Design Guide

Direct Metal Printing Design Guide

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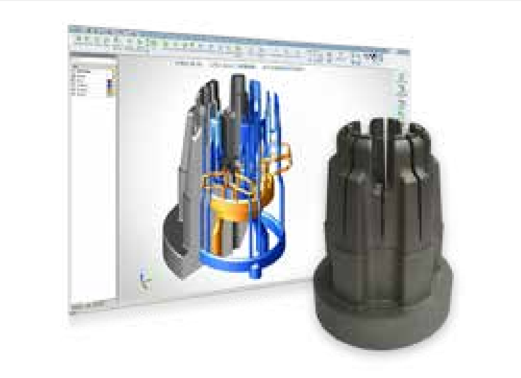
3D SYSTEMS

Contents

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 is manufactured layer by layer. Each layer is melted onto 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.



DMP is ideally suited for manufacturing complex, organically-shaped internal features (e.g. conformal cooling channels)

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
Use of lattice structures, topology optimization, etc.

Greater design freedom
Ability to make optimized organic shapes

Increased functionality of parts
Including thermal, flow, and structural functionality, or integration of various functions into one part

Enhanced system-level performance
Improved fuel efficiency, reduced maintenance

Customized products
Internal structures like complex cooling channels that could not be produced otherwise, patient-specific applications in healthcare, etc.

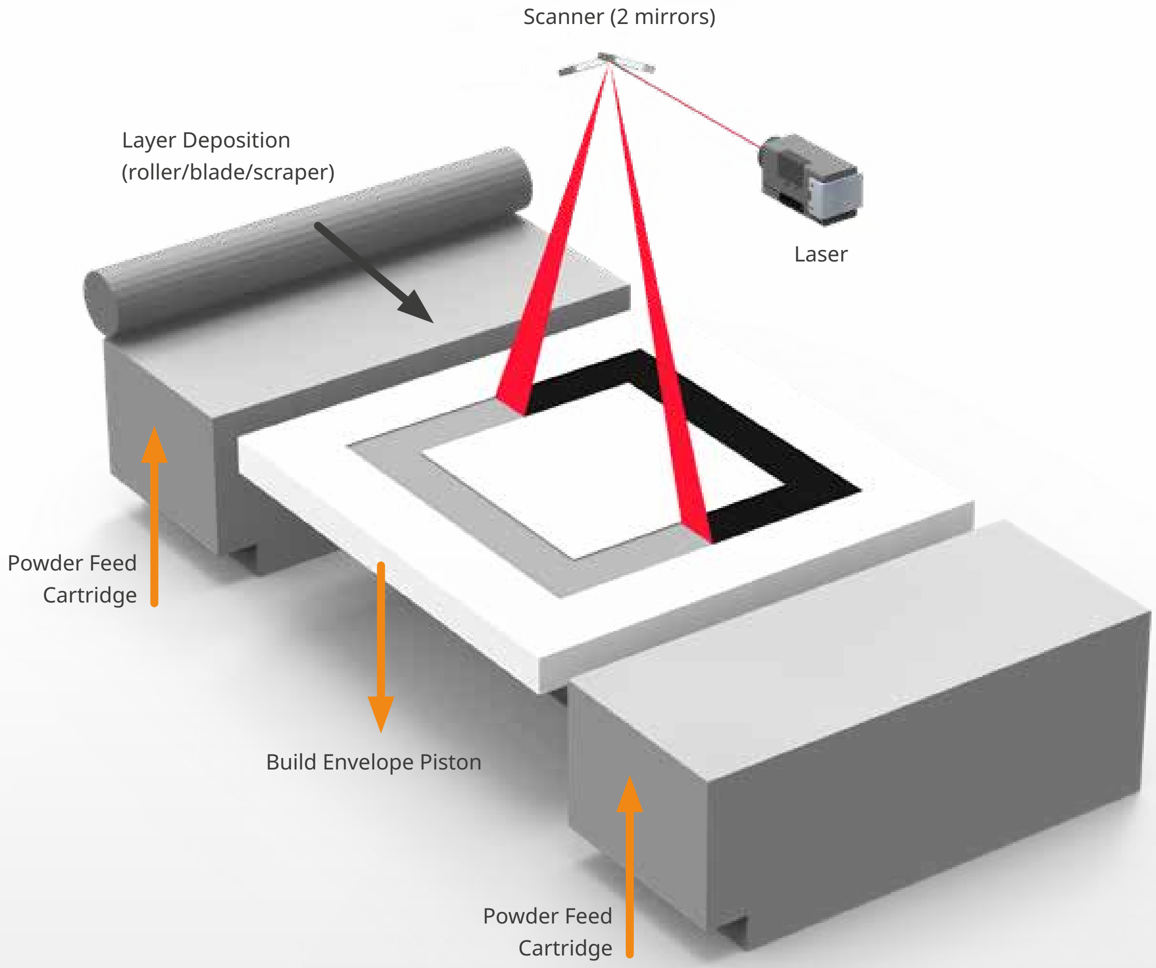
Part count reduction and removal of secondary operations
Reduction or elimination of assembly

Fast production
No tools or extensive programming required

Waste reduction

The Direct Metal Printing (DMP) Process

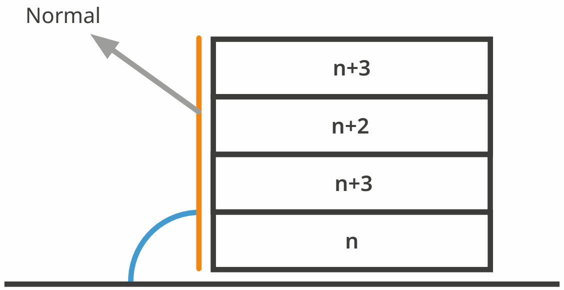
- Layers of metal powder can be deposited in increments as low as 10 microns
- Laser scanners apply optimal energy density to fully melt the powder into fully dense parts (up to >99.9%)
- Bi-directional coating of the powder increases throughput
- Ultra-low vacuum allows for <15 ppm oxygen
- Argon is recycled to minimize consumables for long builds
- Additional in-situ monitoring tools are available to inspect and qualify products



Basic Principles of DMP

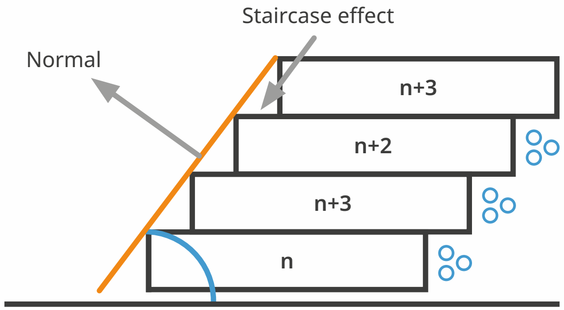
Basic Terminology

MIDDLE SURFACES



Middle surfaces are characterized by the normal of the object pointing parallel to the build platform

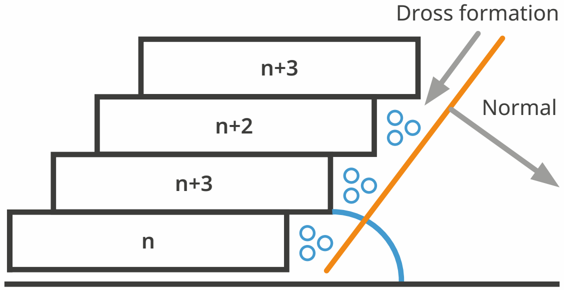
UPFACING SURFACES



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

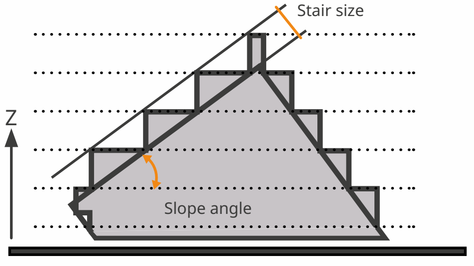
DOWNFACING SURFACES

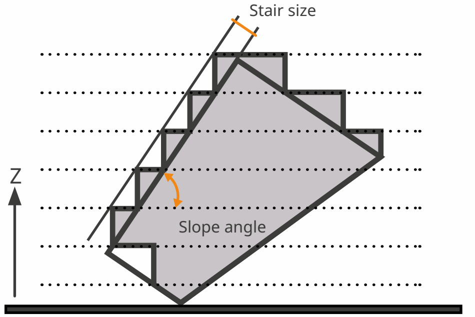
The edges of downfacing surfaces are built on unmelted metal

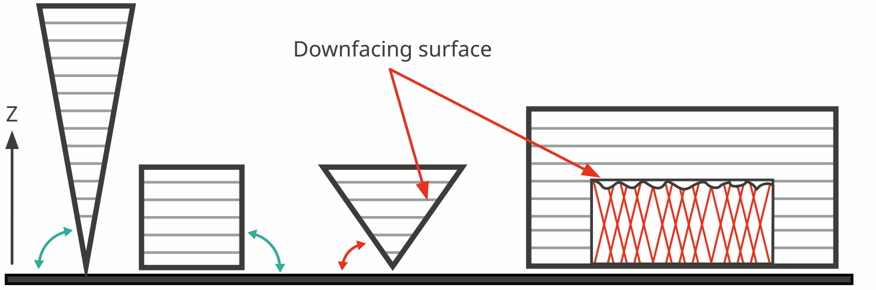


Downfacing surfaces are characterized by the normal of the object pointing towards the build platform

Influences on Quality





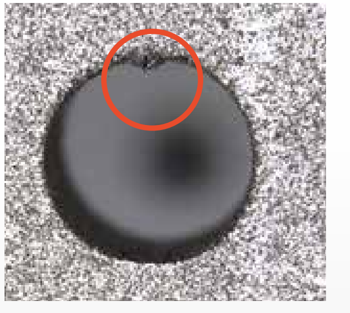


Surface quality in DMP is dependent on the orientation of the surface.

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

On upfacing surfaces this effect is clearly visible and important.

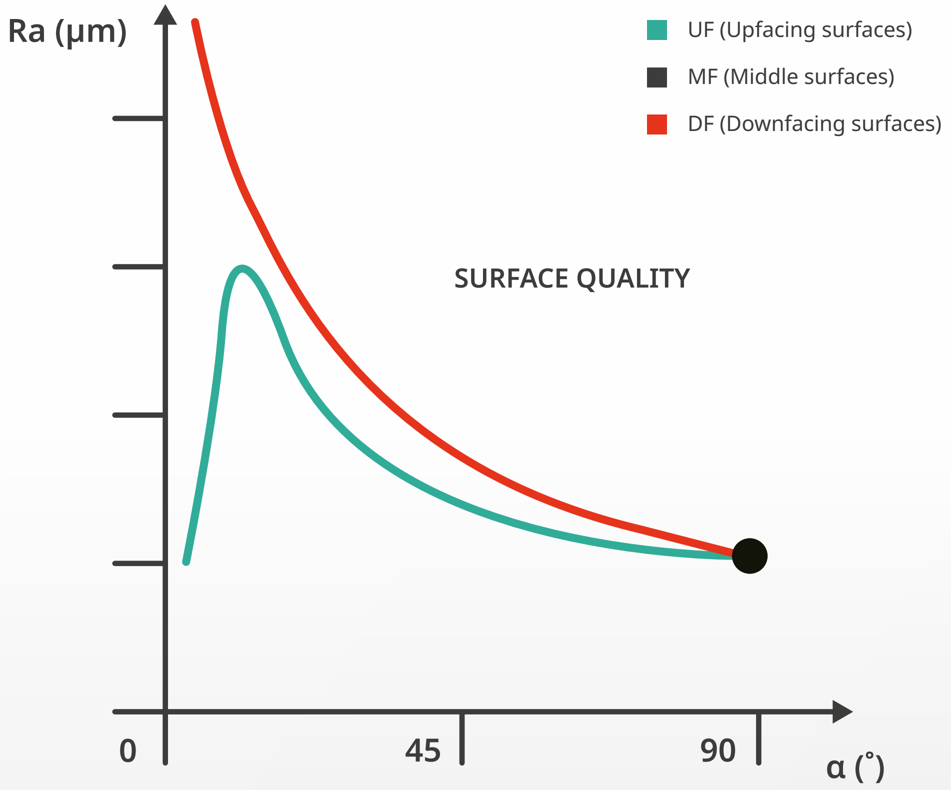
On downfacing areas, the dross formation effect is in most cases bigger than the stair stepping effect. Dross is the undesired amount of molten material and particles as a consequence of melting on loose powder.



- The lower the angle, the more dross formation you have, resulting in worse surface quality
- Low angles need support structures, which are temporary features that provide additional stability during printing, and which are removed in post-processing operations
- Supported faces have worse quality

Influences on Quality

Surface quality depending on type of surface and angle



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 rate 1ms/100°C)
- Stresses accumulate throughout layers, because the top layers are heated and cooled down again for each layer. Expansion and shrinking, blocked by already solidified layers causes residual stresses
- Deformation behavior is material specific

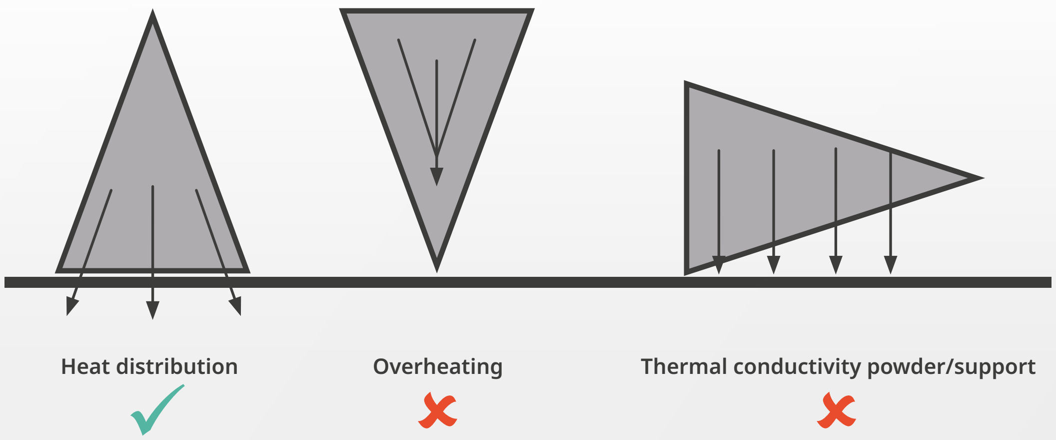
Important influences on those stresses

σT ~ A   Thermal stress 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

σT ~ ΔT Thermal stress is proportionate to the temperature drop during solidification

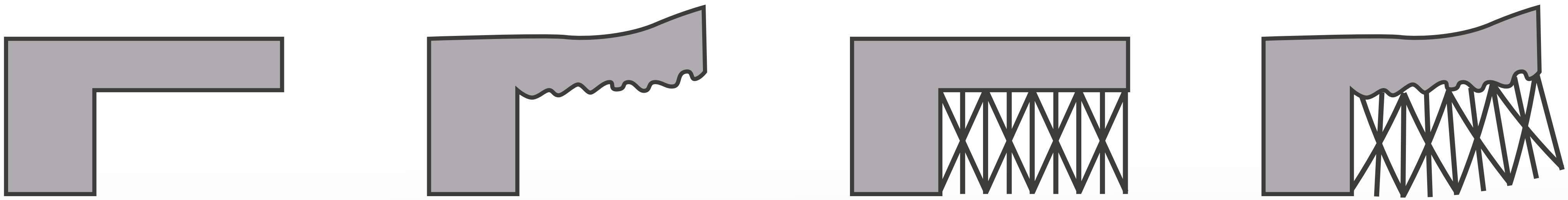
Make sure you have good heat transfer to the base plate and machine. The better the heat is transferred, the less a part will warp.



How to Handle Thermal Stresses

- Residual stresses result in parts that want to warp
- Support structures are 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 unwanted position

Heat treatment is required after powder removal, prior to platform and support removal, to release the stresses



DESIGNED MODEL

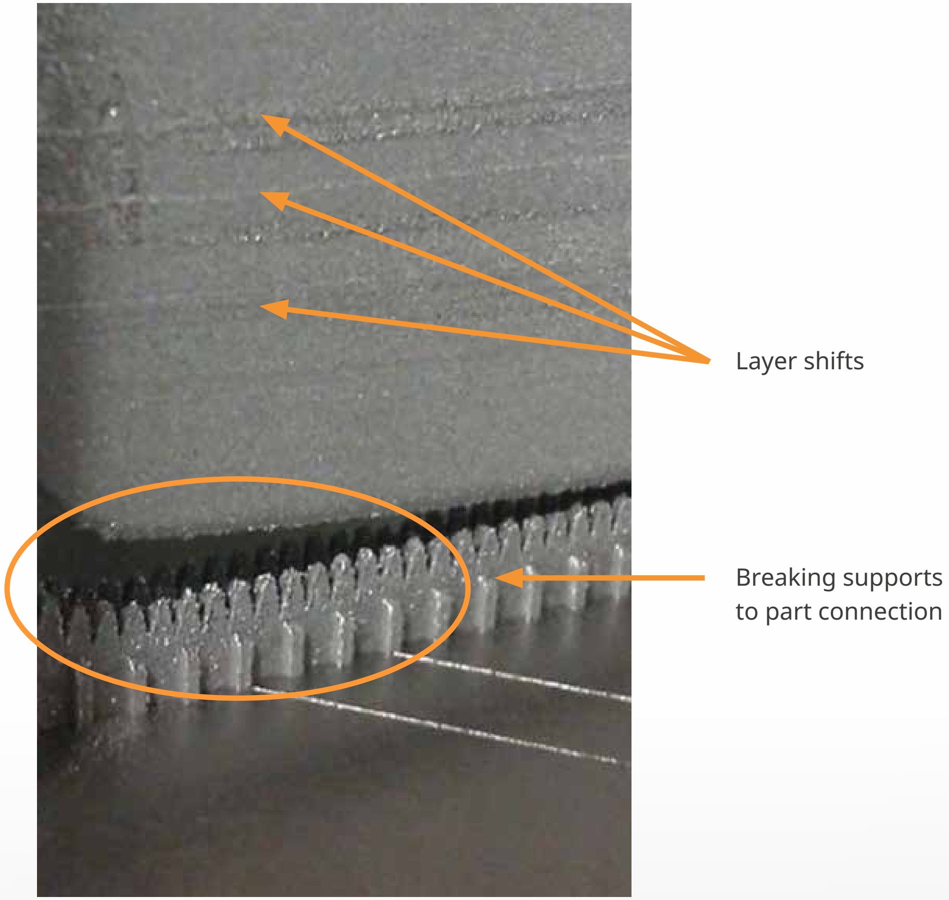
WARP AND DROSS FORMATION

SUPPORT STRUCTURE

WARPING IF REMOVED FROM PLATE PRIOR TO HEAT TREATMENT

Layer Shifts

- Caused by improper supporting
- Connection between supports and parts crack releasing residual stress
- Part shifts as crack propagates
- Laser is unaware of this change and continues to scan according to design intent
- The result is a horizontal 'shift' across the entire scan area

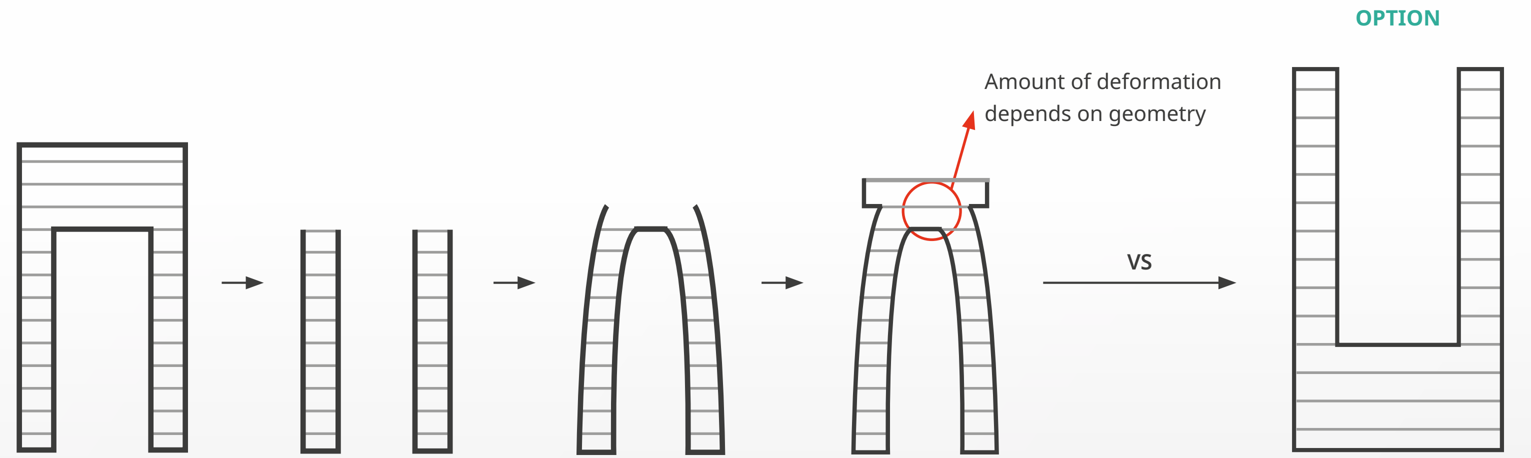


Causes of Shrink Lines

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

Layer shifts = supporting issue
Shrink lines = geometry issue



DESIGNED MODEL

VERTICAL BUILD

As these vertical columns build up, each has its own tensile residual stresses, but they are not interacting with each other.

HORIZONTAL BUILD

A large, sudden change in the cross-sectional area invites shrink line formation due to the interaction of residual stresses.

DEFORMATION

The laser continues to scan based on your designed model.

OPTIMIZED ORIENTATION

Avoid shrink lines by designing or orienting the part so that features diverge rather than converge as they build in the Z-direction.

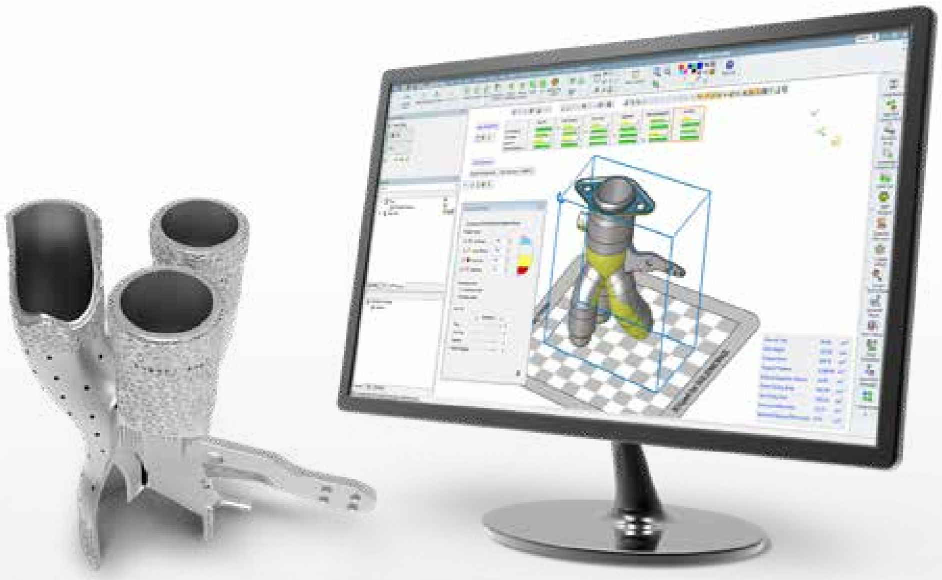
Predicting Shrink Lines Using 3DXpert® Software

3DXpert is an all-in-one integrated software for the entire AM workflow that provides the ultimate combination of automation and full user control.

The simulation tools within 3DXpert enable users to effectively predict where and how displacement may occur on a part in order to optimally place supports for the intended outcome.

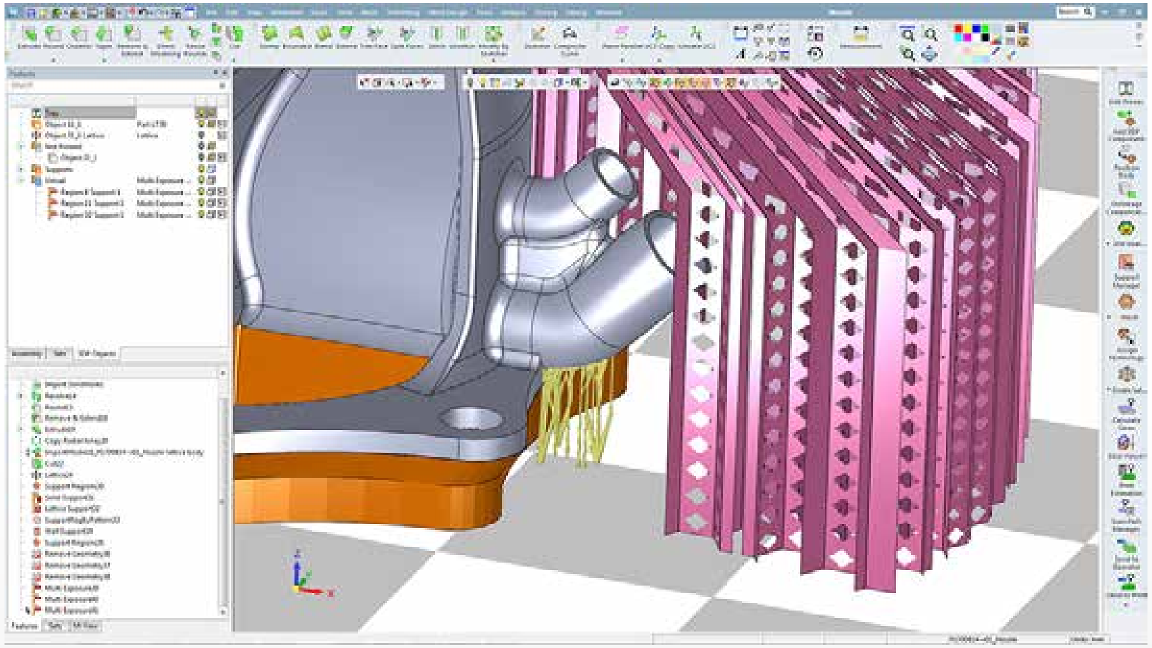
3DXpert also makes it possible to minimize manual operations through the use of compensated models, in which the software counteracts predicted displacements to achieve the ideal state.

3DXpert®



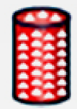
Support Structures

Proper support is needed for heat transfer, to prevent warping, minimize dross formation, and reduce shrink lines.



There are a multitude of possible support structures.

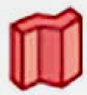
Here are some examples:



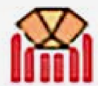
Wall Support

Solid Support

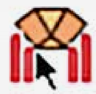
Lattice Support



Solid Wall

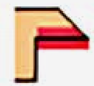


Cone Support



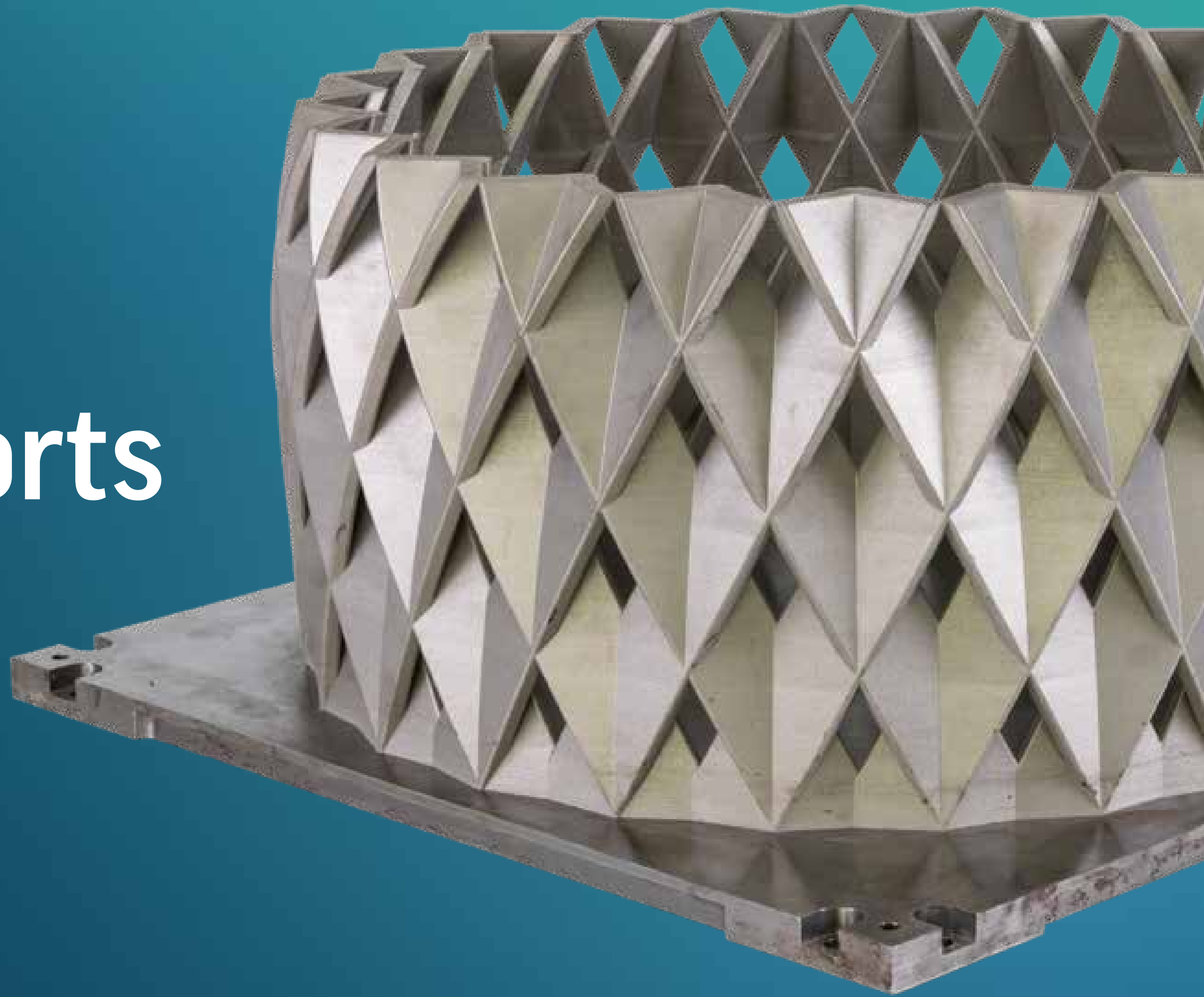
Manual Cone

Skirt Support



Multi Exposure

Strategies for Reducing Supports



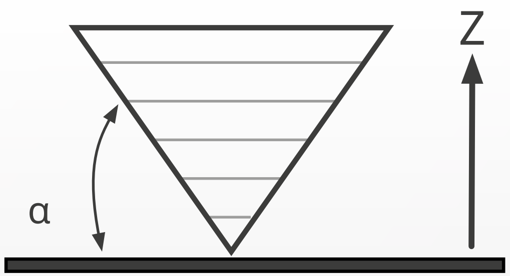
What Can Be Built Without Support?

Steel, stainless steel, Inconel

- Large* downfacing areas α > 60°
- Medium* downfacing areas α > 50-55°
- Small* downfacing areas α > 45°

Titanium, aluminum

- Large* downfacing areas α > 50°
- Medium* downfacing areas α > 40-45°
- Small* downfacing areas α > 35°

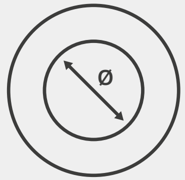


*These values are experience-based for ProX DMP 320 printers and are subject to change based on printer model, specific geometries, and improved build styles.

*The size of these areas is dependent on part geometry.

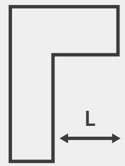
Horizontal circular holes

- Supportless Ømm < 10mm
- Support needed Ømm > 10mm



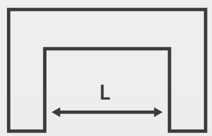
Horizontal bridges

- Supportless L < 1.2mm
- Support needed L > 1.5mm

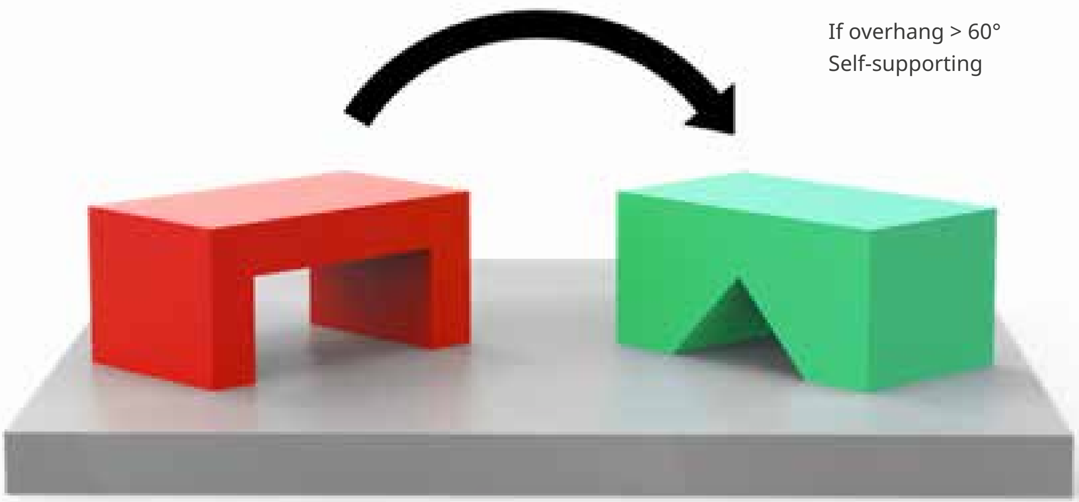


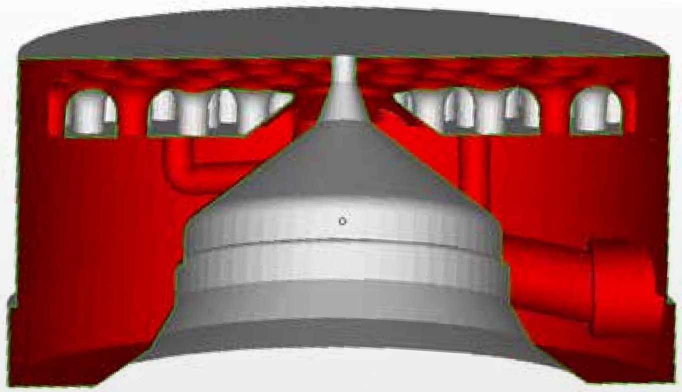
Horizontal bridges

- Supportless L < 2mm
- Support needed L > 2mm



Avoid Downfacing Surfaces and Create Self-Supporting Geometries

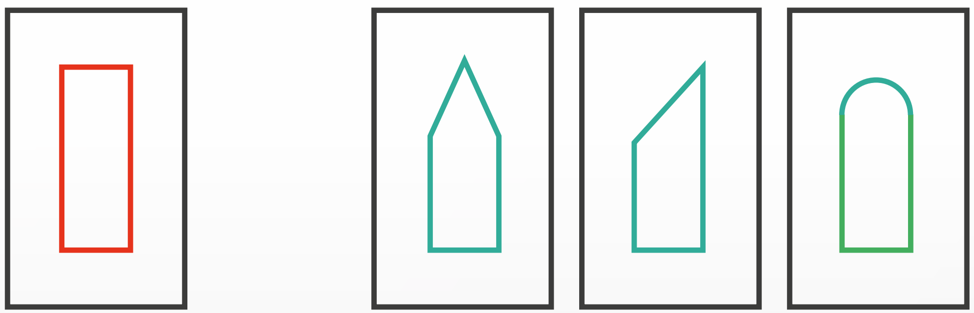


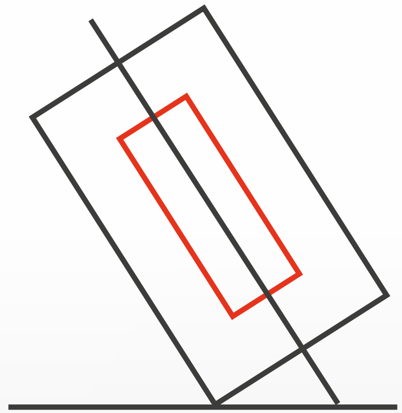


Channel Design

Large (internal) overhangs are not feasible to print

- Change design of internal channels (closing at > 45°)
- Angle part at a self-supporting angle (45°)
- Extra support structure possibly needed on the outside of the part





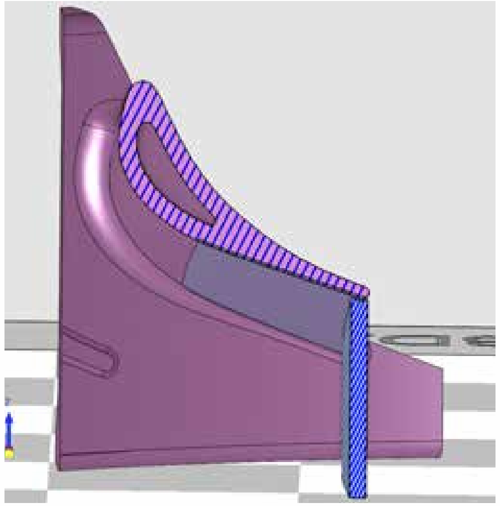
NoSupports™ with 3DXpert®

Strategies powered by 3DXpert® software enable metal 3D printing without supports

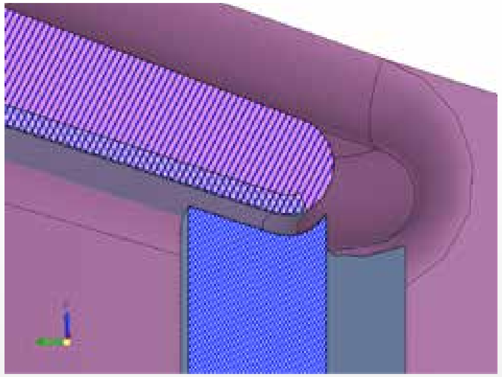
Together with 3D Systems' leading expertise and machine platforms, the 3DXpert software package has advanced metal AM capabilities to help expand your design envelope with features such as multi-exposure and thermal blades to help you realize the goal of no supports.

3DXpert is an all-in-one integrated software for the entire AM workflow.
It provides the ultimate combination of automation and full user control.

- Parametric and history-based hybrid (b-rep and mesh) CAD tools
- History-based approach facilitates changes at any stage
- Built-in simulation speeds up design verification
- Optimize print strategies to ensure quality at reduced printing time



Thermal blade
Contactless support



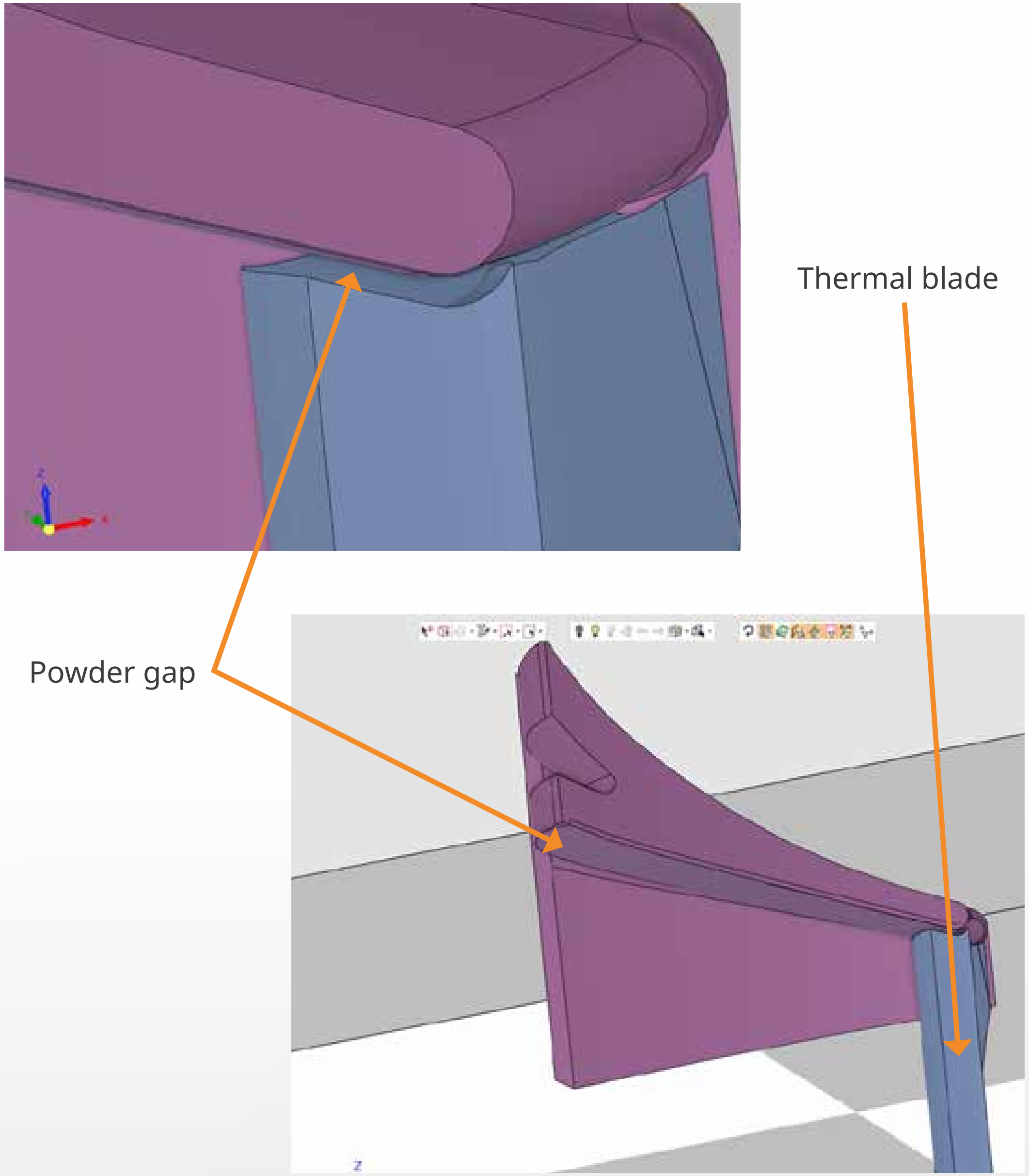
Multi-exposure
Downfacing multi-hatching parameters

Thermal Blades

Contactless support

Thermal blades provide a structure to transfer heat and control the weld process for the lowest-angle features without welding to the part.

- Uses 3DXpert "Solid Support" functionality
- Supports low angle downfacing surfaces and provides thermal management to leading edges
- Thermal blade functions as a heat sink with dissipation of heat through layer of powder to thermal blade
- Optimized gap enables easy removal with no physical supports contacting the part
- No contact remnants to remove

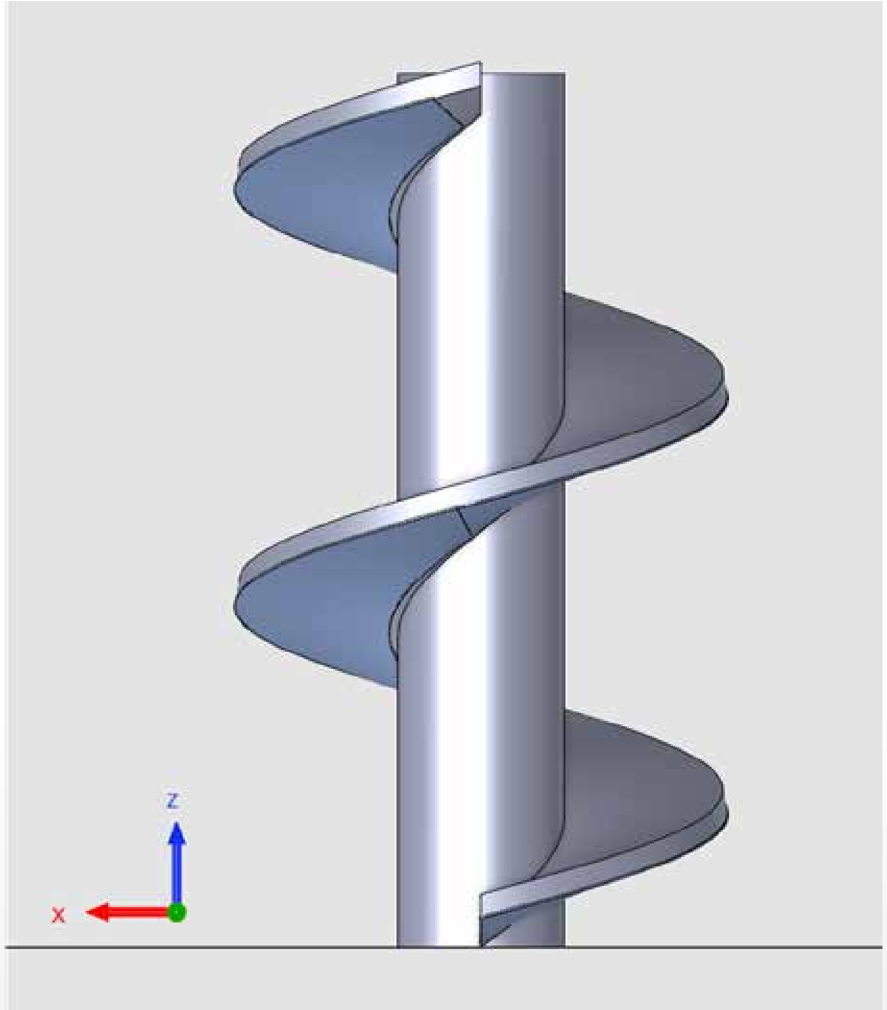


Multi-Exposure

Downfacing multi-hatching parameters

Multi-exposure can drastically reduce the self-supporting angle while maintaining a high-quality surface finish.

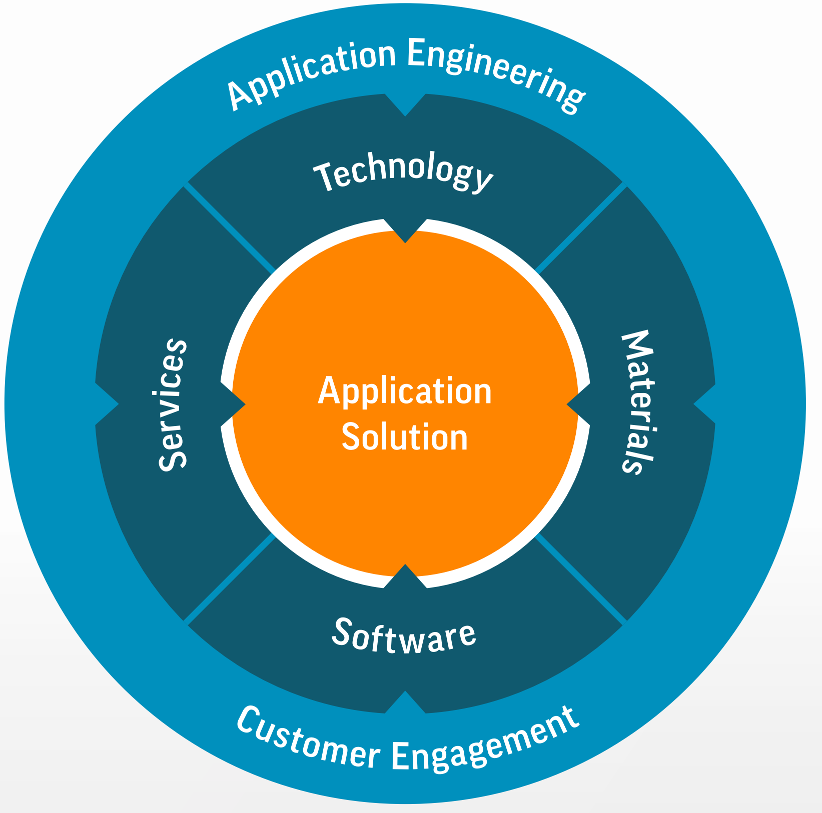
- Strategy to consistently build regions with low overhangs that cannot be designed out or de-supported
- Downfacing improvements
- Multi-exposure parameters can be applied to specific regions



Applying NoSupports to Advanced Applications

3D Systems' Application Innovation Group is engaged in ongoing parameter development for the entire 3D Systems DMP material catalog and routinely works with customers to develop highly optimized parts that cannot rely on traditional DMP support strategies.

For help solving your application challenges, reach out to the Application Innovation Group at 3D Systems.



Part Orientation Guidelines

Overall Build Quality

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

Downfacing surfaces have the poorest quality with a high roughness of the part. By decreasing the amount of downfacing area we are generally able to increase the quality of that part.

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

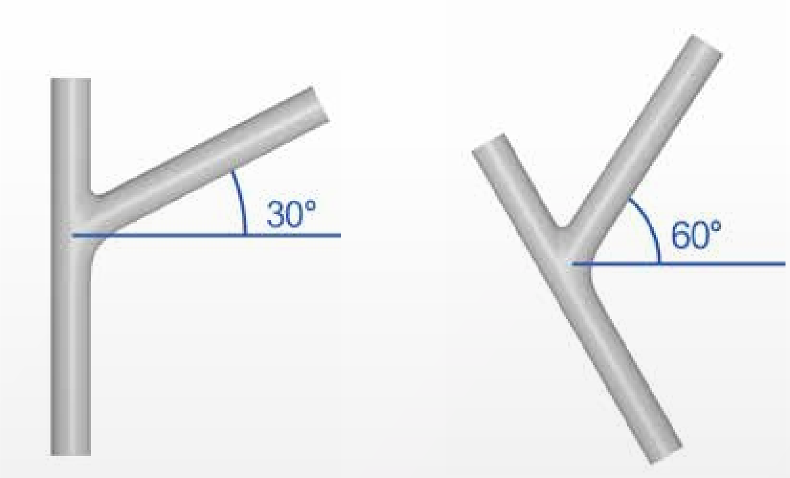
The self-supporting angle depends on material and the printing process.

- Ti-alloys α = 40-45°
- Steel, CoCr, Aluminium-alloys α = 50-55°

The example below illustrates this situation.

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

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



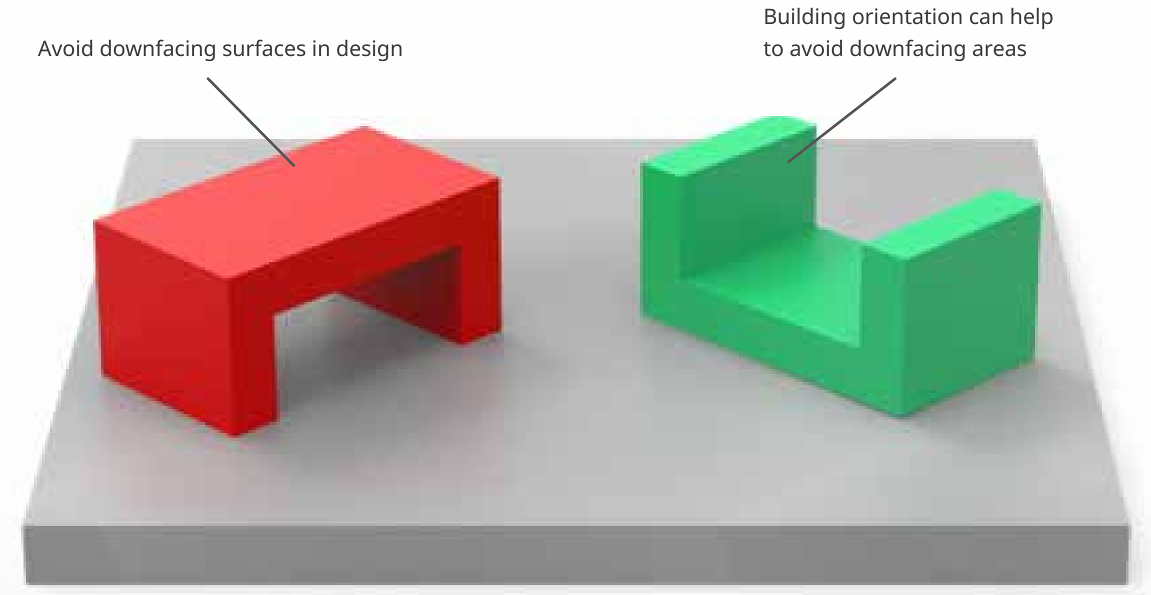
*Metal printers with a roller system, like 3D Systems' DMP machines can reach angles for Ti as low as 30°

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.

- Decreases dross formation
- Decreases potential for shrink line formation
- Fewer supports



Orientation in red is bad, because of the large overhang.

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

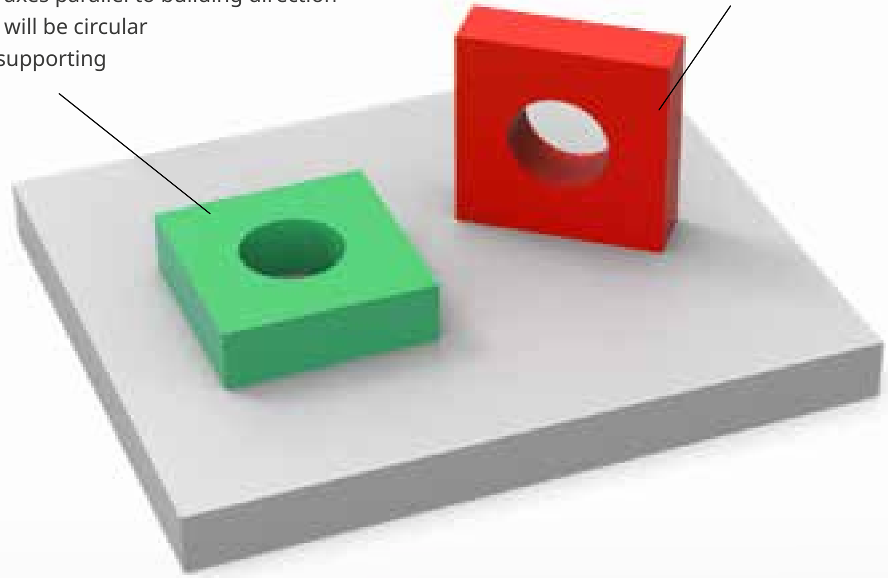
Specific Features

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

The best quality is a result of 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.

Printing features on an angle can mitigate the introduction of shrink lines.The thermal loading conditions are different for domes versus holes, and make it possible for larger dome diameters to be printed without supports. Printing quality is feature specific.




15mm diameter dome printed without supports


Example of a vertically built hole

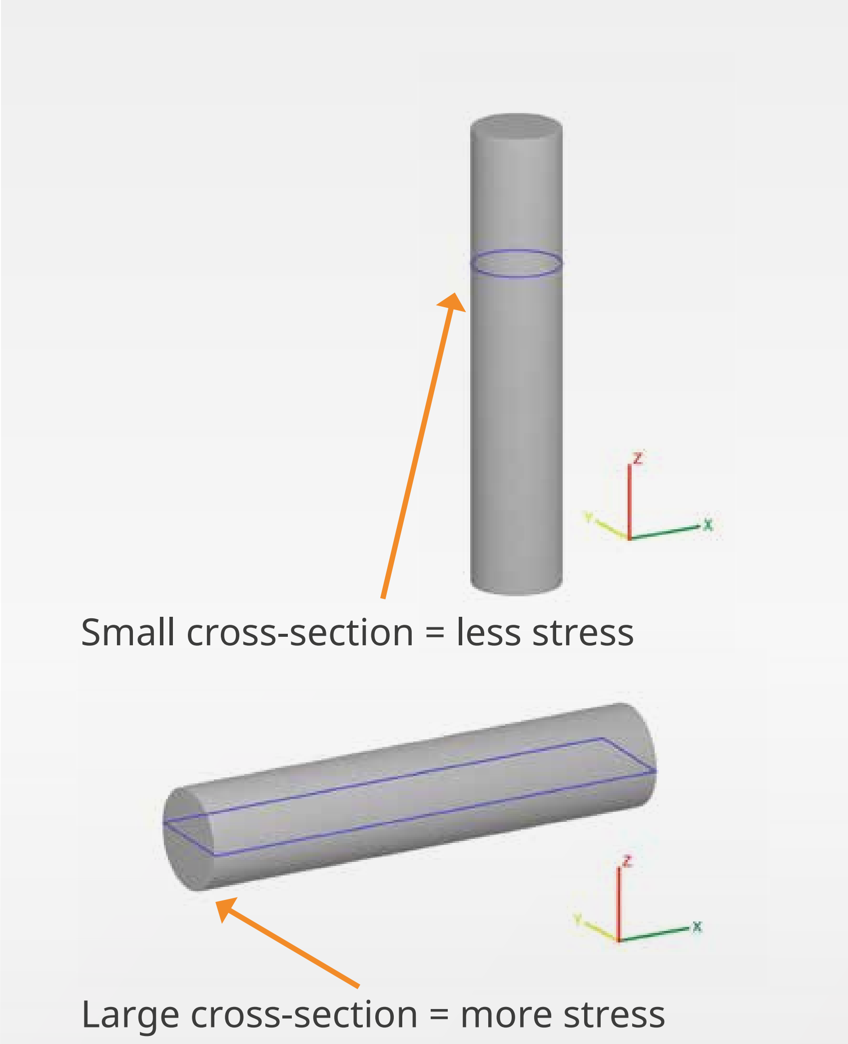

Example of a horizontally built hole

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 the powder locally and a rapid cooling after melting the powder. One way to keep the stresses as low as possible is to keep the cross-sections (what is actually scanned every layer) as small as possible.

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



Small Features

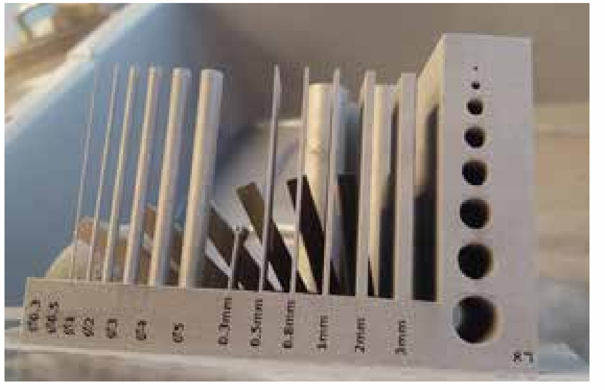
Strongly dependent on

- Material
- Orientation
- Part geometry
- Layer thickness
- Laser spot size

Minimum feature regardless of height

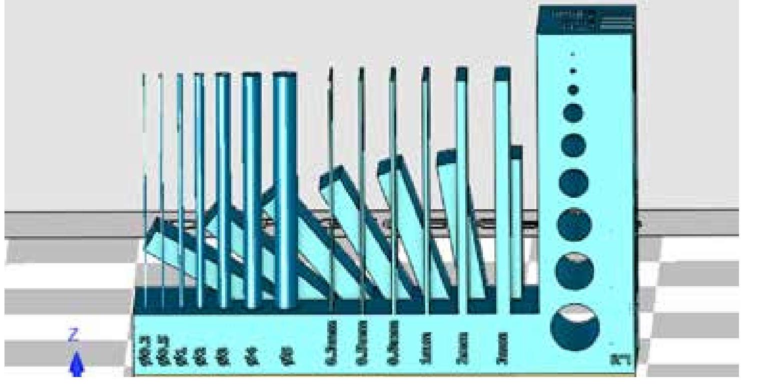
- Wall thickness (gas tight) – 0.20 mm
- Pillar diameter – 0.50 mm
- Minimum feature for heights < 5 mm
- Wall thickness – 0.18 mm
- Pillar diameter – 0.18 mm

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.



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

The smallest pillar was too fragile at this length, causing it to break very easily upon unloading the part.



The smallest wall builds up to a certain height, but then it starts to bend, because it is too 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.

Design Guidelines

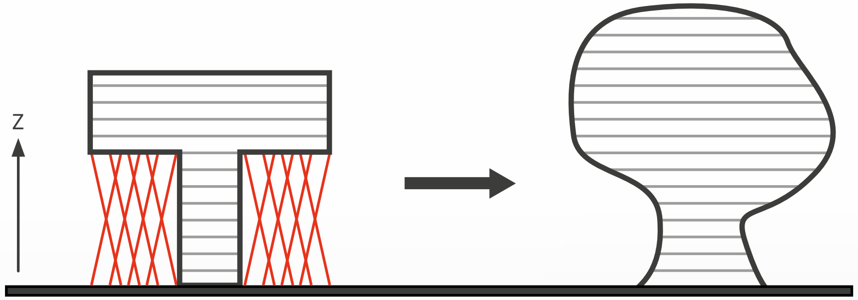
Design Organically-Shaped Structures

Avoid building parts designed for casting or CNC. They typically have:

- Sharp corners
- Sudden change in cross-sectional areas
- Little-to-no cost advantage to being 3D printed

Use organically-shaped structures

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



Dimensional Accuracy

- Gradual transitions between layers:
    - Use fillets (radii), arcs
    - Use chamfers
    - Use organic designs

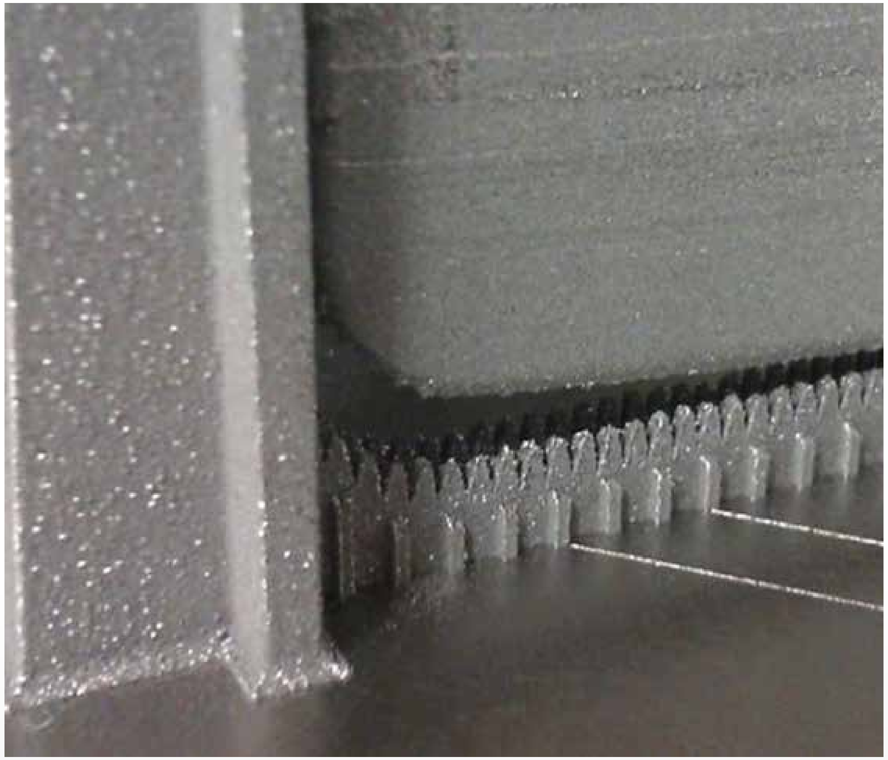
  } Avoid stress concentrations
- Use enough supports to fix the part into position; heat treatment will release the stresses afterwards
- Topological optimization using design for additive manufacturing principles
- Reduce weight
- Reduce printing time
- Increase stiffness-to-weight ratio
- Increasing features that can be printed without supports
    - Less supports + less deformation = better product
- Apply conventional post-machining to increase accuracy

Topologically optimized sattelite bracket for Thales Alennia 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 DMP Flex 350 metal printer

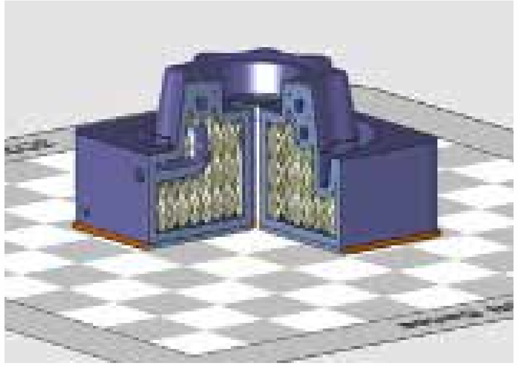
Add Radii

- Massive parts accumulate a lot of stress, and can even lead to warping of the build plate as shown in the illustration
- Need to take care of design to avoid cracking at the base plate 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 base plate
- Typical radius: 2.5 - 5 mm



Weight Saving Techniques

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

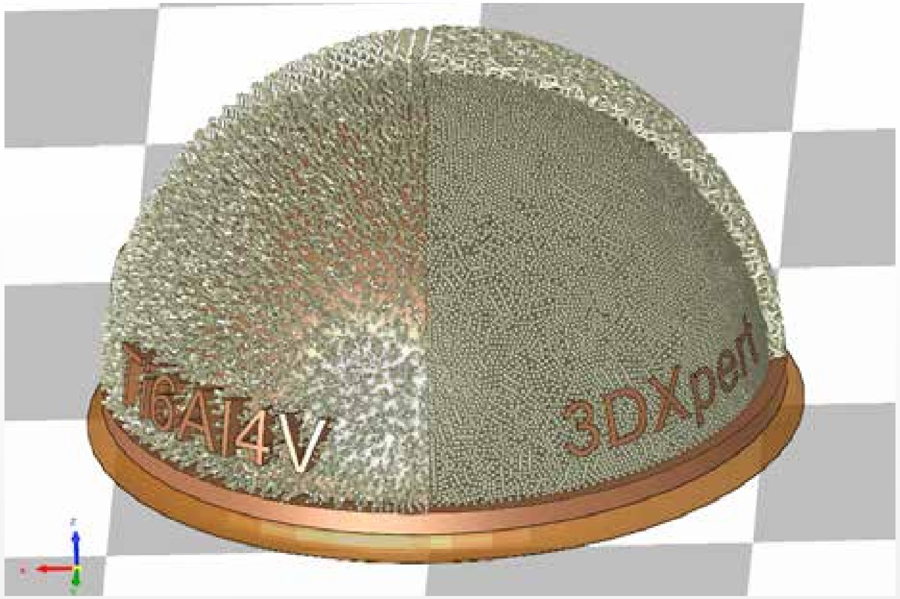
Applying an internal lattice structure considerably reduced the final mass of this part

ESA combustion chamber with a 12% volumetric density mesh for significant weight savings

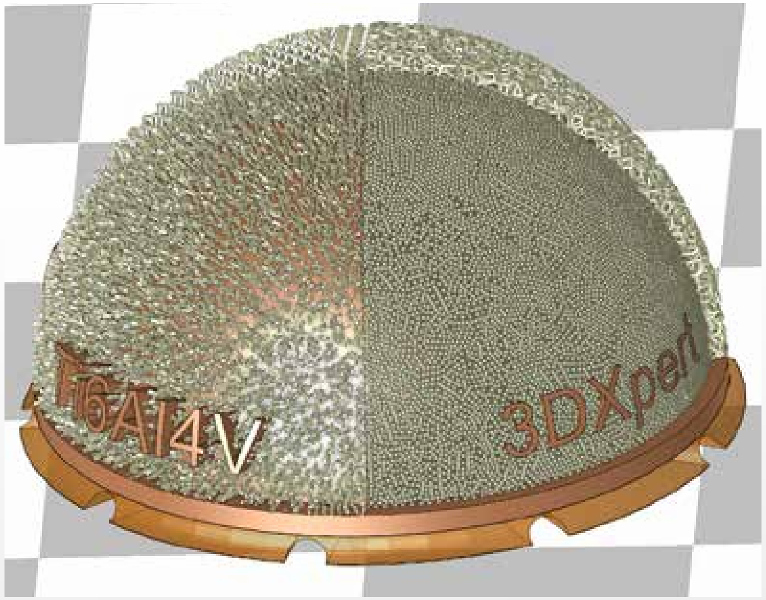
Antenna bracket (190 x 230 x 290mm) for geostationary telecommunications satellites produced by Thales Alenia Space

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



Part designed without powder removal holes



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

Do's and Don'ts

Do

- Increase added value
- Functional requirement priority
- Design in an additive way: topology optimized freeform organic shapes
- $\alpha > 45°$
- Diverging design
- Arcs/fillets/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
- $\alpha < 45°$
- Converging design
- Straight corners, flat overhang
- Section increase
- Manufacturability priority

Post-Processing

Typical Process Flow*

DMP printing → **Powder removal** → **Heat treatment** → **CNC** → **Base plate removal** → **Support removal** → **Finishing** → **Cleaning**

DMP printing
Build the part

Powder removal
Remove powder to avoid sticking after heat treatment, making powder removal more difficult

Heat treatment
- Stress release
- Change mechanical properties
- Improve part density via HIP treatment

CNC
Improve accuracy and roughness on critical surfaces

Base plate removal
- Manual
- Wire EDM
- Band saw

Support removal
Break off the supports

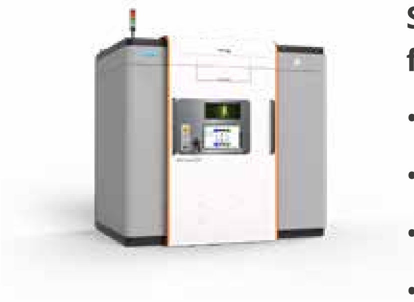
Finishing
- Sand blasting
- Milling
- Polishing

Cleaning
Ultrasonic

*This workflow is for illustrative purposes and is not exhaustive. Additional post-processing operations similar to other production techniques for like materials are possible, though they may require some fine-tuning from an AM expert.

Additional Post-Processing Options

- Apply coating on parts
- Common quality checks:
    - X-ray to check internal channels
    - Optical scan to check dimensional accuracy
    - Geomagic software can show post-build deformation based on scan data
    - 3DXpert can predict post-build deformation and compensate for it



DMP FACTORY 500 SOLUTION

Scalable metal additive manufacturing for seamless large parts

- Build volume 500mm x 500mm x 500mm
- Integrated powder management
- Consistent, low O2 environment
- Intelligent, seamless part production
- Scalable production manufacturing

DMP FLEX 350 AND DMP FLEX 350 DUAL

Robust, flexible metal 3D printer for 24/7 part production

- Build volume 275mm x 275mm x 420mm
- Fast, easy material change
- Consistent, low O2 environment
- High throughput, high repeatability

DMP FACTORY 350 AND DMP FACTORY 350 DUAL

Scalable, high quality metal additive manufacturing with integrated powder management

- Build volume 275mm x 275mm x 420mm
- Integrated powder management
- Consistent, low O2 environment
- High throughput, high repeatability

DMP FLEX 100

Affordable, precise metal 3D printer for finest features and thinnest walls

- Build volume 100mm x 100mm x 90mm
- Fine features, thin walls
- Best-in-class surface finish
- Unique roller/recoater system
- Perfectly layers almost any powder

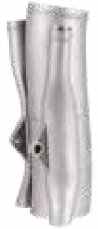
DMP FLEX 200

Professional and precise metal 3D printer with 500W laser source

- Build volume 140mm x 140mm x 115mm
- Easy loading and cleaning
- High performance at lower cost
- Fine features, thin walls
- Best-in-class surface finish
- Unique roller/recoater system
- Perfectly layers almost any powder

Titanium

LaserForm Ti Gr5 (A)
High strength, low weight, excellent biocompatibility



LaserForm Ti Gr23 (A)
High strength, low weight, excellent biocompatibility, lower oxygen than Gr5

LaserForm Ti Gr1 (A)
High strength, biocompatible, extreme temperature and corrosion resistance

Stainless Steel

LaserForm 316L (A)
Able to be sterilized and highly corrosion resistant

LaserForm 316L (B)
Able to be sterilized and highly corrosion resistant

LaserForm 17-4PH (A)
Excellent corrosion resistance, high strength with good toughness

LaserForm 17-4PH (B)
Excellent corrosion resistance, high strength with good toughness

Maraging Steel

Certified M789 (A)
Cobalt free, high strength tool steel with excellent corrosion resistance

LaserForm Maraging Steel (A)
Excellent hardness and strength, good wear resistance

LaserForm Maraging Steel (B)
Genuine tool steel (1.2709), high strength and hardness

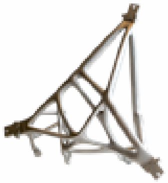
Cobalt-Chrome

LaserForm CoCrF75 (A)
Highly corrosion, wear and heat resistant; biocompatible

LaserForm CoCr (B) or (C)
Highly corrosion resistant, suitable for biomedical applications

Aluminum Alloy

Certified Scalmalloy (A)
High strength aluminum with excellent corrosion resistance



LaserForm AlSi7Mg0.6 (A)
Lightweight, good mechanical properties, and improved thermal conductivity

LaserForm AlSi10Mg (A)
Good mechanical properties and good thermal conductivity

LaserForm AlSi12 (B)
Metal powder for lightweight parts with good thermal properties

A6061-RAM2 (A)
Improved strength, ductility, and surface finish versus AlSi10Mg

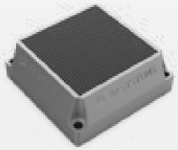
Nickel Super Alloy

LaserForm Ni625 (A)
Excellent corrosion resistance, high strength and heat resistance

LaserForm Ni625 (B)
Excellent corrosion resistance, high strength and heat resistance

LaserForm Ni718 (A)
Oxidation-, corrosion- and extremely high-temperature resistance

Refractory Metals

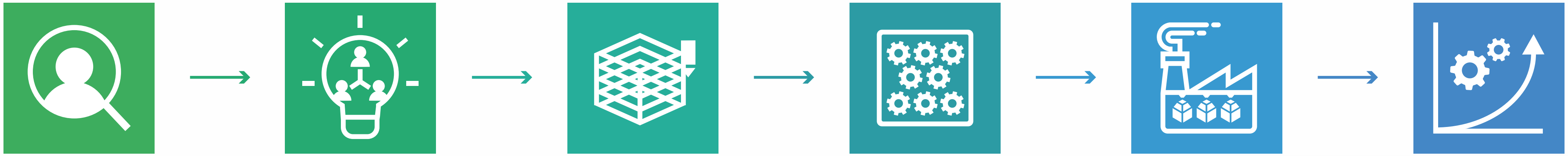


Tungsten (A)
High-density refractory pure metal with excellent radiation shielding capabilities and outstanding corrosion resistance

We're Here to Help

For more than three decades, 3D Systems has demonstrated our industry leadership and expertise to help manufacturers across a variety of industries redefine their workflows to realize the benefits of additive manufacturing.

We are committed to accelerating the development of advanced applications. From installation to hands-on training and consulting support, 3D Systems' experts enable you to quickly and effectively ramp from prototyping to volume production. 3D Systems' Application Innovation Group is a dedicated group of engineers, technicians, and designers who can help you solve your most difficult design and production challenges. Whether that means identifying skill gaps, improving part performance, or scaling your manufacturing flow, we are available at every stage to apply our professional expertise to your unique goals.



Explore

Strategic consulting to identify customer needs

Innovate

Joint applications development and design for additive (DfAM) for specific needs

Develop

QA and process characterization from pre-prototype through prototype

Validate

Training, validation, and certification

Develop

Production and manufacturing services

Scale

Scale up and technology transfer

What's Next?

Our experts are here to support you.
Get in touch today – we will be right with you.

Talk to an Expert