DESIGN ESSENTIALS

for 3D Printing

PROTOLABS
Manufacturing. Accelerated.

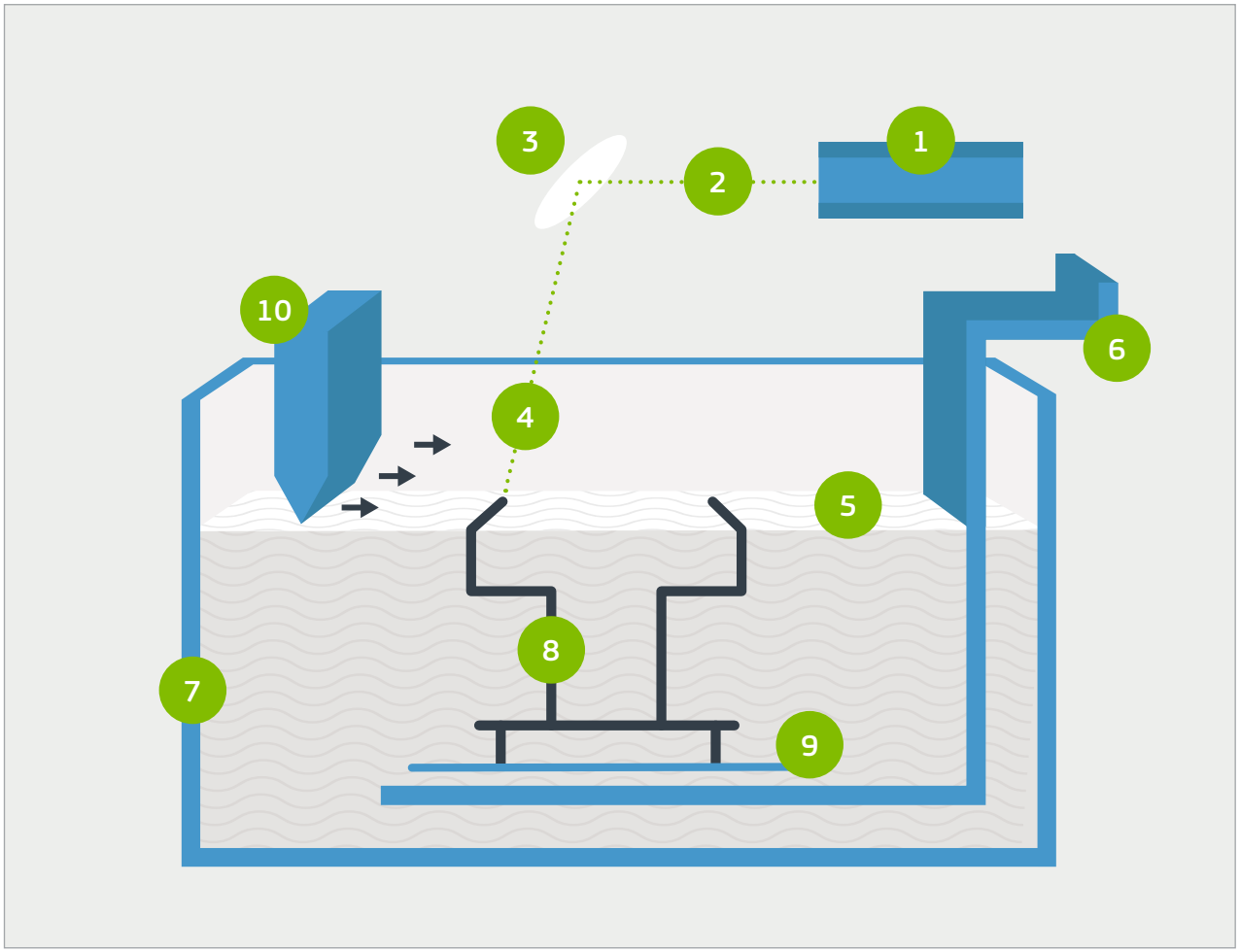
Contents

Industrial 3D printing opens up many new design possibilities, but it's important to keep a few fundamental principles in mind when designing for additive manufacturing processes. Most of these are fairly obvious like feature resolution, surface finish, and material selection, but there's more to 3D printing success than selecting the right material and process. If you will eventually need increased part quantities through more traditional processes like injection molding, you should considering the part's moldability even when designing early prototypes. Understanding the fundamental principles for 3D printing will help you get the most out the versatile technology—whether you're iterating part design through rapid prototyping or creating end-use production parts.

Rapid Prototyping with Stereolithography

Stereolithography, or SLA, emerged in the mid-1980s and established itself as a staple of additive manufacturing (now known as 3D printing) over the next decade. Since that time, SL's ability to quickly and accurately create complex prototypes has helped transform the design world like never before.

As with other 3D printing processes like selective laser sintering (SLS) and direct metal laser sintering (DMLS), SLA relies on lasers to do the heavy lifting. Parts are built by curing paper-thin layers of liquid thermoset resin, using an ultraviolet (UV) laser that draws on the surface of a resin turning it from a liquid into a solid layer. As each layer is completed, fresh, uncured resin is swept over the preceding layer and the process repeated until the part is finished. A post-build process is required on SLA parts, which undergo a UV-curing cycle to fully solidify the outer surface of the part and any additional surface finish requirements.



From left to right, the 3D printing elements of stereolithography include: Laser Unit (1), Laser Beam (2), Mirror/galvo motor system (beam steering) (3), Focus & Directed Beam (4), Resin Surface (5), Elevator (6), Vat (7), SLA Pattern (8), Build Platform (9), and Recoater Blade (10).

Thermoplastic Mimic

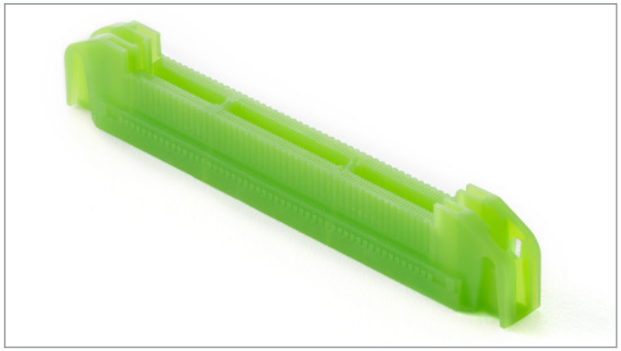
Unlike older generations of SL, today's machines offer a range of thermoplastic-mimic materials to choose from, with several flavors to mimic polypropylene, ABS, and glass-filled polycarbonate available. Protolabs offers many variations of these materials:

- **Polypropylene:** A flexible, durable resin that mimics a stiff polypropylene. It can withstand harsh mechanical treatment and is great for fine details—sharp corners, thin walls, small holes, etc.
- **Polypropylene/ABS blend:** Strong, white plastic similar to a CNC-machined polypropylene/ABS blend. It works well for snap fits, assemblies, and demanding applications.
- **ABS:** Variations of ABS mimics include a clear, low-viscosity resin that can be finished clear; an opaque black plastic that blocks nearly all visible light, even in thin sections; a clear, colorless, water-resistant plastic good for lenses and flow-visualization models; a green micro-resolution resin that enables production of parts with extremely fine features and tight tolerances.
- **Polycarbonate:** A ceramic-filled PC material that provides strength, stiffness, and temperature resistance, but can be brittle.
- **SLArmor:** A nickel-plated material that gives SL-generated parts much of the strength and toughness associated with die cast aluminum.

Please note the term "thermoplastic mimic." This is an important distinction in that the mechanical properties of SLA materials only mimic those of their molded counterpart. If you need to pound on your prototype with a sledgehammer, or leave it in the sun for a few months, be aware that SLA parts do not provide the same strength and durability as parts that are sintered, cast, machined, or molded. This makes SLA the logical choice for prototype parts where validation of form and fit—but not necessarily function—is the most important factor. Customer service engineers at Protolabs can help guide you during material and manufacturing process selection if help is needed.

A Fine Resolution

Despite differences in material properties, SLA is the clear winner over SLS in terms of part accuracy and surface finish. Normal, high and micro resolutions are available, providing layer thicknesses ranging from 0.004 to 0.001 in. and part features as small as 0.002 in. This means very fine details and cosmetic surfaces are possible, with minimal "stair stepping" compared to printed parts built by processes like fused deposition modeling (FDM).



Final SLA parts have support structures built in that are easily removed during post-processing. Supports help prevent part features from distorting during a build.

SLA also has the edge in part size—need a prototype of a new luggage casing, or a lawnmower shell? There's a good chance SLA can accommodate. Protolabs current max build size is 29 in. by 25 in. by 21 in. (736mm by 635mm by 533mm).

SLA is also an excellent choice for prototyping microfluidic devices. Our microfluidic fabrication process allows engineers to accurately test parts that will later be injection molded, avoiding the hassles and high cost of photolithography. If you're designing a protein sensor, micro-pump or lab on a chip, for example, SLA prototyping might be just the ticket.

Stereolithography machines cure liquid thermoset resins with an ultraviolet laser to produce high-resolution parts.

Other Considerations

Stay away from extremely small holes as well, since the relatively high viscosity of the photo-curable resin used with SLA can pose challenges during the post-build process. If you're inventing a newfangled angel hair pasta strainer, one with holes smaller than 0.005 in., SLA is probably not the best choice for a prototype. Thin walls should be monitored as well. The lid for a hi-tech sandwich container, for example, should have walls no less than 0.030 to 0.040 in. thick.

Bear in mind that we may create temporary structures to support your part during the build process, but these are removed prior to delivery and typically little evidence of their existence is found. We may also choose to orient the workpiece to facilitate a better build, in which case the cosmetic appearance of some surfaces can be affected—if certain cosmetic features on your part require an elevated level of surface finish, please indicate those surfaces when submitting your design.

Finishing Moves

Speaking of smooth surfaces, Protolabs offers plenty of options for finishing SLA parts. Most of our customers opt for light sanding to remove the aforementioned nibs left from supports, followed by a fine bead blast. Parts can be shipped "as is" and will show some evidence of the support structures. There are also several coating choices available—aside from the nickel SLArmor, painting (with color matching and masking services available), clear coat, texturing, and even custom decals are also possible.

As for preferred 3D CAD file formats for SL, Protolabs accepts STL files. Most commercial CAD systems can generate STL files, the native format of any SLA machine, but if yours doesn't have this capability, our advice is to submit a neutral file format—such as an IGES or STEP file. But steer clear of the freeware STL generators littering the internet. Some tend to create incomplete STL files, meaning additional rework time and delayed production.

SLA plays an important step in the design process. It bridges the gap between digital models and machined or injection-molded parts, giving people the ability to touch and feel prototype designs within days. Costly mistakes can be avoided, development costs reduced, and better products built in the long run.

Prototyping with PolyJet 3D Printing

PolyJet is one of the few industrial 3D printing technologies that allows the use of multiple materials in a single part build, and is one of the few technologies that can print these materials together in a single layer. In addition, different colors and hardness levels can be combined, again in a single layer just one-fourth the thickness of a sheet of printer paper.

PolyJet can combine multiple material properties such as colors and hardnesses into a single part. It's a cost-effective solution for prototyping elastomeric and overmolded part designs since it does not require tooling.

PolyJet uses a jetting process where small droplets of liquid photopolymer, called voxels, are sprayed from multiple jets onto a build platform and cured in layers that form elastomeric parts. This digital approach provides excellent accuracy, as well as the ability to strategically alter material properties in a way never before possible.

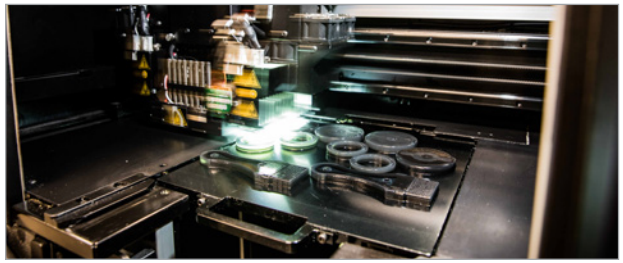
The Technical Lowdown

PolyJet has been around since 2005 and is a mature, well-understood technology. As with other 3D printing processes, it builds parts from the bottom up, one layer at time. But that's where most of the similarities end. PolyJet uses a print head equipped with multiple jets to spray tiny droplets of liquid photopolymer 42 microns (0.00167 in.) across, forming layers just 30 microns (0.00118 in.) thick. These layers are then rapidly cured by an ultraviolet light source. Support material is printed at the same time, so PolyJet parts are self-supporting. When the build is complete, the part gets a quick bath in a chemical solution, dissolving the supports and leaving surfaces that are smooth and accurate. One of the coolest things about PolyJet is its ability to mimic various polymers, including liquid silicone rubber (LSR) and ABS. What's more, those materials can be printed in a range of hardness levels, making PolyJet a perfect choice for prototyping an overmolded electronics case, for example, or a housing cover with a built-in gasket, and doing so in a single build or run of the machine.

Who's Using PolyJet?

Simply put, PolyJet is a great option for anyone who requires a fast, flexible, and accurate way of prototyping parts, but also needs the ability to incorporate multiple hardness levels (durometers) and/or material colors in a single build.

An automotive manufacturer might use it to prototype rubber seals and semi-rigid gaskets, digitally dialing in the "just right" durometer. The medical industry can use it to prototype orthopedic implants and dental prostheses for fit-testing, or create soft grips on hard plastic surgical instrument samples. Two-toned electronics housings with clear plastic covers, flexible straps used on athletic equipment, complex appliance components, and fine-featured but flexible snap-fit cases are just a few of the opportunities for PolyJet prototyping of consumer and industrial goods.



The PolyJet process begins by spraying small droplets of liquid photopolymers in layers that are instantly UV cured. Fine layers of digital materials accumulate throughout the build to create accurate 3D-printed parts.

The Playbook

Sounds great, but what's the catch? Actually, the design rules for PolyJet 3D printing at Protolabs are pretty easy to follow:

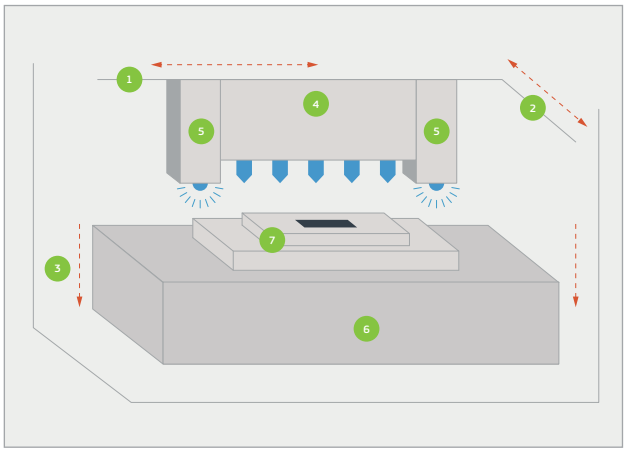
- The maximum part size is 19.3 in. by 15.4 in. by 7.9 in. (490mm x 390mm x 200mm).
- The minimum feature size for PolyJet parts is 0.012 in. (0.3mm) in any direction. Unsupported walls and part features can be as small as 0.030 in. (0.75mm) across, but those serving in a functional or load-bearing manner should be at least 0.040 in. (1.0mm) across. Also, the height of these features depends partly on the material and part geometry, but try to avoid very tall freestanding walls or bosses, as these can be damaged during support removal.
- Even though PolyJet can produce fine details, bear in mind that the expected length and width dimensional tolerance is +/-0.005 in. (0.1mm) for the first inch, increasing by +/-0.001 in. (0.025mm) for each additional inch. Your "mileage" may vary, depending on the part geometry and material used.
- It's difficult to remove support material on holes, slots, and channels much smaller than 0.030 in. (0.75mm) across, especially those with a depth-to-width aspect ratio of 2:1 or greater. In fact, narrow features like this might not form properly at all, so be sure to keep this in mind on part designs. Also, you might be tempted to put in some weep holes (these allow the support material to "weep" or drain out of internal cavities) on internal "land-locked" shapes, like the inside of a cube or sphere. This is fine, provided the holes are large enough to allow rinsing of the support material, but unless there's a compelling reason to do otherwise, just leave them closed. Chances are you won't even notice the trapped support material
- Prototypes for overmolded parts or those with integral gasket material—a soft touch handle, for example, or a cover containing a rubber-like sealing surface—should either be designed with zero clearance or up to 0.002 in. (0.05mm) interference fit. Leave any sort of gap and the components might come apart in your hands, leading to a redesign, reprint, and loss of time in the development cycle.

Advantages: What Can PolyJet Do for You?

Protolabs uses Objet350 and Objet260 Connex3 PolyJet machines that can produce parts with a range of hardness levels, from rigid parts to flexible elastomeric ones with a Shore A hardness value of 30A (similar to the gel inserts in your shoes). Agilus materials are used for added tear resistance and tensile strength; black, white, and clear color options are standard, although custom grayscale mixtures are also available.

As with overmolded part designs, be sure to upload each piece of a "multi-part" assembly with its own separate CAD file, together with one that contains the entire assembly. Select the material hardness, color, and quantity and you'll receive an instant quote. Once ordered, parts typically ship in 1 to 3 days.

In summary, if you're designing a part that will be overmolded, PolyJet is for you. Prototyping a two-shot, injection-molded part? Take a look at PolyJet. Need a part that's rigid in one area but flexible in others, or translucent in some places and opaque in others, then PolyJet might be right for your product. Working on an LSR prototype? Yep, PolyJet again.



From left to right, the 3D printing elements of PolyJet include: X Axis **(1)**, Y Axis **(2)**, Z Axis **(3)**, Photopolymer Jets **(4)**, UV Lamp **(5)**, Build Tray **(6)**, and Part with Flexible and Rigid Materials.

3D Printing Fully Functional Parts with Selective Laser Sintering

Sintering is the process of applying heat and/or pressure to fuse bits of metal, ceramic, and other materials into a solid mass. It's nothing new. Nature has been fusing sedimentary minerals into slate and quartzite for eons, and humans began using similar methods to make bricks and porcelain millennia ago. Today, sintering is used to produce everything from gears and connecting rods to sprockets and bearings. It's also used to 3D-print parts.

Selective laser sintering (SLS) is a close cousin to direct metal laser sintering (DMLS), but builds parts made of plastic rather than metal. SLS uses a computer-controlled CO2 laser versus an ND: YAG fiber laser for DMLS, but both "draw" slices of a CAD model in a bed of material, fusing micron-sized particles of material one layer at a time.

SLS needs none of the support structures typical with DMLS, however, and unlike stereolithography (SL)—the third laser-based 3D printing process available at Protolabs—SLS creates fully functional parts using engineering-grade nylon, and is essentially the only 3D printing technology able to create living hinges and snap-fit assemblies. (These features can be produced with SL, however, they will be much more fragile and not have the life expectancy of those produced with SLS. This makes it an excellent way to prototype injection-molded products, and can even be used as a low-volume alternative to molding in some cases.

Rooted in Nylon

As with any 3D printing process, it's important to understand the many design considerations applicable to SLS. One of these is the material. Despite their wide-ranging uses, all SLS parts are currently limited to nylon materials—the same thermoplastics used in fasteners, flak jackets, frying pans and thousands of other everyday items. Protolabs offers four grades of these versatile polymers:

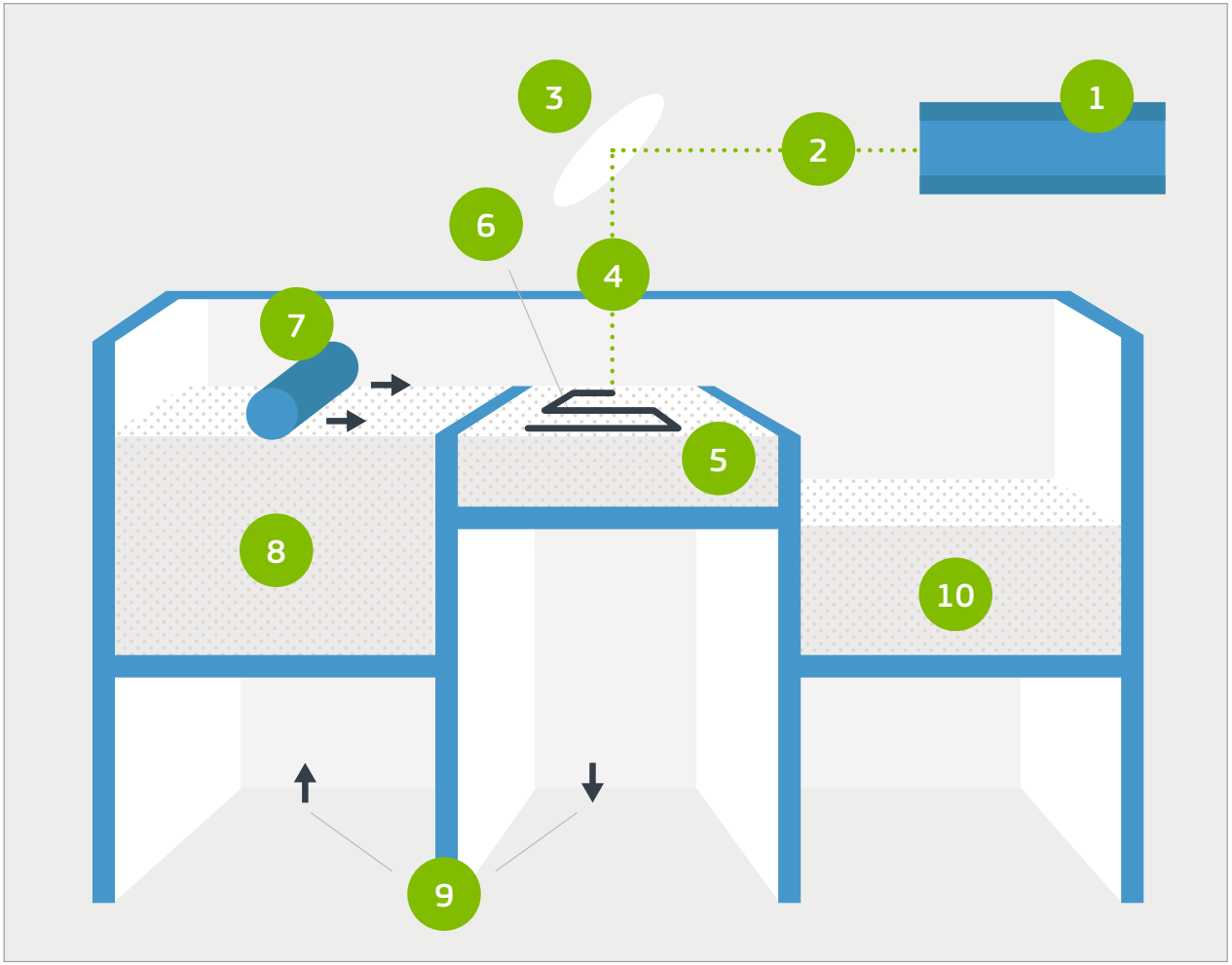
- **PA 850 Black:** Similar to an unfilled Nylon 11, this tough bioplastic is an excellent choice for parts requiring a living hinge—the lid on a pill container, for example—and offers one of the highest elongation break thresholds in the nylon family. It's black in color, produces a smooth surface finish, and good part detail. And due to its superb chemical resistance and low water absorption, is ideal for products such as fuel lines and catheters, tennis shoes, and electrical connectors.
- **PA 650 White:** Similar to unfilled Nylon 12, PA 650 is both stiff and tough, and is used extensively in air ducts, sporting goods, and similar products. It presents a clean, white finish, but with a slightly rougher surface texture than other nylons. It offers high impact and temperature resistance, is very durable and remains stable under a range of environmental conditions. Nylon 12 also has a low coefficient of friction, making it suitable for many types of gears and bearings.
- **PA 620-MF:** A variant of Nylon 12, this material contains 25-percent mineral fiber, and is used for products requiring high structural strength and load-bearing properties. Like most nylons, it offers excellent stiffness at elevated temperatures, which is one reason why MF-filled nylon is a favorite among the aerospace and motorsports industries, and any applicationneeding an material that is strong and durable. It also has directional mechanical properties—the fibers will align in the X direction making it the strongest along that plane.

- **PA 615-GS:** This 50-percent glass-filled flavor of Nylon 12 is known for dimensional stability and resistance to high temperatures. It's especially good for accurate, detailed parts with complex geometries, and outperforms unfilled nylon in demanding applications. However, the glass fill can be abrasive to mating surfaces, something that should be considered when designing parts with this rugged material. Both 615 and 620-MF will be much less flexible and 615-GS will be much heavier due to the glass content. It's also important to note that 620-MF has a much better strength-to-weight ratio than 615-GS.

Managing the Build

These four types of nylon materials cover many different applications. Despite this, roughly 95-percent of the SLS material consumed at Protolabs is PA 850 (Nylon 11) or PA 650 (Nylon 12), although the mineral- and glass-filled variants are gaining momentum. There's far more to effective part design than material selection, however, and controlling the in-build curl and post-build warping common with 3D printing is paramount to good part quality.

Much of this control falls to Protolabs. To keep parts straight and true, our technicians will often tip parts slightly in the build chamber—if you're designing a case for a handheld video game, for example, a compound incline of 10 to 15 degrees in the X and Y axes during the build is probably all that's needed to keep the walls square and the box lid fitting smoothly.



From left to right, the 3D printing elements of selective laser sintering include: Laser Unit **(1)**, Laser Beam **(2)**, Mirror/galvo motor system (beam steering) **(3)**, Focus & Directed Beam **(4)**, Build Chamber **(5)**, Sintered cross-section **(6)**, Roller **(7)**, Powder Supply Container **(8)**, Pistons **(9)**, and Powder Collection Container **(10)**.

It's important to point out that some "stair stepping" may occur as a result of this technique, so it's important to identify cosmetic surfaces when submitting your design to Protolabs for quoting and analysis.

For especially challenging parts, ribs can be used to strengthen large, flat surfaces—if your handheld game design requires a thin lid, a honeycomb, or checkerboard pattern on the inside surface will not only strengthen the lid, but also reduce material cost and potential warping.

It's Never Too Early to Improve Moldability

Many of the rules applied in injection molding also apply to SLS, making it a solid choice for parts that will eventually be molded.

The use of hole bosses and support struts, and avoiding thick cross-sections are good practices for either manufacturing process. Additional design considerations include:

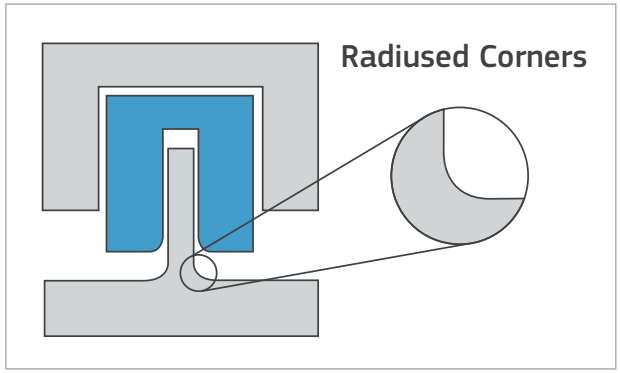
- adding corner radii where walls meet to reduce stress
- uniform wall thickness—between 0.060 in. and 0.150 in. is recommended to reduce in-build curl and potential for warping
- integrating ribs to reduce warping

Where injection-molded parts can contain overmolded metal bushings or threaded inserts, SLS parts achieve comparable functionality via heat-stake inserts—in our handheld game example, threaded inserts can be heat-staked as a secondary process at each corner of the housing for strong assembly purposes.

Look and Feel

The surface finish produced by SLS is a bit rougher than other 3D printing technologies—anywhere from 100-250 RMS—but is still works reasonably well for most functional prototypes. Protolabs also bead blasts the majority of customers' parts to remove loose powder and create a smooth matte finish. Very fine text is another consideration—since the minimum feature size with SLS is 0.030 in., very small fonts tend to get jammed with powder, making letters and numbers less legible. Moving to inset text provides better results, but is still limited to features no smaller than approximately 0.020 in. Lastly, SLS is slightly less accurate than competing laser sintering processes—where DMLS has expected tolerances of ±0.003 in. plus an additional 0.001 in./in. on metal parts, ±0.003 in. plus ±0.001 in./in. is typically achievable with SLS on well-designed parts.

The upside here is that SLS has a build frame of 19 in. by 19 in. by 22 in. (482mm by 482mm by 558mm), far larger than its metal-making sidekick. And because there are no support structures involved, the entire powder bed can be utilized, making it easy to nest multiple parts into a single build. This makes SLS a solid alternative to machined plastic, a logical stepping-stone to injection molding, and an excellent way to produce functional nylon parts in higher volumes than is usually associated with 3D printing.

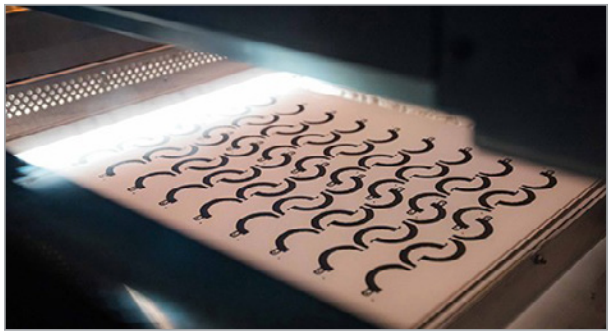


Implementing radiused corners reduces stress, warping, and makes for an easy transition to injection molding.

How to Use Multi Jet Fusion for Functional 3D-Printed Parts

Technology giant HP has developed and launched Multi Jet Fusion (MJF), an industrial-grade 3D printing technology that quickly and accurately produces functional prototypes and end-use parts for a variety of applications. Protolabs served as one of several test sites for this additive manufacturing process because of its experience in industrial 3D printing, and recently added HP Jet Fusion 3D 4200 printers to its suite of manufacturing tools. Here are several considerations to keep in mind when designing for MJF.

Multi Jet Fusion parts are 3D printed in a Nylon 12 material.



Multi Jet Fusion applies fusing and detailing agents across a bed of nylon powder, which are fused in thousands of layers by heating elements into solid functional components.

SLS Similarities

If you're familiar with selective laser sintering (SLS) design principles, you're already close to being an MJF master. Both are powder-bed 3D printing technologies, using a heated chamber, the entirety of which can be used for making parts—there's no need for supports as there is with other 3D printing processes. Where SLS uses a laser to fuse individual powder layers, MJF uses an infrared heating element together with proprietary fusing and detailing agents.

Regardless of the actual manufacturing process, MJF produces fine features and more consistent isotropic material properties, and is suitable for complex, low-volume quantities of parts like brackets and clips, mechanical assemblies, component housings, and durable but accurate jigs and fixtures.

How MJF is Different

- **Resolution:** MJF prints in layers 0.003 in. (80 microns) thick, and boasts a minimum feature size of 0.020 in. (0.5mm). This is finer than the 0.030 in. (0.75mm) produced with SLS, but MJF-produced part details are a bit more variable at this size range, with expected tolerances of +/-0.004 (0.10mm) over the first inch vs. +/-0.001 (0.025mm) for SLS. Be aware that these tolerances will vary depending on part size and geometry, so pay particular attention on designs that require tight clearance such as housings or multiple mating parts in an assembly.
- **Part Size:** At 11.1 in. by 14.9 in. by 14.9 in. (284mm by 380mm by 380mm), MJF's maximum build envelope is a bit smaller than the 19 in. by 19 in. by 17 in. size available with SLS. This means the maximum dimensions of any individual MJF-generated part cannot exceed 13.5 in. by 10.4 in. by 13.7 in. (343mm by 264mm by 348mm), although this is plenty big for many 3D-printed parts..
- **Materials:** Because MJF currently prints only unfilled Nylon 12 (PA12), SLS has a slight edge in terms of available materials and colors (for now). However, Nylon 12 provides a breadth of mechanical or thermal properties that are often required of functional parts and in end-use applications. If cosmetics are important, we suggest dying the natural salt-and-pepper gray of MJF parts black (which Protolabs does in-house), and also recommend a light bead blast for parts made with either MJF or SLS.

At a Glance: MJF vs. SLS

MULTI JET FUSION	SELECTIVE LASER SINTERING
Finer minimum feature resolution	Better small feature accuracy (small feature tolerances)
Requires black dye for consistent color	More consistent surface color without secondary operations
New process with accelerated build time	Established process with longer build time
More consistent isotropic mechanical properties in the Z build direction when compared to other additive manufacturing processes	Broader selection of materials, including filled and specialty materials
Improved surface roughness	Larger available build envelope

Stronger Parts, Faster Process

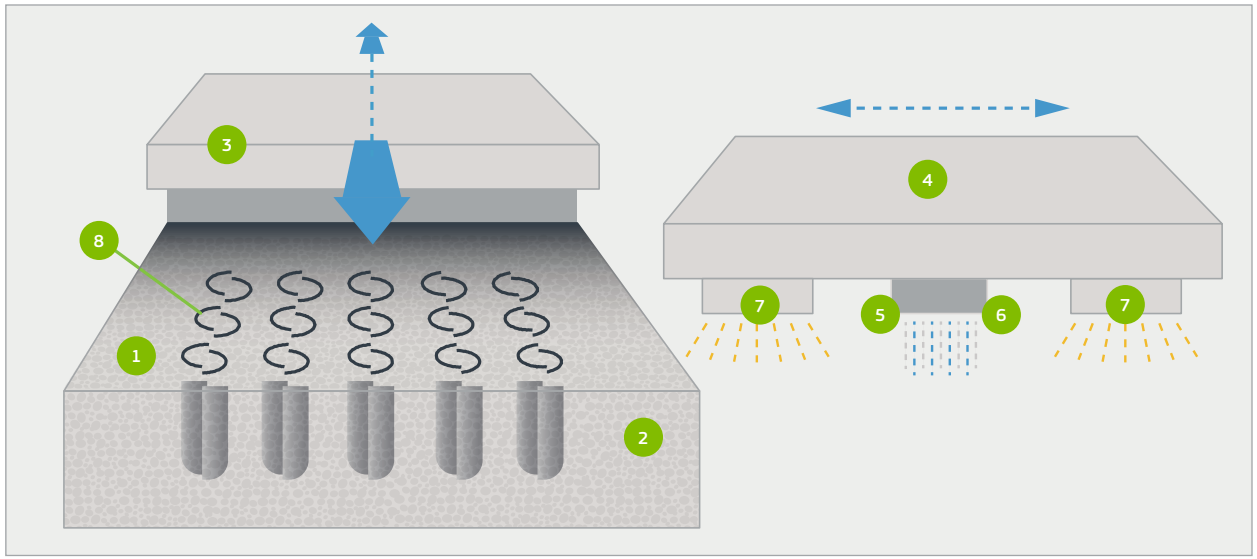
It's also important to consider areas in which MJF excels. For starters, MJF builds strong parts, with tensile strength at the upper end (maximum load: XY and Z 48 MPa/6,960 psi with ASTM D638 method) of what's possible with SLS. More important, MJF produces more consistent mechanical properties in each direction of the part geometry—far more so than other powder-based printers—a factor that's especially desirable with multi-faceted, complex designs where strength and reliability is required everywhere throughout the part. So even though MJF is slightly less accurate than SLS on small part features, those features will be more robust.

MJF is also much faster than competing processes. Rather than tracing each individual detail in a build layer, MJF scans the entire surface on each pass at a consistent rate, regardless of how many parts are in that layer (similar to how a laser printer prints each page in a document). Depending on what's being 3D printed, this provides build speeds several times that of competing technologies, even with larger quantities. To understand what impact this might have on your project, simply upload the CAD file and compare the quoted lead time and price to Protolabs' other 3D printing or machining services.

Design Elements to Consider

Many of the design principles applied to SLS and even injection-molded parts are just as relevant to MJF:

- Thin-walled or large, flat surfaces should be reinforced with ribs or gussets, and holes surrounded with raised bosses wherever possible.
- Raised text and cosmetic part features smaller than 0.020 in. (0.5mm) might not survive secondary post-processing. Check the design for manufacturability analysis that accompanies your part quote for details.
- Wall thicknesses from 0.1 to 0.5 in. (2.5 to 12.7 mm) are ideal. Get much above or below this and part tolerances may be affected.
- MJF does a great job with assemblies, living hinges, snap fits, and pin hinges.
- As with any 3D printing process, MJF produces some stair-stepping on oblique angles. Cosmetic surfaces should be clearly identified on the part drawing or digitally in the product manufacturing information (PMI), so Protolabs can attempt to orient the parts in the build chamber accordingly.
- Protolabs can install heat-stake threaded inserts and metal bushings in MJF parts. And in addition to dying parts black, application of primer paint is also offered.



From left to right, the 3D printing elements of Multi Jet Fusion include: Nylon Layer **(1)**, Powder Bed **(2)**, Material Recoating Unit **(3)**, Print Carriage **(4)**, Inkjet Array **(5)**, Fusing and Detailing Agents **(6)**, Thermal Energy **(7)**, and Part **(8)**.

Sound familiar? As mentioned previously, MJF is similar in many ways to other additive manufacturing technologies, offering predictable part quality and possessing design rules that are well understood. What's different is its unique ability to make accurate parts with isotropic mechanical properties, and in many cases do so more quickly than other 3D printing methods. Together, these attributes have the potential to make MJF an additive game-changer.

And although MJF is limited to PA12 nylon at this time, Protolabs and HP are regularly investigating additional materials, including flame-retardant and glass-filled nylon, elastomers, and multiple colors in a single build. This may be a good time to consider what role MJF can play in your current and future part development projects.

The Basics of Metal 3D Printing Part Design

When the first direct metal laser sintering (DMLS) machines hit the production floor, some in the manufacturing community assumed the end of traditional machining was near. After all, how cool is it to fill a machine with metal powder, load a CAD file, and a few hours later, out pops a shiny new part? How could a shop possibly compete with a machine that creates little waste, has no cutting tools, and touts a setup as simple as the push of a button?

As it turns out, the reality of DMLS is slightly different than those early assumptions. No "Star Trek"-like replicators here, but rather a process that complements traditional machining. DMLS produces fully dense metal parts directly from CAD models, often with an accuracy and surface finish that allows a part to go directly into service. Most important, if you have a highly complex part that is impossible to machine, DMLS may be the answer.

Like other laser-based 3D printing, or additive manufacturing, processes, DMLS builds parts from the bottom up. It uses an ytterbium laser to melt and fuse microscopic grains of metal powder into most any shape imaginable, provided it fits in a build chamber roughly the size of a microwave oven.

Metal powder is brushed away from a bed of intricate aluminum parts.

How Does DMLS Work?

Let's say that you just uploaded a 3D CAD model of your part design to protolabs.com. This could be anything from the next greatest fishing boat propeller to an air intake for an Indy car. Protolabs' 3D printing technicians can turn that electronic dream into a physical reality in a few, relatively quick, steps:

1. The CAD model is digitally sliced into paper-thin layers, and any needed support structures are designed in to aid in the laser sintering process. The file is then uploaded to a DMLS machine.
2. The powder bed is filled with one of five high-strength alloys: aluminum, stainless steel, titanium, cobalt chrome, or Inconel. A thin layer of the material selected is then distributed across the build platform.
3. As the build begins, a high-powered laser goes to work, drawing the bottom layer of the batch of parts, along with any temporary support structures necessary for the build process.
4. A rubber wiper scrapes another thin layer of metal powder across the parts, and the lasing process is repeated.
5. Once complete, the nearly finished part is removed from the build chamber. The build supports are removed, and the parts may then be further processed per customer requirements.

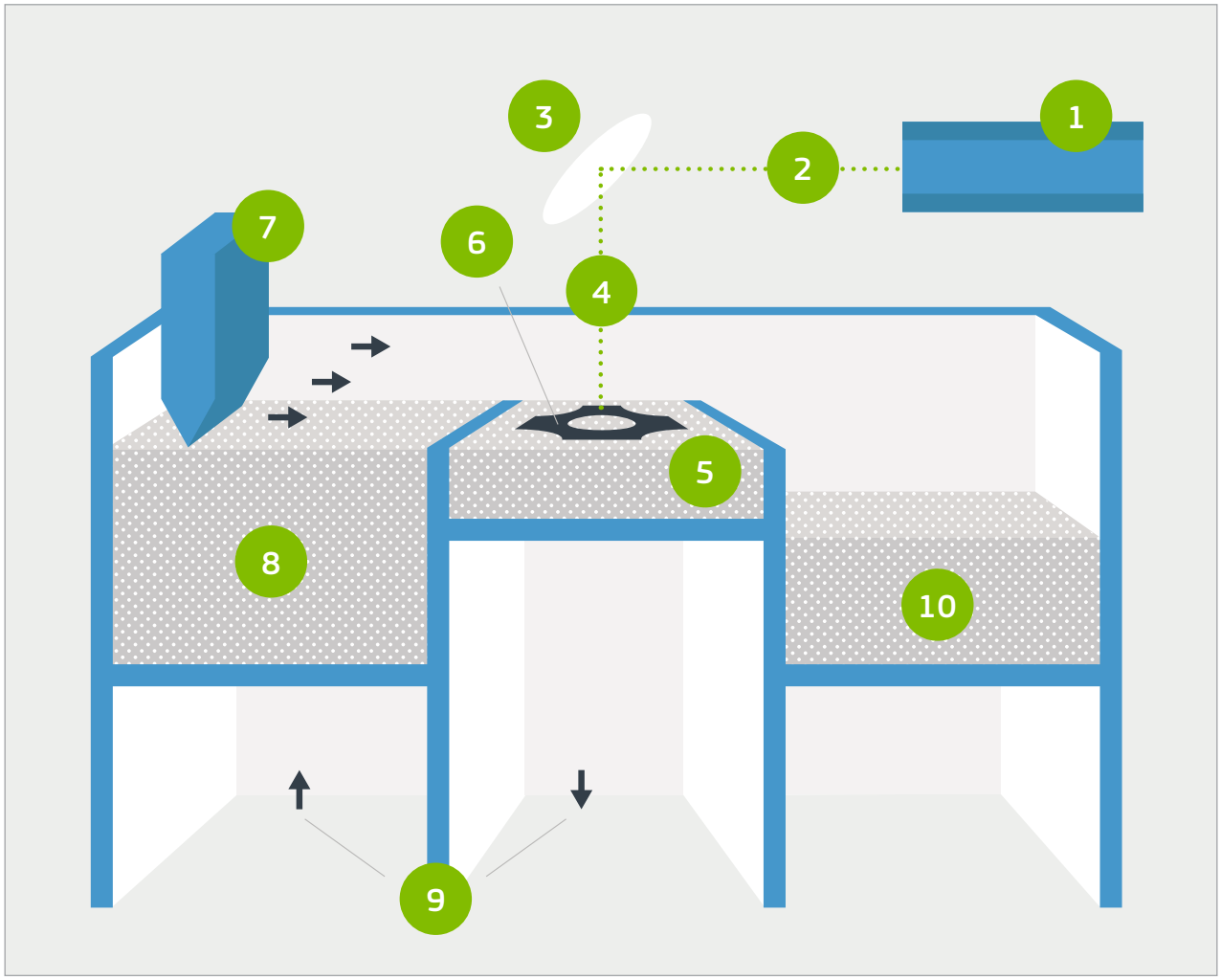
That is essentially DMLS. As in every other 3D printing process, part quality is very dependent on a sound build strategy. For starters, DMLS requires support structures to hold features in place as the part is being built. Without them, flat areas may curl—a T-shape would turn into a Y, a dinner plate would become a pie tin. For the most part, Protolabs customers can leave support placement to the DMLS experts, but should understand that unsupported surfaces do tend to warp during the build, and secondary post processing will be needed to saw, grind, or machine those supports away.

DMLS Tolerances and Surface Finish

Part tolerance is another design consideration. High-resolution DMLS builds at a layer thickness of 0.0008 in. (0.02mm) and can produce quite accurate parts, with tolerances to +/- 0.003 in. (0.076mm), part features as small as 0.006 in. (0.152mm), and surface finishes similar to that of a sand casting. If you require a smoother finish, Protolabs offers a number of finishing operations, including bead blasting, hand polishing, and painting.

For those concerned about the metallurgical properties of laser-sintered parts, don't be. DMLS uses laser power to actually melt individual metal particles. Each pass of the beam overlaps the previous one and re-melts the layer directly underneath, merging the metal into a homogenous mass that's 99 percent as dense as conventionally formed materials.

The ability to create intricate internal features by "drawing" them one layer at a time opens the doors to previously impossible part designs. Complex structures and multi-part assemblies can be greatly simplified using DMLS. For example, GE Aviation reduced the part count in a fuel injector assembly from 18 to just 1 by using DMLS, and anticipates that more than 100,000 laser-sintered parts will be produced in this manner by 2020. And with the variety of alloys



From left to right, the 3D printing elements of direct metal laser sintering include: Laser Unit **(1)**, Laser Beam **(2)**, Mirror/galvo motor system (beam steering) **(3)**, Focus & Directed Beam **(4)**, Build Chamber **(5)**, Manufactured Part **(6)**, Recoater Blade **(7)**, Powder Supply Container **(8)**, Pistons **(9)**, and Powder Collection Container **(10)**.

available, DMLS is enjoying increased use in the aerospace, medical, and consumer industries—everything from orthopedic implants and surgical tools to gas turbine and exhaust components are being produced today, in prototype and production quantities alike. The message here is that those who understand how to take advantage of metal laser sintering technology have highly complex metal parts manufactured with ease while reducing overall bill of materials (BOM).

Part of that understanding comes from knowing how DMLS works. Because parts are built in layers, so-called "stair stepping" will occur on angled surfaces—for example, the sides of a pyramid-shaped part will be rougher than those of a cube. Protolabs will attempt to orient the part build to minimize this effect, but it's important to point out any critical surfaces or features when submitting your part design, so these can be placed in the horizontal build plane. Overly thick sections should be avoided wherever possible, as these add to build time and increase internal material stresses. And if very close tolerance holes or features are required, the design should include extra material for subsequent reaming or secondary machining. As always, a conversation with one of Protolabs' applications engineers is recommended if any questions arise.

Remember that DMLS is not necessarily a faster, simpler alternative to machining. Part size is limited, since even a large-format DMLS machine maxes out at around 10 inches cubed at Protolabs. The upside to this is that the entire volume can be utilized—if you wanted to produce a thousand microscopic surgical instruments in 316 stainless steel, DMLS can make them in a single build. The process of melting metal one ultra thin layer at a time also isn't terribly fast—our instruments may take a few days to build. For many parts, CNC machining remains the most economical choice. For everything else, DMLS may offer a number of advantages, chief among them design flexibility.

After a DMLS build, some machining is required to remove support structures.

Lightweighting Parts with Metal 3D Printing

If you're thinking about trying DMLS, another bit of advice is in order: Parts can be laser sintered far more quickly and at substantially less cost if they're hollow. Unless you're looking for the world's most expensive paperweight, there's no reason to melt every square inch of each powder layer when all that's required is tracing enough of the outline to ensure its structural integrity. For this reason, DMLS is a great option for product designers aiming for lightweight parts—compared to machining, where lightweighting increases time and cost, DMLS is the opposite, becoming less expensive as part weight goes down. This is an important point to aircraft and automobile manufacturers, where every ounce counts in terms of fuel efficiency. As mentioned previously, DMLS produces complex parts in lightweight material such as aluminum and titanium.

Ultimately, part design is a key factor in determining which process is best. Due to their complex three-dimensional shapes, tiny surgical instruments work well with laser sintering, whereas parts containing straightforward features—mounting brackets, manifold blocks, electronics housings, and many other components can be readily machined in lower volumes. Whichever way you go, it's a brave new world of metal fabrication, one that Protolabs is well-equipped to help you explore.