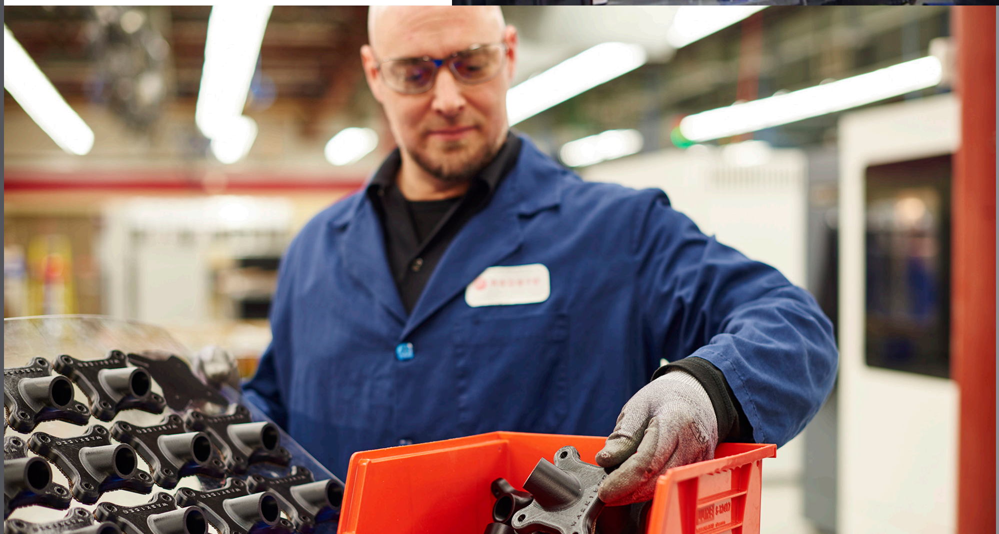
Manufacturing-Ready

Maximize production capability with the Stratasys F900 3D Printer



White Paper

Manufacturing-Ready

Conventional manufacturing continues to evolve, embracing “smart” capabilities involving greater connectivity and flexibility all the way to full-on Industry 4.0 transformations. Additive manufacturing (AM), also known as 3D printing, continues to evolve too, as it capitalizes on opportunities traditional manufacturing technologies can’t exploit due to their inherent limitations.

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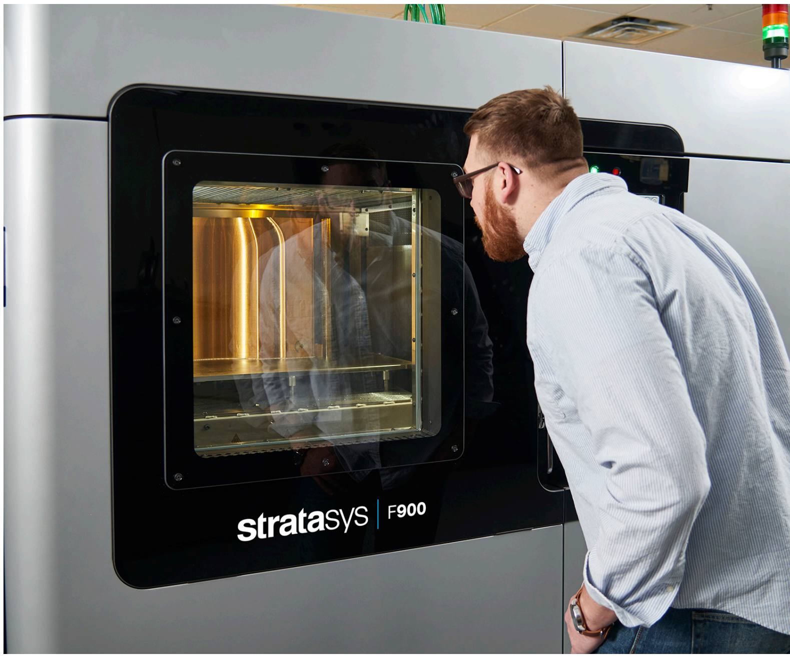
Although additive manufacturing may never completely replace machining, molding and casting, it continues to develop and as new materials emerge, it is increasingly becoming the most suitable choice for certain applications.

A fitting example of this is the Stratasys F900™ 3D Printer. This white paper will show how the F900 represents a true manufacturing-ready AM platform, with the broadest array of thermoplastics and the largest build volume of any FDM® (fused deposition modeling) 3D printer in the Stratasys portfolio. More importantly, it will show how manufacturers are using it to take advantage of opportunities that aren't possible with conventional technology and also compare the F900 to competing AM technologies.



Versatility and Capability

The F900 Printer is the third generation of Stratasys large-capacity, full-capability 3D printers. Its FDM technology is one of the most widely used forms of 3D printing, building parts by applying a thin bead of thermoplastic material in successive layers. What makes the F900 unique among FDM printers is its versatility, coupled with productivity-enhancing capability and reliability. A lot can be achieved with the F900 and manufacturers have come to depend on its consistent, dependable results.

A Broad Range of Materials

Versatility starts with a diverse range of materials that gives manufacturers more options to meet the needs of diverse applications. The F900 uses engineering thermoplastics, each designed to address specific needs and applications. All-purpose ABS and ASA provide an economical means for prototyping and production when speed and/or quantity are needed. For more demanding applications, high-performance materials such as ULTEM™ thermoplastics offer high strength and thermal stability. Certified ULTEM 9085 resin material is traceable back to the original manufacturing lot, a key requirement for aerospace production parts. ULTEM 1010 resin parts are biocompatible and autoclave-capable, an optimal choice for composite fabrication tools and hardware for the food and medical industries. Carbon-filled nylon 12 provides superior stiffness for production parts, tools and fixtures that require maximum rigidity without metal's weight penalty.

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This kind of material capability saved the Aerostructures business of UTC Aerospace Systems 63% on the cost of a replacement machine part for their factory. The division builds a number of large assemblies including engine nacelles, thrust reversers and pylons for aerospace companies like Boeing and Airbus. It typically uses its 3D printers for prototyping but has also used them to substantially reduce the cost and lead time to build replacement machinery parts, as well as tooling and fixtures.

When a fume collection nozzle in their facility needed replacement, production workers suggested designing a new, simpler nozzle to better collect fumes, which could be made on the 3D printer. UTC Aerospace technicians redesigned the nozzle and 3D printed it with ABS material but it wasn't able to withstand mounting clamp loads. As a solution, UTC decided to switch to ULTEM 1010 resin, to take advantage of its high strength.

"We tested the new material and the results were very promising so we decided to produce the new nozzle in ULTEM 1010," said Larry Crano, automation specialist for UTC Aerospace. The cost, including material, was $750 and the part was produced in one day, a 95% time savings over traditional fabrication. "ULTEM 1010 provided the qualities needed for the nozzle," Crano said. The new part provided the necessary durability and solved the fume control problem.

Another enabling material in the F900 portfolio is ST-130™, a soluble model material designed primarily for the creation of lay-up tools for complex composite parts. It avoids the need for complex tooling and/or multi-piece designs typically required for shapes that result in trapped-tool scenarios. Instead, with ST-130, the tool can be dissolved away after the composite lay-up is cured, resulting in a simpler yet stronger one-piece composite part.

UTC Aerostructures designed a new fume collector for their facility using 3D printed ULTEM 1010 resin material.

Large-Scale Prototyping

The large build capacity of the F900 means you can prototype large parts or produce a tray of differently configured parts to speed design iteration. Minimizer, maker of aftermarket semi-truck fenders, exemplifies the first strategy. A new industry tire configuration called for a new fender design, but creating all-new tooling was a big investment. And because the design had to be right before committing to the new tooling, functional prototyping was essential.

Using their onsite 3D printer, Minimizer built functional prototypes of the large truck fenders in a few days using black ULTEM 9085 material. The black color lets Minimizer make concept models look more like production parts. "About 90 percent of our products are black in this industry," says Minimizer CEO Craig Kruckeberg. Black ULTEM models look like the real thing right out of the build chamber, which is helpful for a business that's constantly trying out new ideas.

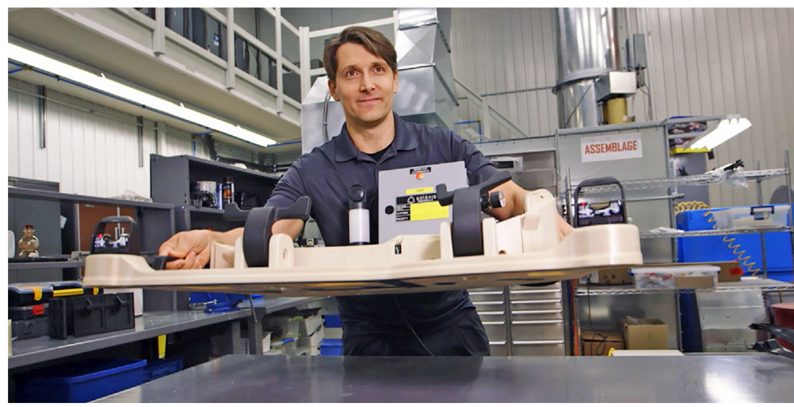
Smaller additive manufacturing systems wouldn't be able to produce prototypes the size of Minimizer's truck fenders, at least not in one piece. Producing them in several pieces and bonding them together is an option, but requires additional steps for assembly and the possibility that they might not stand up to functional prototyping.

Minimizer put their ULTEM 9085 resin material prototype fenders through real-world functional testing.

Fast, Easily Customized Tooling

One of the most overlooked capabilities of an additive manufacturing system like the F900 is its capacity to produce large, highly effective, cost-efficient manufacturing aids. Machining jigs and fixtures is costly and takes up valuable machine time for production of higher-value parts. The process can be outsourced but lead times generally takes weeks or months, depending on the machining contractor's backlog.

In contrast, additive manufactured tooling can be created on-demand, in a fraction of the time it takes for machined tools. AM-fabricated tools are lighter and can easily incorporate ergonomic features that make them easier to transport and use compared with bulky metal tools.



Solaxis president Francois Guilbault demonstrates the lightweight assembly jig produced with FDM technology.

Solaxis Ingenious Manufacturing, located in Bromont, Canada, makes it their business to design assembly jigs without any of the negative features of conventional tooling. Using their 3D printer, the company designed and manufactured a jig for an automotive supplier, which uses it to assemble high-volume plastic door seals. After developing several iterations of the jig, Solaxis was not only able to produce a 3D printed version that is over 100 pounds lighter than a typical tool, but it also slashed the design and manufacturing time by at least two thirds compared with traditional methods.

The Solaxis jig, which is 34 inches by 22 inches and weighs just 28 pounds, is light enough for anyone to pick up and move. In addition, the jig saves workers an average of four seconds per assembly cycle. With 250,000 cycles a year performed by a typical employee assembling the seals, the supplier has saved hundreds of hours in labor time. "Just that cycle time gain alone justifies the price of the jig," said Solaxis president Francois Guilbault. "So their ROI is achieved within 12 months."

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Production Parts

A typical mindset associated with 3D printing is that it's a prototyping solution, lacking the speed and throughput needed in manufacturing. But that mindset is typically rooted in the belief that the demands upon manufacturing are static and unchanging, and that current methodologies are sufficient. However, that's not the reality. Manufacturing is changing to meet new demands. Customization, on-demand and low-volume production are driving alternatives to conventional manufacturing methods. AM technologies may never completely replace CNC machining or casting but the advantages of a system like the F900 make it uniquely qualified to cost-effectively meet these demands.

For example, FDM technology makes it possible to produce production parts across the entire product life cycle, even in historically non-profitable segments. In the early phases of product release, it can make parts for pilot production runs. Once the product has been validated and all component designs are frozen, FDM technology is used as a bridge to production: production parts are 3D printed while waiting for the ramp-up of tooling, manufacturing equipment and processes for mass production.

For more complicated geometries and custom solutions, additive manufacturing with FDM technology is the more practical option. Since traditional tooling is aimed at production of a single design, FDM technology is an efficient and optimized solution for products that are continuously changing – either through product revisions or through order-by-order customization.

When a product approaches end of life, companies should once again turn to FDM technology. As orders decline and tooling requires replacement, FDM technology is an alternative that extends the product life with minimal expense or inventory. FDM technology can also continue to manufacture spare parts even after products are retired.

An illustration of this concept is how Siemens' mobility division met the need for low-volume production, responding to increasing customer demand for one-off, customized parts. Traditional manufacturing processes cannot economically address this need but 3D printing with FDM technology can.

The rail transportation provider in Ulm, Germany, asked for Siemens' help producing a new, optimized design for the train's driver seat to include control system buttons. Despite the seeming simplicity of the request, tackling this with conventional manufacturing necessitated either the purchase of expensive tooling or outsourcing, which would delay the process. Both options made production costs for quantities under 10 units unsupportable.

Siemens opted to use their Fortus 900mc 3D Printer, a close relative to the F900, for this scenario. "Before we integrated 3D printing into production, we were limited to higher quantities of parts in order to make the project cost-effective. For small-volume part demands, we would store excess parts until they were used, discarded or became too outdated to use. With the Fortus 900mc, we can now create a design that is 100% customized to specific requirements and optimized several times before it is 3D printed. This takes our production time down from weeks to a matter of days, in a way that we can now produce a single customized part cost-effectively in low volumes," explained Tina Eufinger of Siemens' business development group.

Particularly important for Siemens is the ability to print larger production parts along with the capability of its flame, smoke and toxicity-compliant thermoplastic material, required by fire protection regulations. This capability lets Siemens employ the 3D printed parts directly into the city's trains.

Andreas Düvel, Siemens sales representative, explains, "Customers like the Ulm city rail provider see availability as their most important business asset – trains and services need to be available and run constantly throughout the day to maintain profitability. The ability to quickly and cost-effectively 3D print customized parts specific to customer requirements enables clients to be closely involved in the design and production of its own parts." According to Düvel, the outcome of this direct involvement has been an increase in customer satisfaction.

FDM technology helps keep the trains in Ulm, Germany, running.

"Through customized additive manufacturing we are achieving maximum customer satisfaction, because the client is actively participating in the creation and optimization of its parts. This would not be possible with mass production," he explains.

Beyond offering 3D printed production parts for customers in the transport industry, Siemens' mobility division expanded its business branch online, allowing customers to shop for customized 3D printed parts. Customers needing replacement parts or changes to existing ones can simply go online and order. This has seen the birth of an on-demand production business model, whereby customers can have part requirements met – how they need it, when they need it.

Manufacturing-Ready Capability

When Henry Ford developed the assembly line that heralded the genesis of mass production, a key requirement was the need for consistent parts and assemblies. Without it, there would be no guarantee that part A would fit with part B further down the line. Quality assurance plays a role in weeding out errant parts, but the cornerstone of production regularity starts with a manufacturing process that produces consistent results, part to part.

One of the hurdles to broader adoption of additive manufacturing among manufacturers is the perceived lack of consistent results in strength, quality and accuracy, build to build, printer to printer. According to Deloitte, an industry research firm, this makes many manufacturers hesitant to embrace the technology, despite documented evidence of any gains they might make. Add to that the steady influx of new entrants to the AM industry and the result is manufacturers that are even more confused and reluctant about which technology to employ, if they should at all.

Achieving consistent results with additive manufacturing starts with choosing the right technology. FDM technology is one of the most widely used and mature AM processes, though other additive methods are available and touted as being manufacturing-ready.

To determine how the FDM process compares with other AM methods for repeatable parts with consistent properties, Stratasys performed a comparative study. The primary objective was to determine the mechanical consistency and dimensional precision among the different 3D printing methods.

For mechanical consistency, key properties such as ultimate tensile strength, Young's modulus and elongation at break were tested according to ASTM D638, which governs standard test methods for these material properties.

Dimensional precision was determined using a test standard, a 3D printed geometric shape containing multiple features of varied dimensions. Using various 3D printing processes, the features were measured to determine their correlation to the governing CAD model.

FDM technology is manufacturing-ready, with the most build volume for large parts or multiple smaller parts.

Team Penske counts on the reliablity of FDM technology to help them win races, producing race-ready car parts and tools like this composite lay-up mold.

The following additive technologies (hereafter referred to as "AM processes") were evaluated alongside FDM:

- MJF – Material Jet Fusion
- SLA – Stereolithography
- SLS – Selective laser sintering
- FFF – Fused filament fabrication
- CLIP – Continuous Liquid Interface Production

Test coupons were printed in two orientations (XY and ZX) for each AM process. Two machines were used per orientation to capture variation between printers and each printer built three batches to determine build-to-build repeatability. Coupons were tested by an independent outside laboratory.

Overall variability was determined using the coefficient of variation (COV), allowing the comparison of the different AM processes, with each having their own unique mechanical properties. COV is the ratio of the standard deviation to the average. In simple terms, this method determined how accurately the printer achieved its "goal" (for example, producing a physical feature) and how much variation occurred when repeating that task.

Mechanical Consistency

FDM, MJF and SLA had the smallest COV, or lowest amount of variance, for ultimate tensile strength, Young's modulus and elongation at break. Low COV means there is little variance, a desirable outcome for manufacturing. FDM had the lowest COV for Young's modulus, followed closely by MJF and SLA. The tests demonstrate that FDM, MJF and SLA AM processes produce parts with consistent mechanical properties.

Dimensional Precision and Accuracy

Accuracy and repeatability reflect the printer's precision in building a part's geometric features. Accuracy is the ability to produce a physical feature to its nominal specified size. Precision, characterized by amount deviation, represents how often it achieves that result on multiple parts/builds. Precision is synonymous with the repeatability of an AM process.

Testing showed that FDM was the most precise achieving the test part's overall dimensions, and was most accurate for small dimensions but trended slightly less accurate for large dimensions.

Unlike the mechanical consistency test, MJF had the largest standard deviation or "spread," showing the least precision. SLS demonstrated the best accuracy, meaning dimensions for each test part were closest to the specified dimension, but had a larger standard deviation than FDM, demonstrating less precision (repeatability).

Similar checks were done for "positive" features (built-up in the Z direction) and "negative" features (holes). Both FDM and SLA achieved the best precision and accuracy for positive features. MJF displayed the lowest accuracy and precision.

For "negative" features (holes), FDM demonstrated the best precision across most of the features and the best accuracy on all. MJF was accurate for negative squares but demonstrated poor accuracy with holes. SLA negative features were all undersize and exhibited varied precision, depending on feature shape.

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The conclusion of these tests revealed that among these 3D printing methods, FDM technology is among the top three for the least mechanical variability, exhibits good dimensional accuracy and has the best dimensional precision. SLA also demonstrates excellent precision but falls off somewhat on accuracy. SLS retains good accuracy but poor precision and MJF also exhibits poor precision, especially between printers. When considering a manufacturing-ready AM process, FDM's high ranking coupled with its lack of hazardous processes or materials or the need for personal protective equipment means it should bear serious consideration.

Reducing Risk

Beyond these capabilities, the F900 is designed to reduce risk by giving users greater visibility and monitoring capability of the build process. Because moisture is an inherent risk in any FDM-based process (resulting in voids, bubbles and higher rates of tip plugging), the F900 employs a larger dryer for improved moisture control within the material filament tubes along with a dew point monitor that offers vigilance over operating conditions.

The F900 also has the capability for connectivity with manufacturing data streams through MTConnect. MTConnect is an open-standard, communications protocol for manufacturing operations. It allows the connection of manufacturing tools within the factory and the assimilation of data and information from those tools to assess the health and status of the operation.

Conclusion

No manufacturing operation runs with 100% uptime. At some point in the manufacturing process, stoppage will occur for one or more causes, some planned, others unplanned. The unit cost of downtime varies by industry but in many cases, it's not insignificant. A survey of 101 auto industry executives ranging from part suppliers to automakers put downtime costs at $22,000 per minute on average1.

One obvious way to mitigate this impact is by increasing equipment reliability. This can be accomplished by upgrading existing equipment or installing new machines that possess a demonstrated level of reliability and dependability.

Broadening the visibility to the components and processes in the manufacturing system can also act as a deterrent against unplanned downtime. Seeing when a problem or work stoppage is about to occur avoids response delays and helps speed corrective action.

What is machine downtime costing your manufacturing operation? Do you have any real-time visibility to it when it happens? You may not be on par with the auto industry's $22K-per-minute loss but if a machine is not operating, it's costing you money.

Adding 3D printing into the manufacturing workflow provides measurable benefit, as the case studies outlined previously illustrate. But not all 3D printers are designed for a manufacturing environment, with large build capacity and the capability for connectivity that's needed in today's digital factory.

The F900 3D Printer is built on a foundation of FDM technology development that spans several decades, each evolutionary step building on the last to refine and perfect the technology. It offers the largest build platform and widest array of engineering-grade materials of any FDM 3D printer, including carbon fiber-reinforced nylon. Demonstrating high build accuracy, repeatability and reliability, the F900 is a system designed for a production environment that demands consistent throughput and minimal disruption. Remote monitoring and MTConnect capability provide real-time visibility to the build process and the printer's status.

Whether you need capacity for large parts or the production of many smaller parts in one build, the manufacturing-ready F900 offers opportunity for increased productivity, time efficiency and cost savings compared with conventional production methods. To learn more about how the F900 can benefit your manufacturing operation, contact a Stratasys representative today at Stratasys.com/contact-us.

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