FORMLABS WHITE PAPER:

Introduction to Desktop Stereolithography

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Introduction to Stereolithography 3D Printing

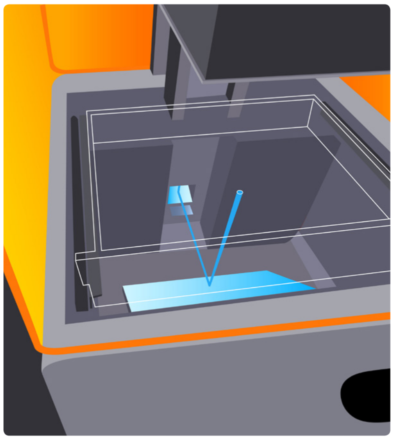
Advancements in 3D printing continue to change the way we approach prototyping and small batch production. Today's technology is more accessible and more affordable than ever before. These changes in technology creates major opportunities for designers and engineers to evaluate more options while rapidly iterating and improving their designs.

In the past, industrial rapid prototyping has been a significant investment. Beyond purchase costs, systems require skilled technicians and costly service contracts to maintain. Industrial 3D printers are often housed in model shops, printing laboratories, or jobs are outsourced to industrial service bureaus. For these reasons, industrial 3D printing is often limited to priority projects and final presentation models, rather than being fully integrated into the individual designers' workflow.

Recently, the introduction of desktop 3D printing has widened access to this technology. Fused Deposition Modelling (FDM) was the first technology to gain adoption in desktop platforms. While this affordable extrusion-based technology has aided the widespread use of 3D Printing, the quality of parts, and printer reliability has limited these machines when repeatable, high-quality results are crucial to success.

The introduction of desktop stereolithography (SLA) 3D Printing in the Form 1+ offers the quality of industrial 3D Printing in an affordable, accessible desktop package. With SLA, professional designers and engineers are printing high quality objects on the desktop, reducing iteration cycles from days or weeks, to hours. This paper will outline the function and advantages of desktop SLA from the viewpoint of a professional user.

How Does SLA Work?



SLA is a light-based process, in which individual layers are cured by a directed laser beam. The resin tank peels away to release the cured material and then the build platform moves up from 25 to 200 microns depending on the chosen layer height. The part appears to be built 'upside down', and so this is something referred to as 'inverse stereolithography'.

1. THE LASER

At the beginning of each Form 1+ print is a blue 405 nm laser. Custom circuitry activates the laser in timed bursts, generating the energy to turn the photopolymer from liquid to solid.

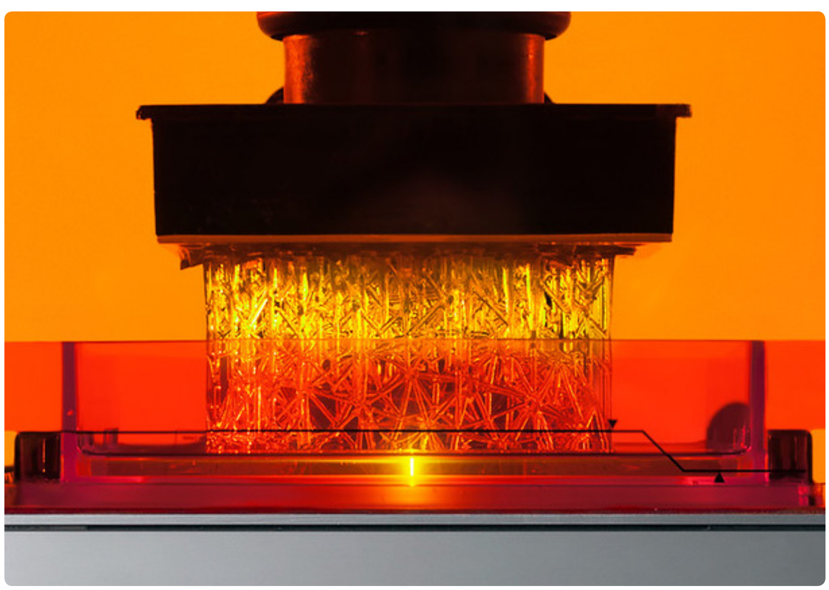
2. THE GALVONOMETERS

As the laser travels along the optical pathway, it's reflected by two rapidly oscillating, finely tuned mirrors which can accurately draw the laser or position it as it turns on and off. This control hardware sweeps the laser repeatedly across the build platform hundreds to thousands of times per second with submillimeter accuracy.

3. THE RESIN TANK

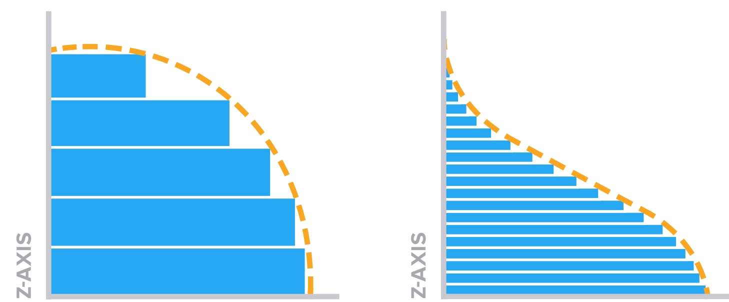
The underside of the replaceable resin tank is an optically transparent window. Layered over this is a layer of clear, non-stick silicone, which allows the beam of the laser to pass into the tank of resin. The non-stick surface serves as a substrate for the liquid resin to cure against, allowing the for the gentle detachment of newly formed layers.

The Curing Process. As the laser contacts a thin layer of resin it chemically hardens, bonding with nearby layers, creating a fully dense, watertight part.



THE TIME / RESOLUTION COMPROMISE

3D printers give control over layer height and build time. Larger layer heights, such as 200 µm, provide improved print speed while increasing the visibility of layers, particularly on shallow slopes relative to the build platform. Fine layers heights of 25 µm produce much smoother surfaces desirable for casting as well as fine details, but build times increase.



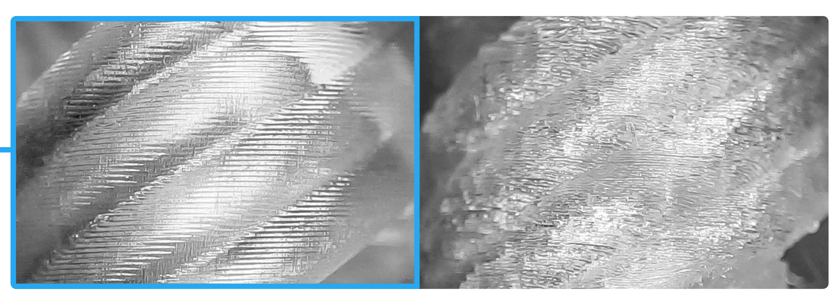
Thick Layer Height (200 µm)

- Parts build faster
- Rougher surface finish

Fine Layer Height (25 µm)

- Parts build slower
- Fine surface finish

3D printers work by virtually "slicing" digital models and building them layer by layer in a physical form. 3D printers are often compared by the thickness of these layers, also referred to as layer resolution. However, a part printed at 100 micron layers on an FDM printer looks different from a part printed at 100 micron layers on an SLA printer, because of the way the layers are built. The process by which a layer is created has a dramatic impact on the quality and physical properties of the final part.



Surface Finish: Parts created on a Form 1+ (left) display a significantly smoother surface finish than desktop FDM prints (right).

UK startup Sutrue (above), focused on developing suturing devices for hospitals, decreased their iteration cycle from months to days using a Form 1+.

The Advantages of Desktop SLA

RAPID PROTOTYPING

Fast turnaround time is a huge advantage to owning a desktop 3D printer. When working with a printing bureau, lead times, communication and shipping all create delays. With a desktop 3D printer, parts are in-hand within hours, allowing you to run multiple prints a day. When considering other FDM desktop printers, the Form 1+ is faster when using identical layer height settings.

TIME REQUIRED FOR A 100 µm ROOK

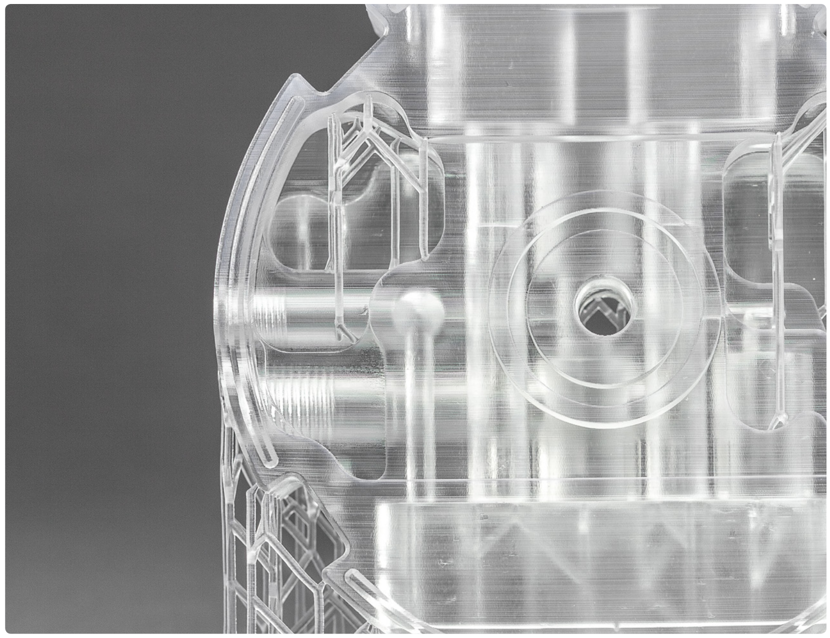
Typical Service Bureau	Leading FDM Printer	Form 1+
Hours to print, days to ship	1 h 39 min to print	39 min to print

QUICK DESIGN CHANGES

Desktop 3D printing allows you to verify fit and feel of a design. SLA creates components with the quality required to evaluate the design of injection molded parts without additional post-processing. Mechanisms and assemblies can be tested at your desk and easily modified over the course of a few days, helping to drastically reduce product development time or avoid costly tool changes.

Rapid Iterations. A partial inventory of the iterations designed by Sutrue.

Cost Savings. This baseblock (part of a larger gripping robotic assembly), was printed on a Form 1+, saving the cost of machining the prototype instead. The part features threaded connectors that were required to hold a vacuum.



COST TO CREATE 1 BASEBLOCK*

Form 1+ Material Cost	$36.28
Service Bureau Form 1+ SLA	$684.60
Machine Shop CNC Milled Aluminum	$1085.00
Number of Prints to Recover Printer Cost	5

*Service bureau costs were estimated for advertised Form 1+ 3D Hubs users with 5 stars. Machining quotes were received from Protolabs.com. Both quotes were received 03/2015.

COST SAVINGS

Industrial SLA printers can cost upwards of $60,000 and require trained technicians and compulsory service contracts to operate. A similar investment in desktop printers can purchase a “farm” of 3D printers, with greater potential throughput and reduced user wait time, or machines may be distributed on the desks of individual designers and engineers. Integrating this technology into day to day development can drastically change the prototyping workflow, making 3D printing much more accessible.

Owning a Form 1+ 3D printer results in significant savings over 3D printing service bureaus and traditional machining, illustrated in the chart to the left. Costs per print can be calculated by multiplying part volume in the Form 1+ PreForm software by the cost of resin ($0.149/mL). **PreForm** is a free download, and can be used for cost estimates without ordering a Form 1+.

DESIGN FREEDOM

The low cost and high speed of desktop 3D printing changes the design workflow. The immediacy of a person or team working with an individual 3D printer allows for rapid verification of designs and the freedom to attempt risky or unconventional ideas. Teams that work in multiple locations with multiple printers can print and verify designs independently, sharing physical objects over digital channels.

FILE SECURITY

Many engineering and design firms must keep 3D assets in-house to protect intellectual property. Easy-to-use systems like the Form 1+ create professional results without requiring freelance contractors or off-site service bureaus.

Desktop 3D Printing and Quality

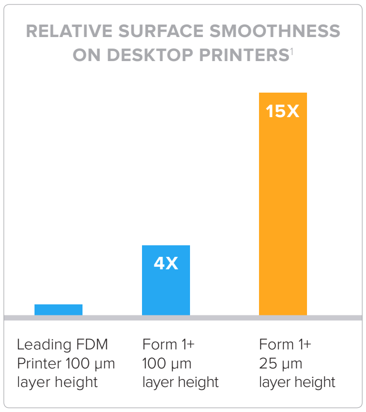
High quality 3D prints help move projects forward in a working environment. If a part is rough, inaccurate, or incapable of showing fine detail, colleagues or customers can get hung up on these flaws. Formlabs printers provide superior part quality when compared to FDM machines, the current standard in dekstop 3D printing.

PART FINISH

SLA creates parts with a smooth surface finish directly from the machine. Parts are ready for painting, or with wet sanding and polish, exhibit a glossy surface. This is ideal for applications requiring a flawless surface, such as investment casting for jewelry or electroplating. At the other end of the spectrum, the combination of smooth surface finish and fine resolution allows for the creation of high fidelity textures, allowing designers and artists to capture more detail on the desktop than ever before.

Applications:

Presentation Models, Burnout, Advanced Finishing, Moldmaking

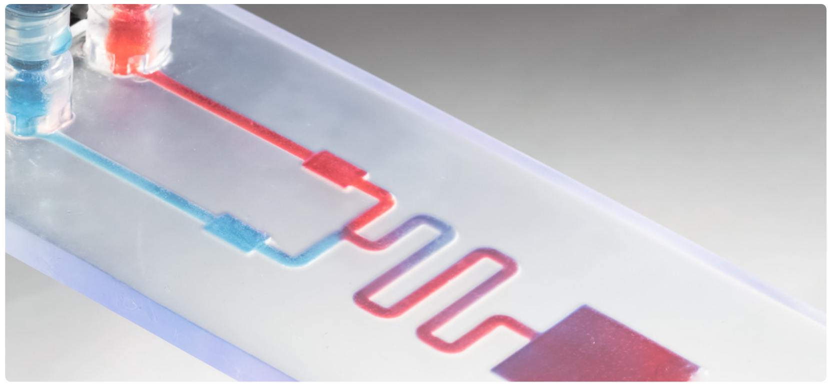


FINE DETAILS

Achievable detail on an SLA 3D printer depends on the laser spot size, the ability to accurately control that spot size, and the curing properties of the photopolymer resin. Depending on part geometry, positive and negative surface features can be produced at 300 micron or less (0.3 mm).

Applications:

Precision Assemblies, Jewelry Design, Character Design, Modelmaking



A Millifluidic Blender printed on a Form 1+, this device blends fluids within internal channels. The surface was polished to provide a clear view of the interior.

FULLY DENSE PARTS

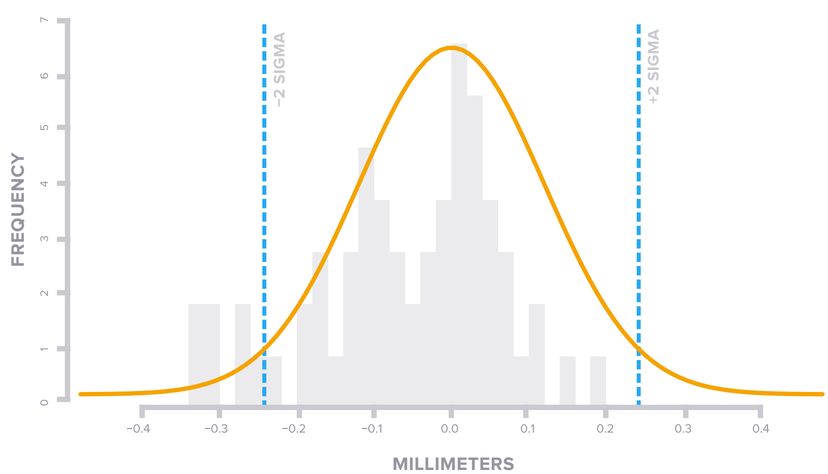
While FDM produces a mechanical bond between layers, SLA creates a chemical bond by cross-linking photopolymers across layers, resulting in fully dense parts. The bond is water- and air-tight, and strength does not change with orientation. Dense parts have several functional advantages. Microchannels can be designed through a solid part to allow liquid transfer and mixing. Parts can be threaded or tapped, creating airtight connections using teflon tape for low pressure pneumatic prototyping. Fully dense parts transmit and refract light. Standard Clear resin can be used to create lenses or allow clarity for visibility into complex assemblies.

Applications: Microfluidics, Research, Lens Prototyping, Pneumatics

ACCURACY

Formlabs printers are capable of creating accurate parts, with repeatable dimensions. This is important for designers or engineers creating assemblies or printing parts for investment casting. In recent testing, 95% of prints were measured to within 240 μm or less (0.24 mm) of the designed dimension.

Applications: Mechanical Assemblies, Prototyping, Design Error Checking



Accuracy: Histogram with normal distribution curve for dimensional deviation shows a standard deviance of 240 μm.[2]

The Formlabs Ecosystem

Bringing SLA to the desktop required reimagining the entire 3D printing process. The workflow of 3D printing must be quick and simple to easily fit in with day-to-day design development. Formlabs has created a complete, end-to-end system to allow users to 3D print from the convenience of their desktop.

FILE PROCESSING WITH PREFORM

3D Printing on the Form 1+ starts with PreForm, a software package designed to prepare any .STL or .OBJ for printing. PreForm has several functions, two of which are essential to quality printing: orientation and support generation. Both of these functions have been automated in PreForm, allowing users to perform these complicated tasks quickly and reliably. PreForm also automatically repairs files if there are any issues. Once a file has been uploaded quickly via usb, you can disconnect the printer allowing the system to run alone or overnight.

MATERIAL PROPERTIES

Once a file has been prepared for printing, a specific resin type must be selected for the print. Formlabs offers a growing library of acrylate photopolymer resins, in two categories: Standard and Functional. Standard resins feature tensile strength comparable to monolithic ABS, in a variety of shades and transparencies useful for prototyping. Functional resins allow designers to take advantage of material properties for specialized applications, such as flexibility or clean burnout properties for investment casting. With multiple light-blocking resin trays, materials can be swapped in seconds and stored near the printer.

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AFTER PRINTING: FINISHING

After a part has been printed, it will still be coated with excess liquid resin. Each Formlabs printer includes a finish kit designed to make part cleaning simple and organized. Users remove models from the build platform, followed by washing parts in isopropyl alcohol for 20 minutes. Once the part is dried, supports are removed with the included flush cutters and the print is ready for use.

WARRANTY

In a production environment, uptime of equipment is essential to maximizing productivity. Formlabs provides a 1 year warranty as standard with each printer, including same-day email response. For professional users, an upgraded service plan is available, offering dedicated training, phone support, and prioritized servicing.

[1] Relative roughness was calculated based on roughness average values (Ra) of flat samples printed in 0°, 45° and 90° orientations, with and against layer grain. Readings were taken in triplicate using Daktek 150 profilometer using standard scan settings across a 4000 µm sample area.

[2] A test piece with 9 features ranging in size from 10 mm–40 mm was printed and measured 7 times across multiple printers for a total of 63 measurements. This chart is based on the standard deviation of the error found in each feature across all printers.