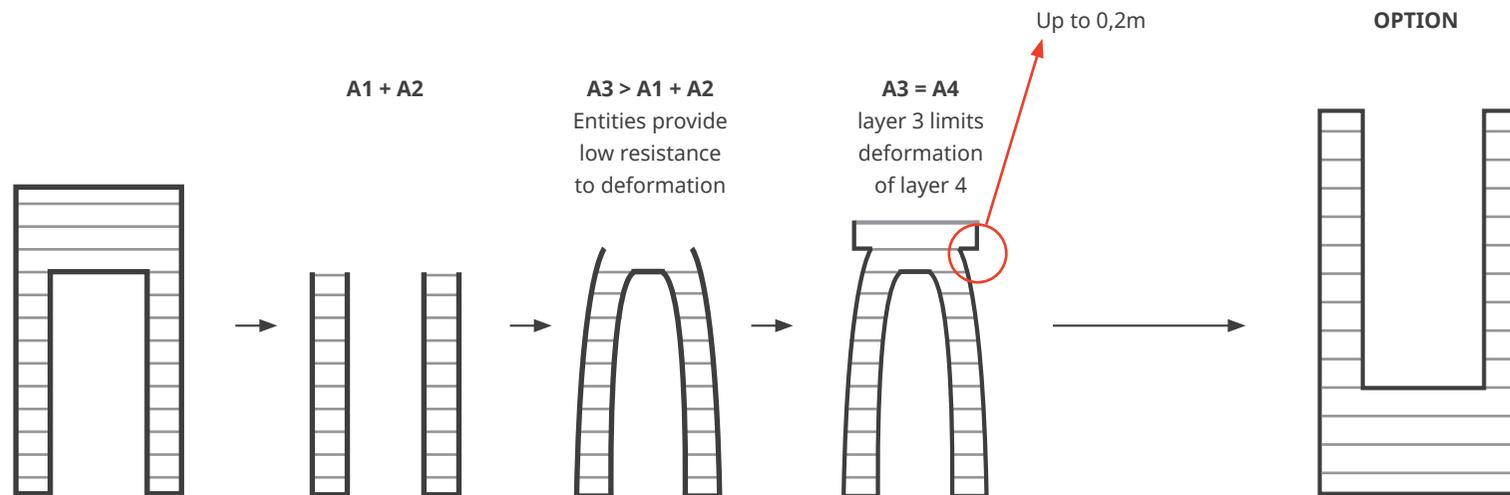


SUPPORT STRUCTURE

Shrink lines

Shrink lines appear when two separate entities are connected in one layer

- The connection surface shrinks and pulls the two entities towards each other
- Next layer is printed on original dimensions again
- Line visible in the part
- Typical on bridges/internal channels



Supports

Supports are necessary to minimize droop formation, warping and shrinking lines

- Less droop formation on downfacing regions
- Better heat transfer through solid supports
- Prevent warping and keep part on fixed location
- Minimize shrink lines

There are a multitude of possible support structures. Here are some examples:



Wall Support



Solid Support



Lattice Support



Solid Wall



Cone Support



Manual Cone

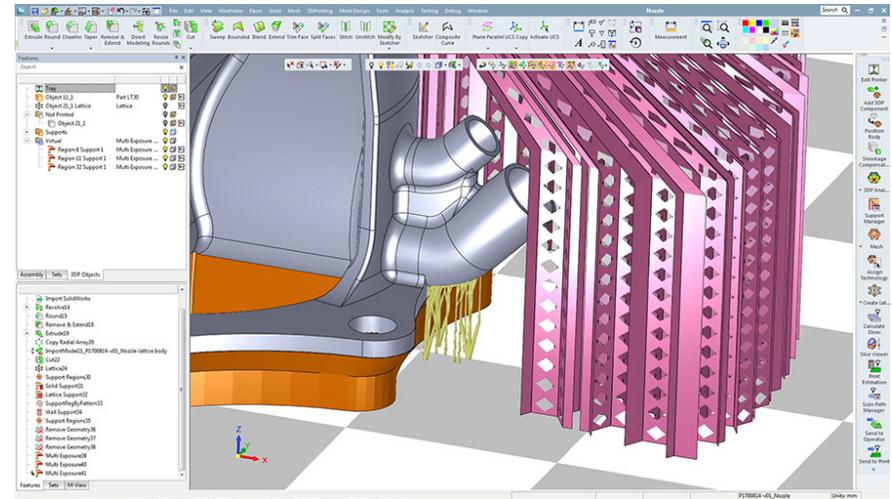


Skirt Support



Multi Exposure

- Block supports are good against droop formation
- Solid support is needed for heat transfer, to prevent warping and reduce shrink lines



Part Orientation Guidelines



Part Orientation

Overall build quality

Orienting the part based on overall quality is mainly based on the downfacing surfaces.

Downfacing surfaces are the worst surfaces with a high roughness of the part. So by decreasing the amount of downfacing area we can say in general that we will increase the quality of that part.

Downfacing surfaces are the surfaces below the self-supporting angle (α).

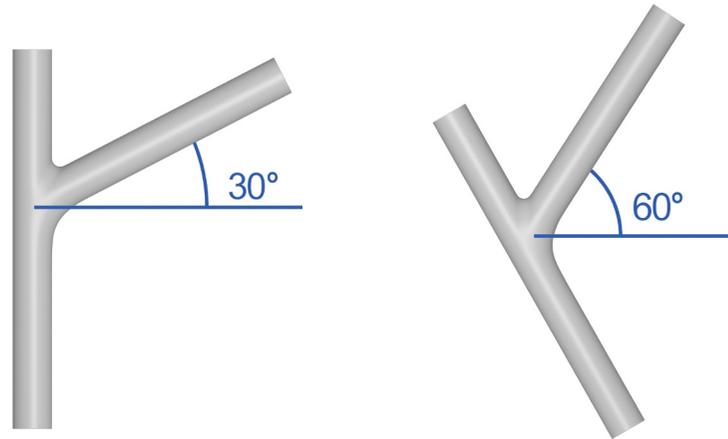
The self-supporting angle depends on material and the printing process

- Ti-alloys $\alpha=40-45^\circ$
- Steel, CoCr, Aluminium-alloys $\alpha=50-55^\circ$

The example below shows an example of this situation.

The left part has a leg that makes an angle with the buildplate of 30° , so this leg has to be supported (because it is below the self-supporting angle)*.

By rotating the same part 30° we see that the leg makes a 60° angle with the buildplate. In this way we don't need to put support in this region increasing the overall quality of that part.

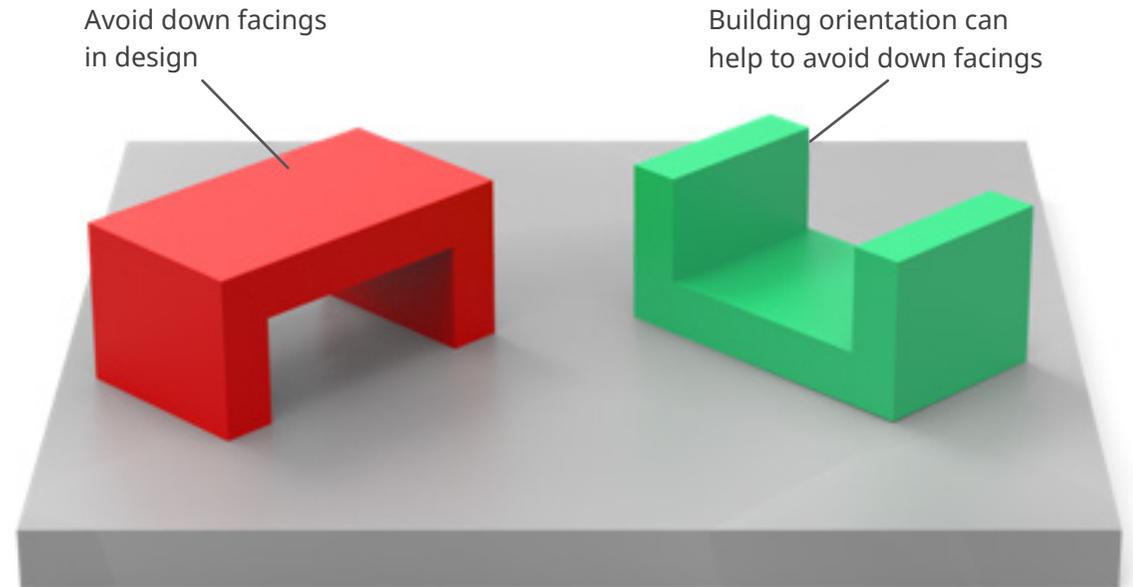


*Metal Printers with a roller system, like ProX DMP 100, 200 and 300 can reach angles for Ti as low as 30°

Part Orientation

Avoiding downfacing surfaces

Avoid big overhang sections or large downfacing sections. Parts will build much better if you have middle and upfacing sections instead of downfacing areas.



Orientation in red is bad, because of large overhang.

Orientation in green is good because it is built immediately on the baseplate and has no downfacing area.

Part Orientation

Specific features

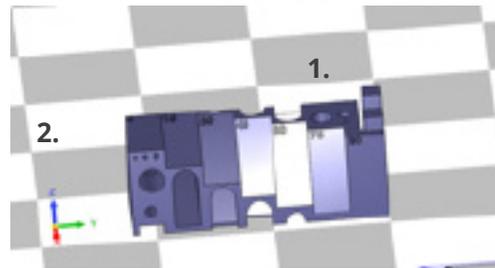
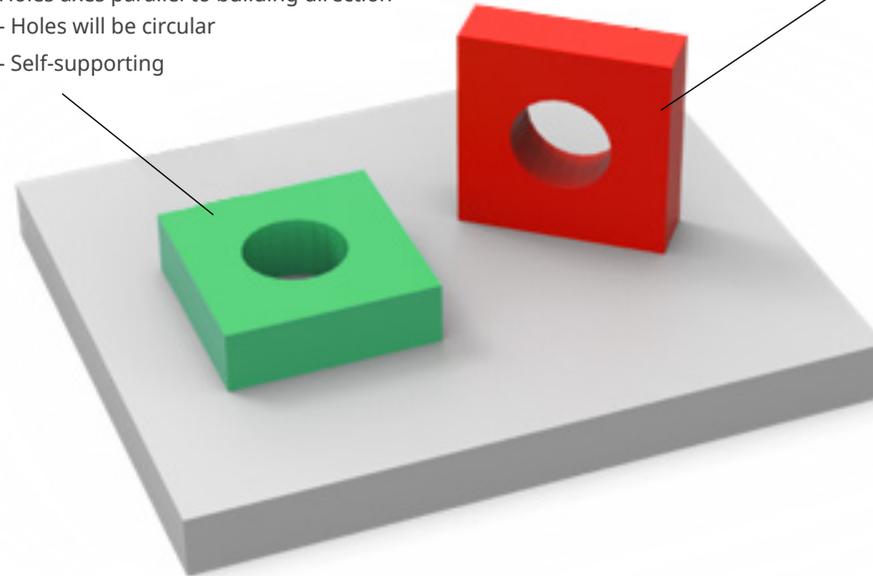
The quality of printing features like holes, pockets, screw threads, etc. depends on the orientation of the part.

The best quality is when printing in the Z-direction (perpendicular to the build platform).

When printing these features in the X/Y-direction (parallel to the build platform) the quality of these features gets worse due to the downfacing effect.

Holes axes parallel to building direction
- Holes will be circular
- Self-supporting

Holes axes perpendicular to building direction
- Holes will be oval
- Diameter > 8mm - Support needed
- Diameter < 8mm - Self supporting



1. Holes in the z-direction
2. Holes in the X/Y-direction



Dross formation in downfacing surfaces.

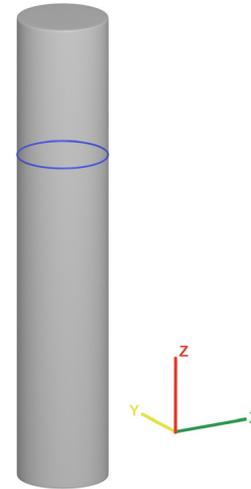
Part Orientation

Thermal stresses

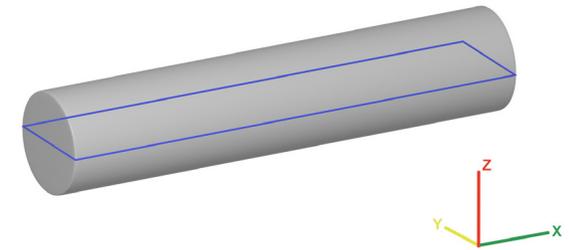
When orientating the parts we want to keep the thermal stresses as low as possible.

These thermal stresses are created by first heating locally the powder and a rapid cooling after melting the powder. One way to keep the stresses as low as possible is to keep the cross-sections (so what is actually scanned every layer) as small as possible.

In the picture on the right: The left orientation has the smallest cross-section and the thermal stresses would be reduced to a minimum. The orientation on the right can be printed but a very rigid support structure is necessary to keep the part in place.



Small cross-section

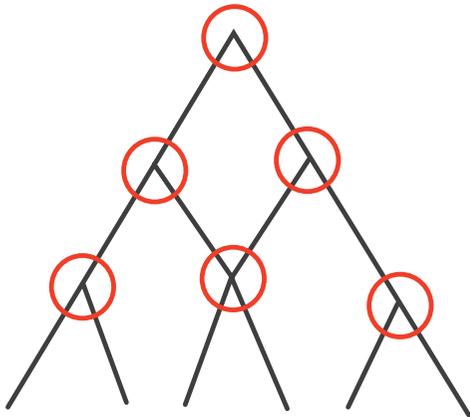


Large cross-section

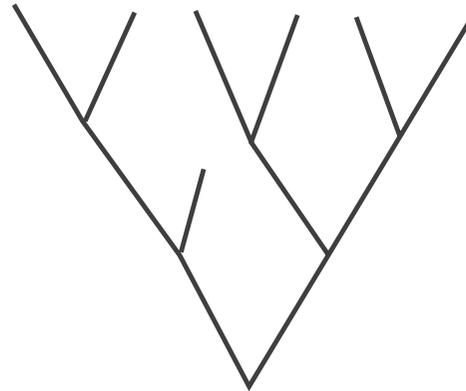
Part Orientation

Avoiding shrink lines

Diverging orientation preferred over converging



Everywhere you have two entities coming together, you create a shrink line, so at every red circle you will get a visible line.



In this design you are diverging and so new entities are made instead of connected, thereby eliminating shrink lines.

Design Constraints



Design Constraints

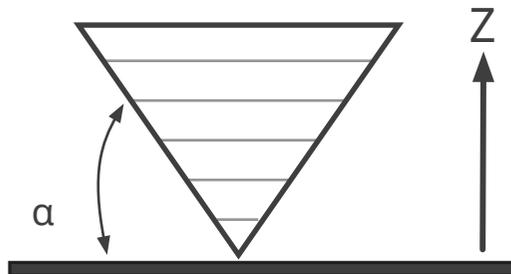
What can be built without support?¹

Steel, stainless steel, Inconel

- Big surface $\alpha > 60^\circ$
- Medium surface $\alpha > 50-55^\circ$
- Small surface $\alpha > 45^\circ$

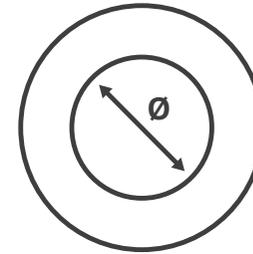
Titanium, aluminum

- Big surface $\alpha > 50^\circ$
- Medium surface $\alpha > 40-45^\circ$
- Small surface $\alpha > 35^\circ$



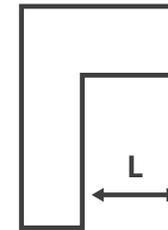
Horizontal circular holes

- Supportless $\text{Øin} < 8\text{mm}$
- Support needed $\text{Øin} > 10\text{mm}$



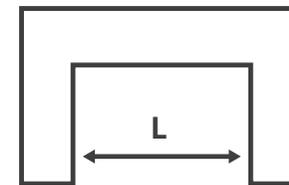
Horizontal bridges

- Supportless $L < 1,2\text{mm}$
- Support needed $L > 1,5\text{mm}$



Horizontal downfacing flange

- Supportless $L < 0,75\text{mm}$
- Support needed $L > 0,75\text{mm}$

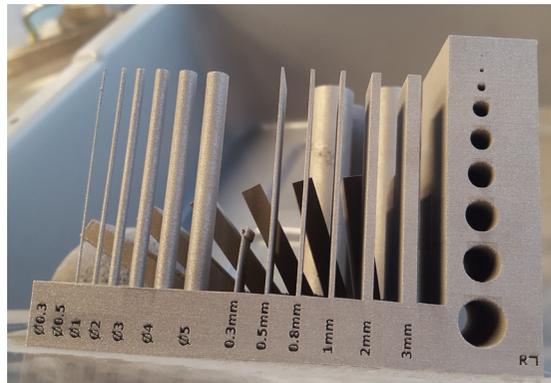


¹ These values are experience based for ProX DMP 320 printers and are subject to change based on printer model, specific geometries and improved build styles.

Design Constraints

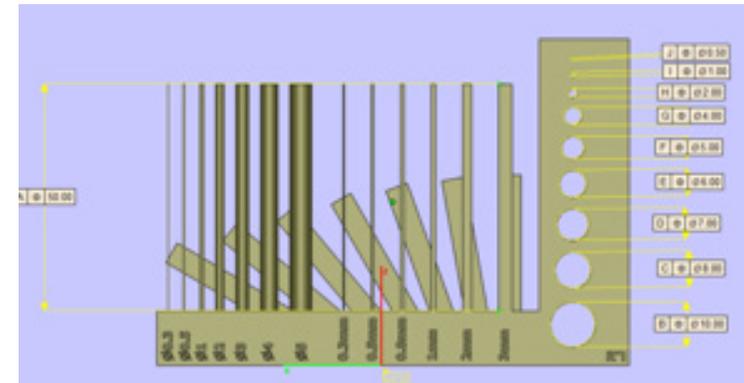
Small features¹

- Strongly dependent on
 - Material
 - Orientation
 - Part geometry
- Minimal achievable values
 - Minimal wall thickness
 - 0,18mm (not gas tight)
 - 0,20 - 0,25mm (gas tight)
 - Minimal pillar size
 - 0,18mm
 - Minimal hole size
 - 0,30mm



This test sample illustrates geometry dependence. The 0.3 and 0.5mm pillar and the 0.3 mm rib broke off, as here they were designed as stand-alone features in 50mm high.

The smallest pillar was to fragile on this length that it breaks very easily on unloading the part.

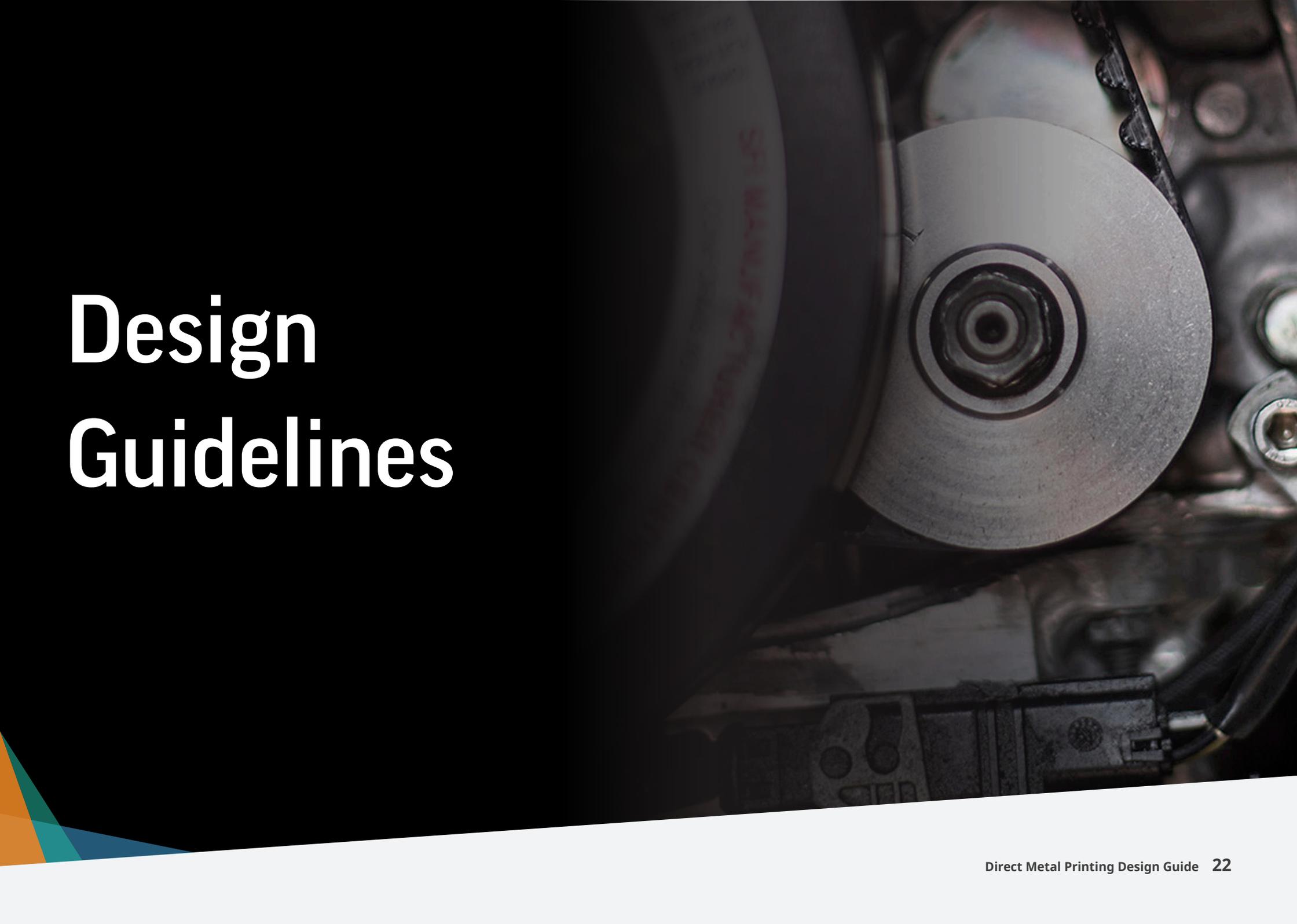


The smallest wall build up to a certain height, because than it starts to bend, because it is to fragile, this shows that we can perfectly build those walls but only for a limited height.

For the smallest hole size: if we need to print very small holes horizontally, it is advised to offset them, so you compensate the dross formation on the top of the hole.

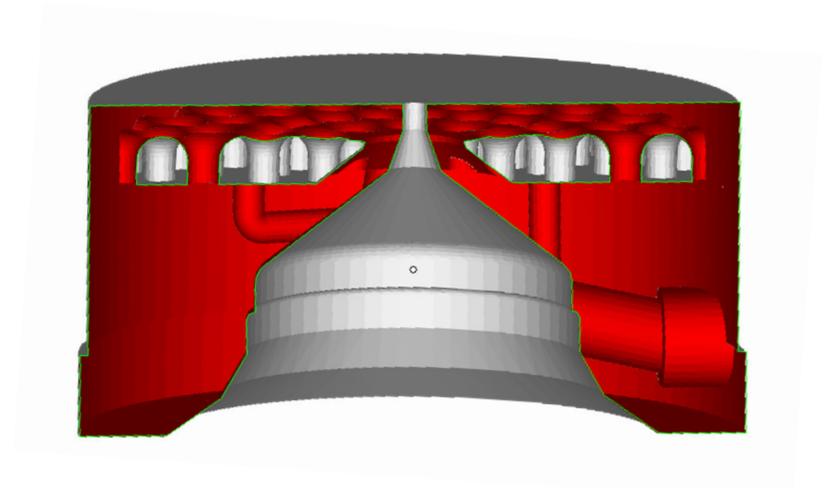
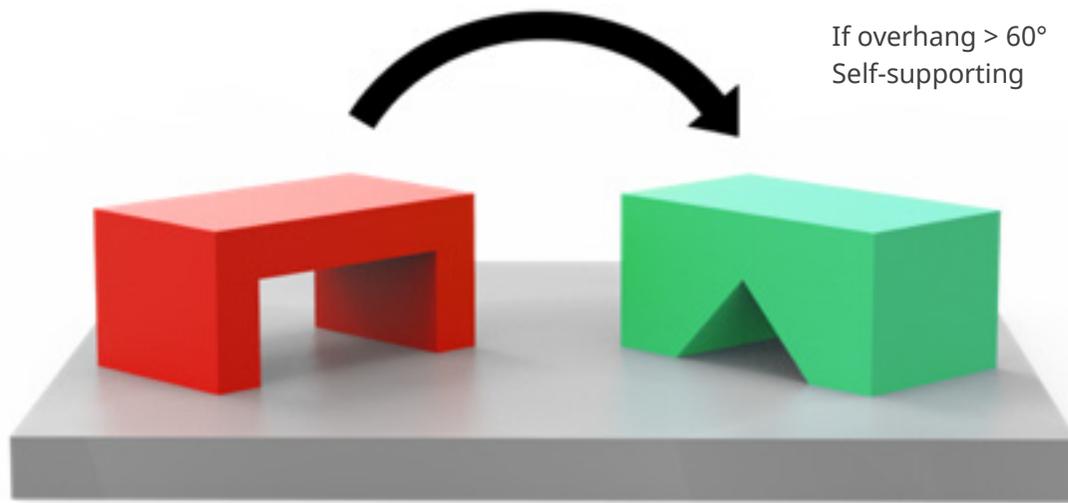
¹ These values are experience based for ProX DMP 320 printers and are subject to change based on printer model, specific geometries and improved build styles.

Design Guidelines

A close-up photograph of a metallic component, possibly a nozzle or valve, with a circular opening in the center. The component is set against a dark, blurred background of other mechanical parts. The lighting highlights the texture and contours of the metal.

Design guidelines

Avoid downfacing surfaces and create self supporting geometries

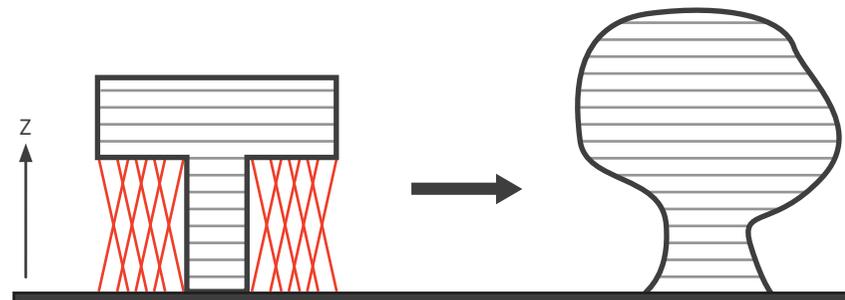


Design guidelines

Design freeform structures

- Avoid building parts designed for casting or CNC. They typically have:
 - Sharp corners
 - No progressive build up

- Use freeform structures
 - Avoid downfacing area resulting in better surface quality and less support needed
 - Achieve higher level of accuracy
 - In many cases achieve more weight reduction



Design guidelines

Dimensional accuracy

- Gradual transitions between layers:
 - Use fillets (radii), arcs
 - Use chamfers
 - Use organic designs } Avoid stress concentrations
- Use enough supports to fix the part into position, heat treatment will release the stresses afterwards
- Topological optimized designs
 - Often easy to build
 - Often lower α 's possible without supports
 - Less supports > less deformation > better product!
- Apply conventional post-machining to increase accuracy



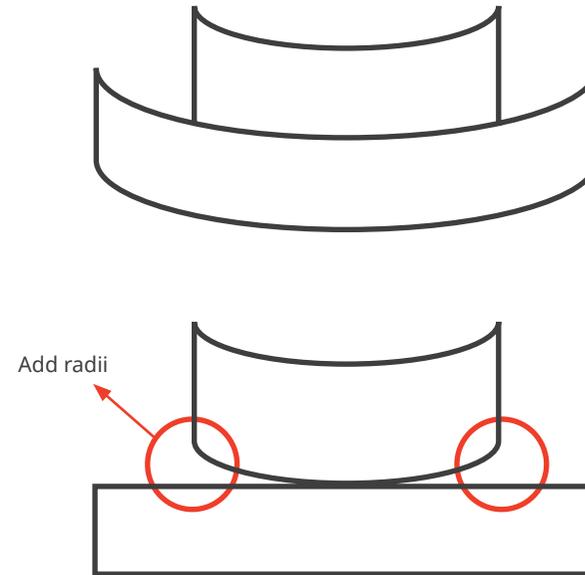
Topologically optimized satellite bracket for Thales Alenia Space

- 189.0 x 229.5 x 288.5 mm
- Better stiffness-to-weight ratio and 25% weight savings vs traditional design
- Printed with LaserForm® Ti Gr5 (A) on a ProX® DMP 320 Metal Printer

Design guidelines

Add radii

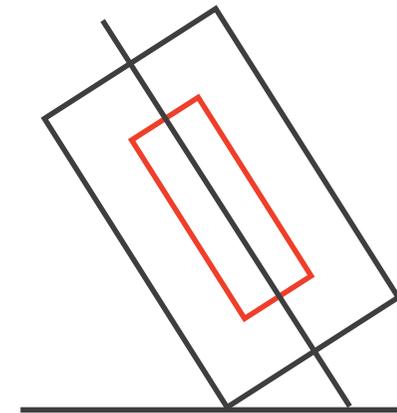
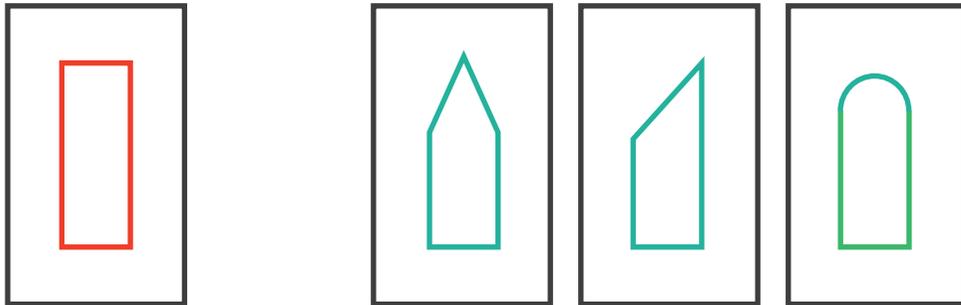
- Massive parts accumulate a lot of stress
- Need to take care of design to avoid cracking at the baseplate or on geometry changes.
Crack initiates where you have a high stress concentration, for example on corners
- Use radius and offset in connection with the baseplate
- Typical radius: 2.5 - 5mm



Design guidelines

Channel design

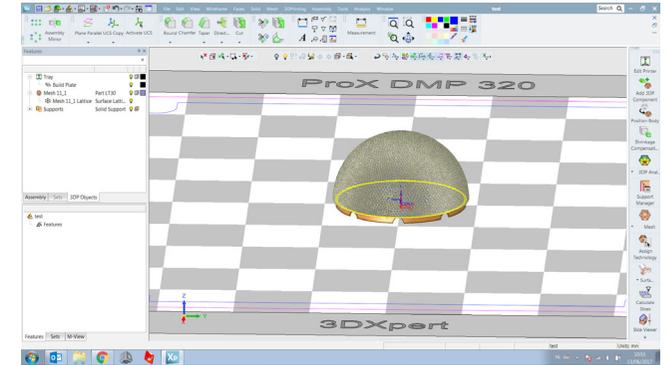
- Large (internal) overhangs are not feasible to print
 - Change design of internal channels (closing at $>45^\circ$)
 - Angle part at a self supporting angle (45°)
 - Extra support structure possibly needed at the outside of the part



Design guidelines

Weight saving techniques

- Scaffold/lattice structures
 - Save weight
 - Increase bone attachment for medical applications
- Different types of scaffold/lattice structures are possible
- Mechanical parts require additional analysis



This part shows different scaffold structures that all enable increased bone attachment in medical implants.



Combustion chamber, Crosssection of an ESA combustion chamber with significant weight saving with a 12% volumetric density mesh

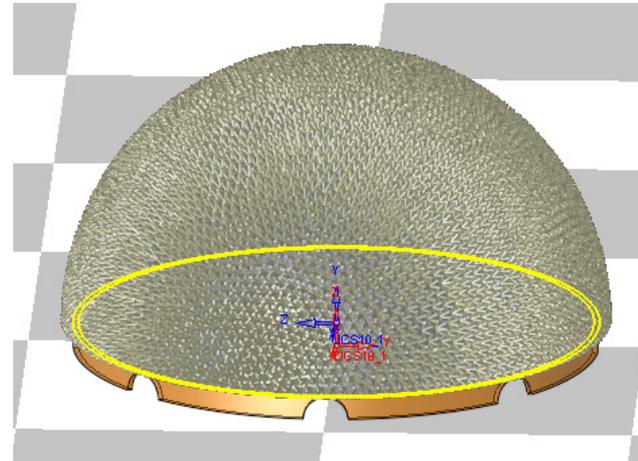


Antenna bracket (190 x 230 x 290mm) for geostationary telecommunications satellites produced by Thales Alenia Space

Design guidelines

Powder removal

- Check internal cavities, on part because powder can become trapped here
 - Add powder removal relief holes at strategic locations in the part
 - Add small tubes to enable blowing air into the part more easily
- Powder typically has good flowability, making removal possible with pressurized air and vibrations



The inside of this part is hollow, so it contains a lot of powder. Holes at the bottom below the wire EDM offset to remove the powder

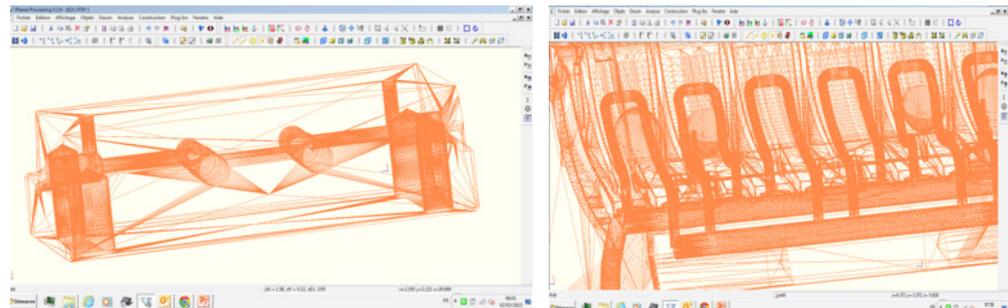
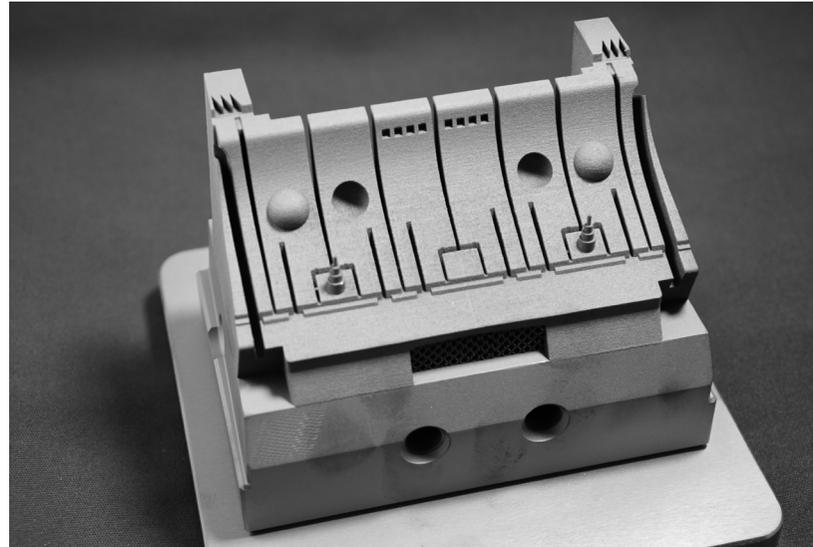
Design guidelines

Hybrid build-ups

Bulky parts are not always feasible for AM or maybe too massive.

The following two approaches offer an economic solution:

1. Building complex structure on already created CNC part
 - Careful alignment in the machine is important
 - Top section needs to be flat
2. Building complex structure on baseplate and mill baseplate afterwards:
 - Used for mold applications



Mold with conformal cooling printed on a CNCed section of the mold

- Lower left: Low complexity, cnced section of the mold

- Lower right: Complex conformal cooling channels in 3D Printed section of the mold

Design guidelines

Do's and Don'ts

Do

- Increase added value
- Functional requirement priority
- Design in an additive way: topology optimized, freeform
- $\alpha > 45^\circ$
- Diverging design
- Arcs/filles/chamfers
- Decrease area = decrease volume
- Avoid big area changes between layers
- Determine build orientation as soon as possible during design process

Don't

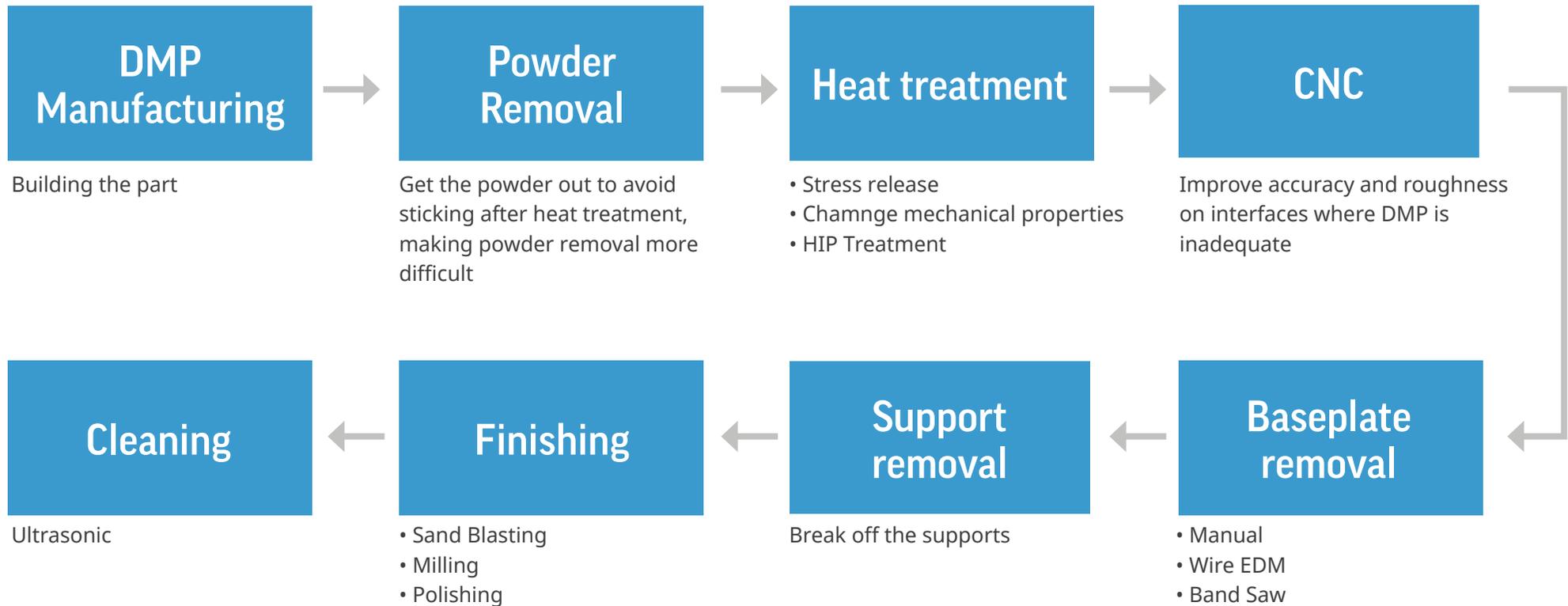
- Design in a subtractive/conventional way
- $\alpha < 45^\circ$
- Converging
- Straight corners, flat overhang
- Section increase
- Manufacturability priority

Post Processing



Post Processing

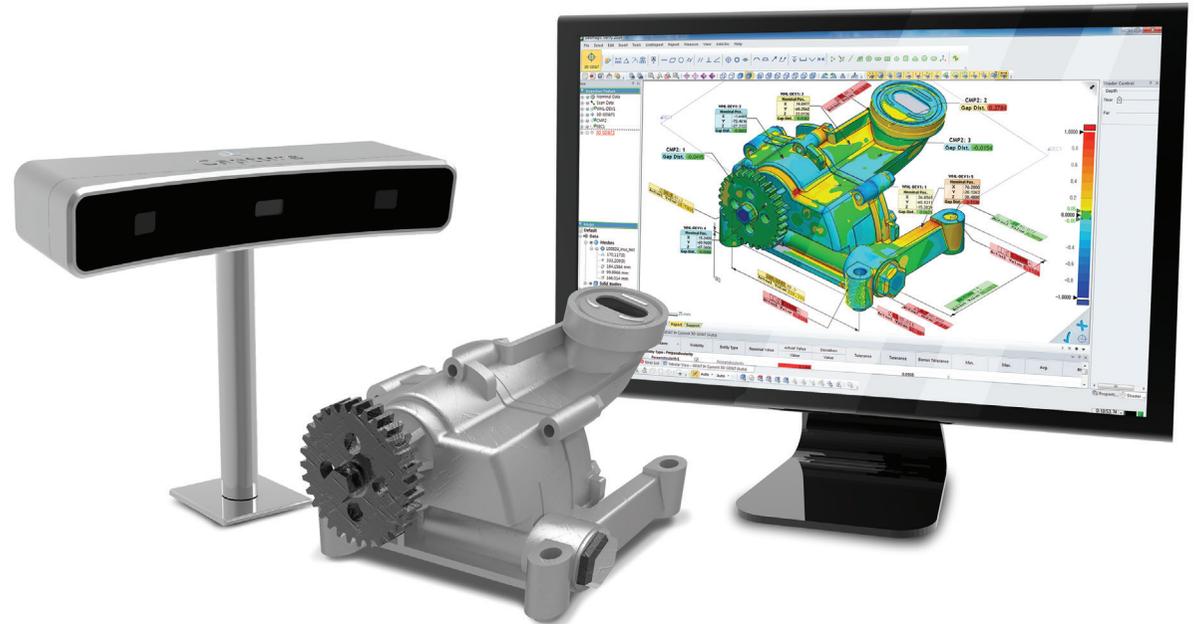
Typical process flow



Post Processing

Additional post-processing options

- Apply coating on parts
- Quality checks:
 - X-ray to check internal channels
 - Optical scan to check dimensional accuracy
 - 3D Systems Geomagic software can deform the part based on scan results to compensate for inaccuracies



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