stratasys

Designing for Additive Manufacturing in the Agricultural Equipment Industry

Application Opportunity Brief

How 3D Printing Addresses Manufacturing Challenges

While processes like machining, molding and casting have proven to be reliable ways of making things, they also come with inherent drawbacks. Making prototypes, tools and production parts with these methods is usually associated with significant burdened cost and lengthy lead times. The need for skilled labor and reliance on long, conventional supply chains make them vulnerable to labor shortages and unanticipated disruptions that also drive cost and add delays. Traditional manufacturing systems also preclude the ability for customization and low-volume production because tooling costs often negate a satisfactory return on investment.

In contrast, additive manufacturing (AM) using FDM® technology offers a faster and less costly alternative to these traditional manufacturing practices. Prototyping with FDM allows manufacturers to iterate more often to arrive at a better design. 3D printed tooling can be created and deployed faster and for less cost than heavier metal tools. Out-of-production and customized parts can be produced cost-effectively due to the tool-less nature of additive manufacturing.

An Additive Manufacturing Solution for Large Parts

Despite these benefits, 3D printing large parts – approximately 600 mm (24 in.) and up in a particular X / Y / Z direction – is challenging. Many 3D printers cannot build large parts due to build chamber size limitations. For many manufacturers, 3D printing large parts requires dividing them into multiple pieces and fastening them together. But this adds more time and cost to the workflow.

The Stratasys F770™ 3D printer was developed to provide manufacturers with an affordable and reliable means to use AM for big parts. The F770's build chamber dimensions are 1,000 x 610 x 610 mm (39.4 x 24 x 24 in.), providing an overall build volume of 372 liters (13 cubic feet). The F770 is also built on the proven foundation of Stratasys FDM technology. Precise thermal control within the build chamber, linear motors and industrial-grade components provide reliable, accurate print performance. Soluble support material lets you build complex parts since the support material can be dissolved hands-free in a solution bath.

Included in This Application Report

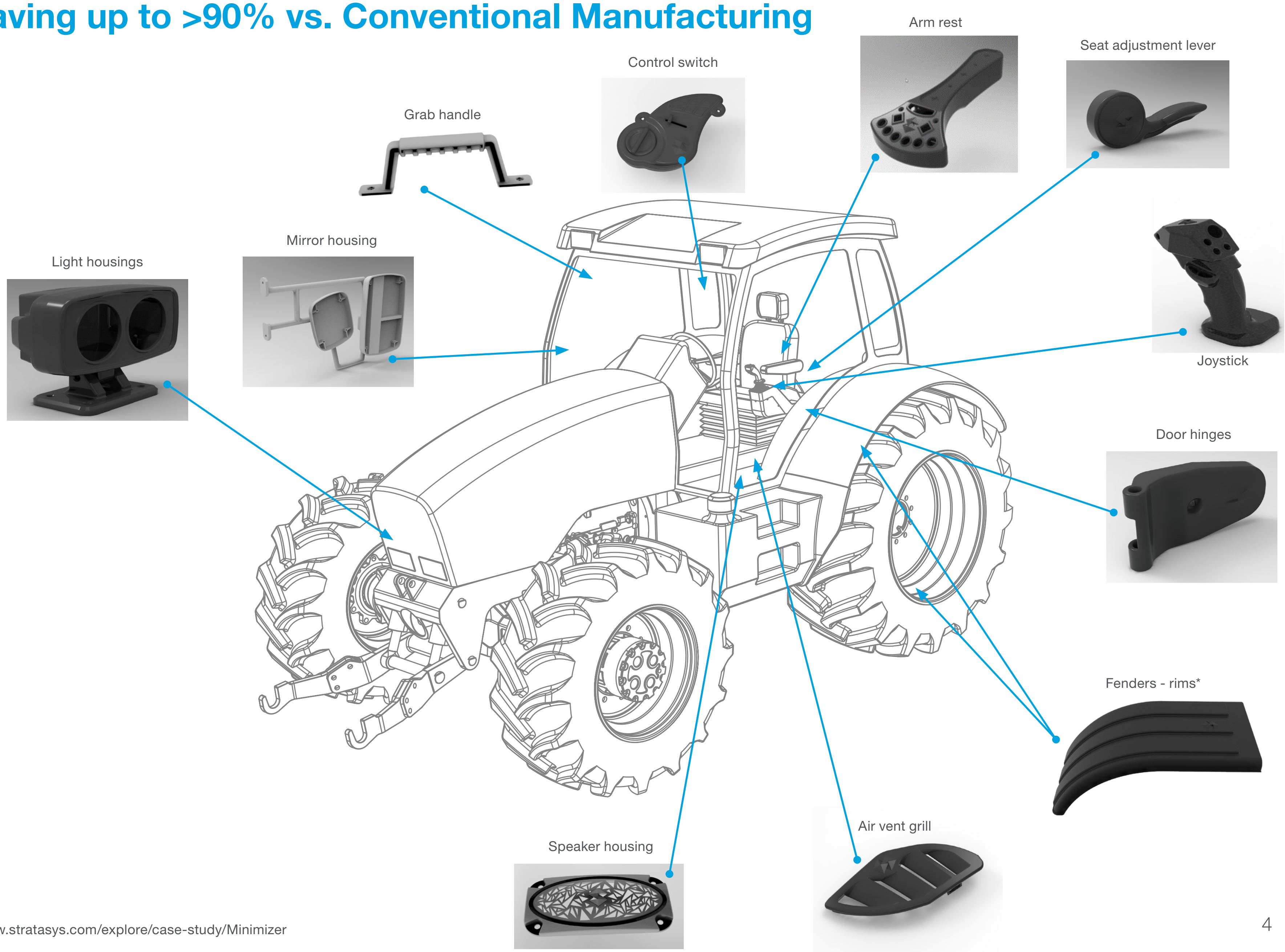
This Application Report highlights relevant AM applications for manufacturing agricultural equipment using the F770 3D printer. It also offers guidance on how to design parts with AM, which is different than designing them for conventional manufacturing. Finally, it presents valuable insight on how to get the best results when printing large parts with the F770 printer.

The Stratasys F770 is able to print large parts for prototyping and validating new designs in the large agricultural equipment industry. It also offers an economically viable means for end-use parts either as a bridge to full production or to produce low volumes of out-of-production parts.

The F770 is also capable of quickly and cost-effectively making large jigs, fixtures and manufacturing aids. The design freedom of AM allows these tools to be more user friendly, ergonomic, lighter and more efficient than their heavier metal counterparts for certain applications.

Overview of 3D Printing Applications for Agricultural Machinery

Saving up to >90% vs. Conventional Manufacturing



* www.stratasys.com/explore/case-study/Minimizer

Headlight

Made of 3 parts

Build time	F770 1 day, 15 hours, 2 minutes (T14 Tip)
Material	ABS/ASA
Cost to Print	Material cost - $15 Material plus running cost* - $167
CNC Cost	$2,076
Savings	92%

* Includes printer depreciation plus annual service contract. Labor cost is excluded.

Speaker Grill

Made of 1 part

Build time	F770 5 hours, 10 minutes (T14 Tip)
Material	ABS/ASA
Cost to Print	Material cost - $1 Material plus running cost* - $21
CNC Cost	$732
Savings	97%

* Includes printer depreciation plus annual service contract. Labor cost is excluded.

How to Design Parts for **Additive Manufacturing**

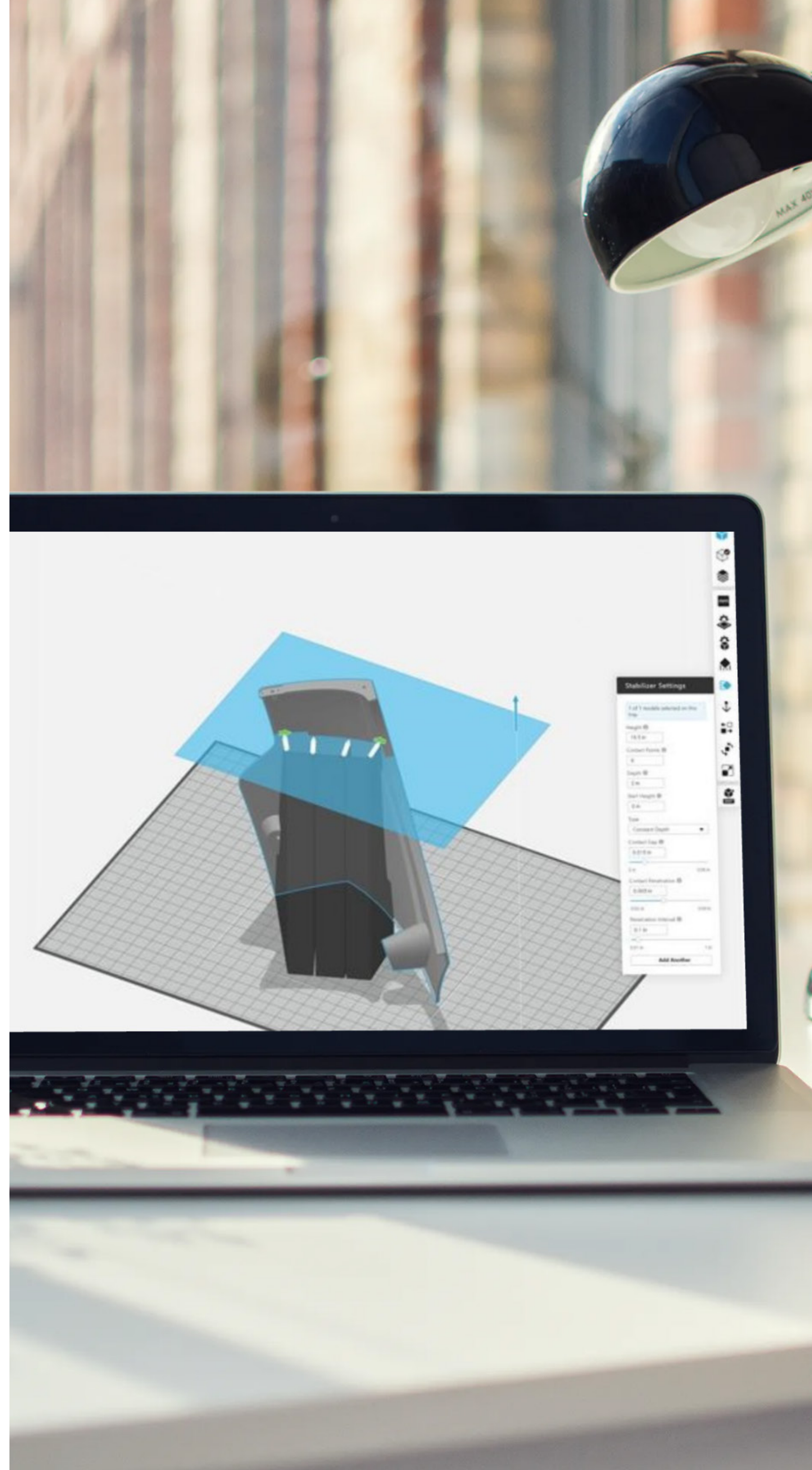
Designing for traditional manufacturing such as machining and injection molding is restricted by the inherent limitations of those technologies. In contrast, additive manufacturing (AM) doesn't have these limitations which lets your engineers concentrate on the best design rather than manufacturability.

AM gives manufacturers a set of capabilities that eliminate the constraints governing traditional manufacturing processes. A fundamental advantage of AM is design freedom. Machine tools have physical limitations and products made with that technology must be designed to accommodate those limitations. It's a process called "design for manufacturability" (DFM). But using AM instead of traditional machining frees designers from the constraints of DFM.

For example, Table 1 highlights typical injection molding design rules and how they're handled when using a design-for-additive-manufacturing (DFAM) philosophy.

Injection Molding	Design for Additive Manufacturing
Draft angles must be included in the tool or parts won't eject properly.	No need for a draft on the part. You can even have "negative (back) draft" on a DFAM part.
Uniform wall thickness is required in order to minimize warpage and sink marks.	Wall thickness can be varied throughout a DFAM part and thick-wall to thin-wall transitions cause no problems.
Radiused (rounded) corners are required to reduce stress concentrations and improve plastic flow during molding. Radii are required on most inside and outside corners of a molded part.	With DFAM, you can have sharp corners wherever desirable.
Since each material has a specific shrink rate, it may not be feasible to change materials once a tool has been made.	With DFAM you can change your material with each new build.

Table 1



Although AM can be implemented without change to existing design principles, a little education goes a long way in getting the maximum value from the process. To maximize AM's potential, start with the following DFAM design tips:

Design Methodology

Forget Design for Manufacturability (DFM)

Instead, design for additive manufacturing. DFAM isn't bound by traditional manufacturability limitations. When you employ DFAM, it's essential that you let your mind expand beyond what's been learned through years of education and practice with traditional manufacturing processes.

Focus on Function

The design process begins with an intense focus on function. Make the parts as complex, intricate and detailed as they need to be. For industrial designers, the converse holds true — focus on form and let fit and function follow. With DFAM, complex designs can be produced (3D printed) as easily as simple designs.

Iterate

Designing for additive means iterations and design refinement can continue into the product development cycle, primarily because of the speed of the process. Whether you're making prototypes or production parts, each can be 3D printed with little effort, minimal cost and no delay. The only difference between the final prototype and a production part is its intended use.

Refine the Design

DFAM can be performed with various additive technologies, so it is important to have a good understanding of the one you will use. Each technology has different specifications in areas such as minimum wall thickness, expected tolerance, producible surface finish, and deliverable material properties. Refine the product's design to accommodate these characteristics. If you can't produce the needed part qualities using the AM process at your disposal, you will have to either outsource production or purchase a system that can produce your product.

Question Tradition

Don't let past practices, old traditions or previous decisions dictate design options and process selections. For example, a part previously made of sheet metal may be an ideal candidate for plastic because the rationale for the original decision was based on traditional machining and is no longer valid with AM.

Design Techniques

Make it Feature-Rich

With traditional manufacturing methods, each feature adds cost because that feature must be machined into the part, mold or die. This isn't the case with DFAM.

Rethink Wall Thickness

Many manufacturing methods have a narrow range of recommended wall thicknesses. For example, the sweet spot for injection molding is 0.04 to 0.08 inch. When designing a part for AM, the only consideration is to stay above the minimum wall thickness needed for the part to perform as specified. To maximize strength while minimizing weight, consider making the walls hollow.

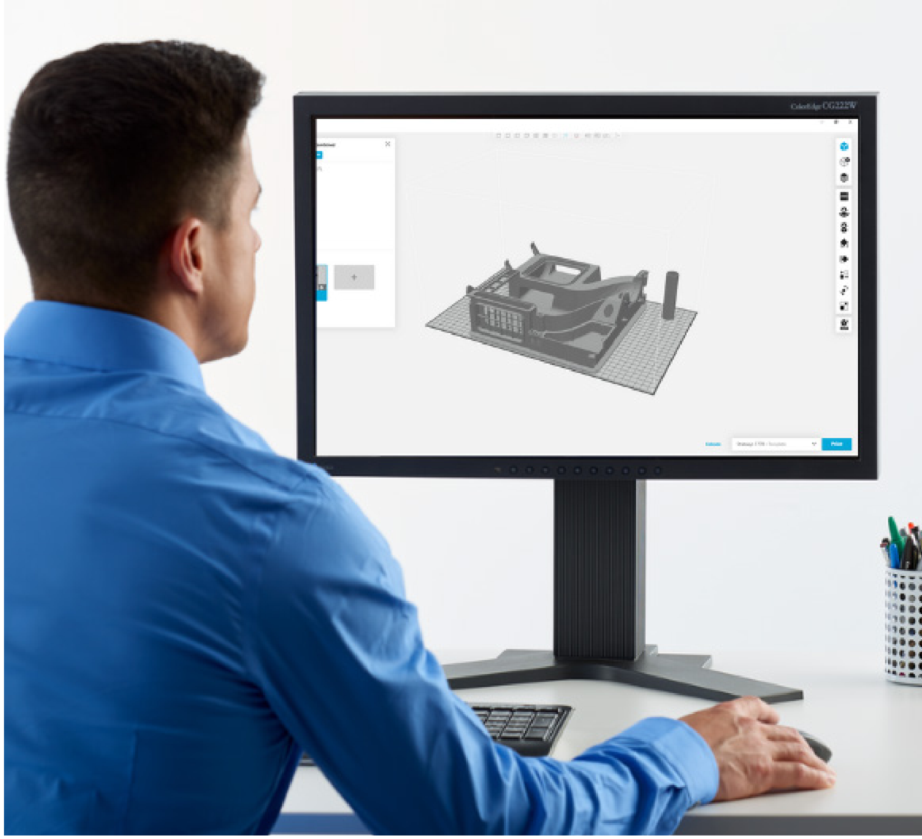
With FDM 3D printing technology, this construction style is called sparse fill. Walls are made with a lattice structure and skinned with bounding surfaces to provide the necessary mechanical strength while decreasing material volume. Although the volume reduction can vary greatly, a typical application might yield a 60 percent volume reduction. Hollowing out features also has the added benefit of reducing material cost, construction time and weight.

Consolidate or Segment

Consider consolidating parts whenever possible. Rather than producing a multi-piece assembly, the entire unit may be consolidated into a single component. This reduces or eliminates the assembly process and simplifies inventory management, lowering manufacturing costs. This is possible even for larger assemblies when using the spacious print capacity of the F770. Part consolidation may also be used to overcome an overly tight tolerance specification. For example, a tight-tolerance interface can be avoided by simply consolidating mating parts.

Forget the Details

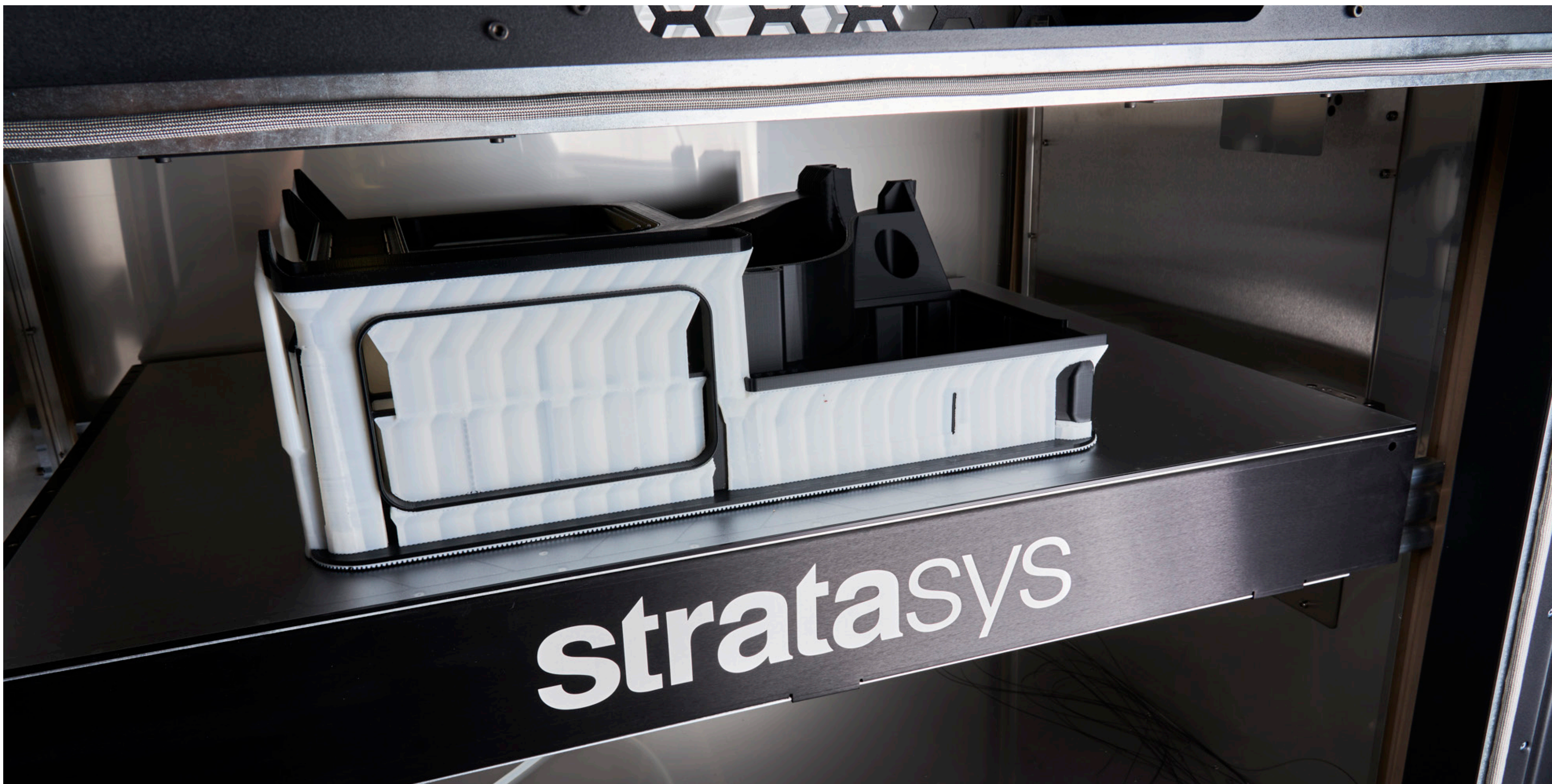
When the design is complete, there's no need to spend time defining parting lines, adding draft angles and determining how to incorporate them without changing form, fit and function. These types of process constraints no longer exist.



Above all else, be creative. Allow the time necessary to design a part, sub-assembly or product in order to capitalize on the unique capabilities of AM. Finally, never stop redesigning. Continually refine designs as needed, maximize manufacturing efficiencies and minimize production costs.

Additional tips for successful large-scale printing.

Beyond addressing the typical hurdles associated with printing big parts, there are other techniques you can use to optimize your results. These added pointers will help you achieve higher-quality parts and get them in your hands sooner rather than later.



Additional tips

Optimizing with orientation.

Orientation describes how the part will be built inside the printer – upright, on its side or at some angle. The choice you make depends on whether you want to optimize the part for strength, speed of build or the quality of the surface finish. And that decision depends on the part's function: concept model, functional prototype, manufacturing tool or end-use part.

In the end, these orientations aren't mutually exclusive. It is possible to achieve a blend of benefits, depending on your part's geometry. But in practical terms, when you're printing large parts, or any size part for that matter, consider your primary objective in light of your constraints. If strength is the priority, orient for that result. If the production schedule is your limiting factor and strength and surface finish are secondary, position the part for maximum print speed.

Orienting for surface quality.
How you position the part in relation to its geometry governs its surface quality. Parts made with extrusion printers exhibit fine layer lines that are more or less evident depending on the layer thickness and the shape of the part. On curved surfaces, these layer lines are more pronounced, resulting in a "stair-stepped" look. If your part has curved or angular surfaces, orienting it so those surfaces are built parallel to the Z axis will result in smoother surfaces.

Orienting for strength.
Similar to surface finish, build orientation impacts the strength of a part or particular features. In general, orienting it so that important elements requiring strength or durability are parallel to the build plane and perpendicular to the Z axis produces the best results. This is because extrusion printers produce the greatest strength in this plane.

Orienting for speed.
The part's position in the build chamber affects the amount of support material needed during the build process, which ultimately impacts overall build time. Orienting your part to minimize its Z height requires less support material, resulting in a faster build. We'll cover build speed again in the next section when we consider the possible opportunities and risks associated with shortening the time it takes to complete the part.

Optimizing Time to Part

There are several approaches you can take to speed up the time it takes to get parts in hand. However, there are tradeoffs and risks associated with some of them, which we'll cover in this section.

Use less infill.
The first technique is to choose a less-dense infill. In extrusion 3D printing, the outer surface of the part is called the "contour." The interior of the part is made up of "infill," which can range from sparse to fully dense.

The sparser you can make the infill of your 3D printed part or tool, the faster the build process will be because there is simply less material to lay down. Obviously, if strength is a concern, fill density might have to change. The best solution involves adjusting the density in different areas of the part to suit design needs. 3D printers with this capability let you use full density in areas where it's needed and sparser infill where it is not.

Use a thicker slice height.
The second method involves using a thicker slice height, which refers to the thickness of the extruded layer. Applying more material per layer decreases build time. Layer lines will be more apparent as layer thickness increases but this may not matter if surface finish or fine details are not important.

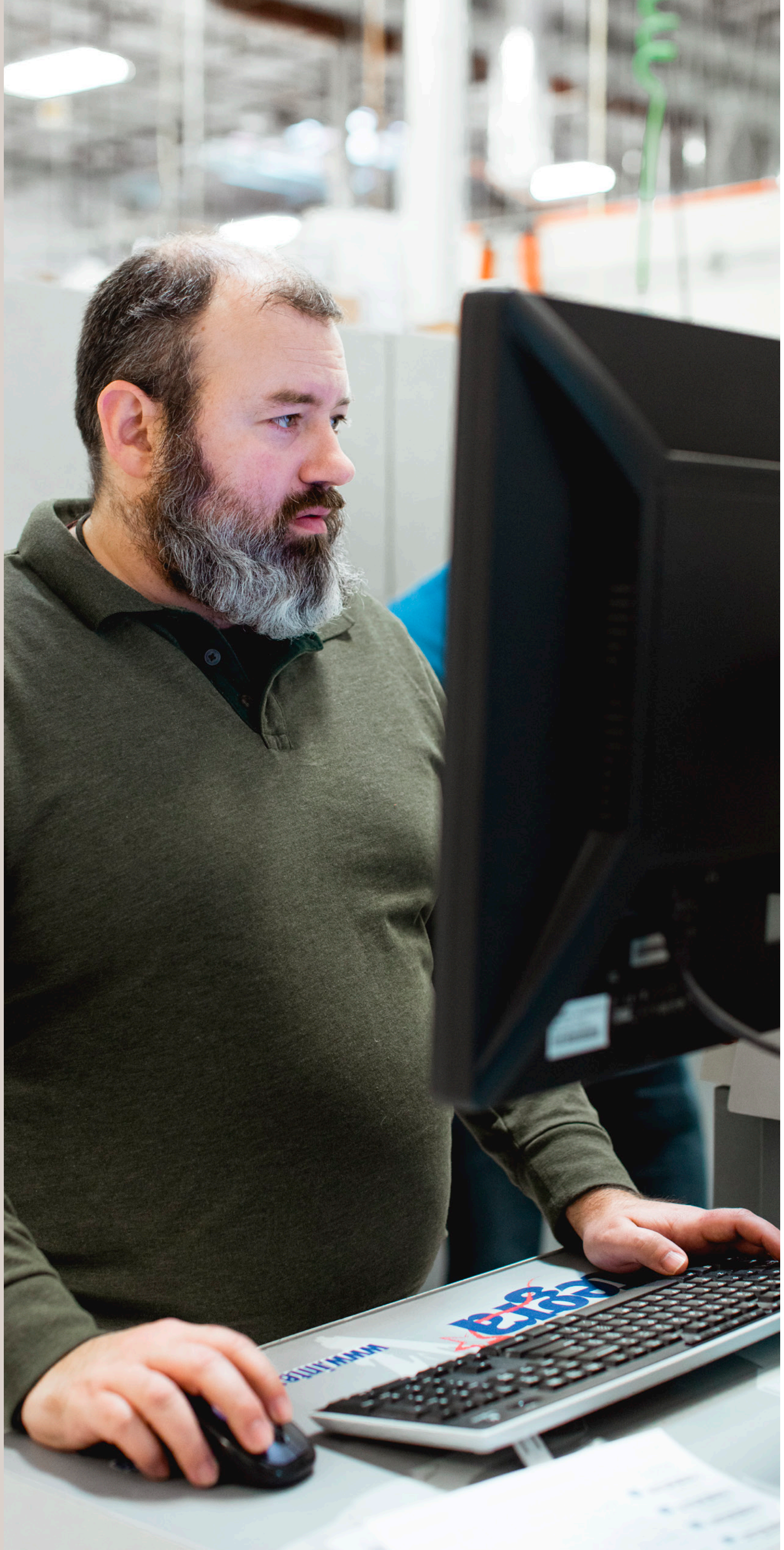
Additional tips

Use multiple slice heights – for speed and aesthetics.
On the other hand, if both speed and aesthetics are important, using a combined slice height offers a best-of-both-worlds scenario. This entails using thicker layers on vertical surfaces, where layer lines are least noticeable, which increases throughput. On sloped surfaces or where more detail is needed, a finer slice is used to reduce stair-stepping and increase visual quality.

Minimize part height.
Third, as mentioned in the previous section, you can orient the part to minimize its height and/or reduce the number of unsupported or overhanging features. This results in less support material needed to prop up these features, reducing build time.

Hand vs. tank removal of support.
Soluble support material is a very effective tool that enables printing complex designs with internal channels, provided your 3D printer has this capability. But where the support is fully accessible, it can be removed by hand much faster than immersing the part in the dissolution bath.

This process can also be accelerated by the addition of perforation layers – layers of model material added between sections of support material. Perforation layers are usually employed when 3D printing with breakaway (non-soluble) support materials to make removal easier. However, they can also be used with soluble support, usually where large blocks of the material are used, speeding its removal time. While this process doesn't accelerate the print process, it can reduce the total time it takes to get parts in-hand.



Additional tips

Changing the default settings – balancing risk and reward.

Most 3D printers offer default settings designed to provide acceptable results for general purpose applications. However, the ability to change them may be available depending on your printer configuration. They include toolpath width, number of standard contours, support style, and slice heights, among others. Under the right circumstances, these adjustments can shave time off the build process. However, this benefit also comes with potential liabilities.

For example, building large parts can take considerable time and depending on your printer's reliability, the risk of a problem occurring rises with print duration. Also, Stratasys engineers found that adjusting build parameters on large-part builds only saved as little as 5% of the overall print time on average. If you decide to change settings, you need to ask yourself if the risk is worth the reward. Would saving four hours on an 80-hour build be worth it? It might be – but if a failure occurred at hour 75, you've just lost three days of print time – and possibly missed your production deadline. Consideration of how much schedule flexibility you have is important.

In contrast, a scenario where adjustments may be advantageous includes production builds, where you need to print multiples of larger parts. Taking the time to adjust file settings and then doing a test print to verify success may be worthwhile. Even if it saves just a little time on each build, the cumulative effect over multiple builds could be very beneficial.

The bottom line here is that large-format printing is doable, provided you know what you're up against. Since no one can alter physics, the realities of extruding hot thermoplastic to build things need to be dealt with, and that can be easy or difficult. But the right printer not only makes things easier, it lets you achieve impressive results in both the size and quality of your printed parts. So let's introduce you to the 3D printer that's just right for the job.

The opportunities of large-scale printing **with the F770.**

3D printing large parts on a reliable scale is no longer the exclusive realm of high-end, premium systems. The Stratasys F770™ 3D printer offers over 13 cubic feet of build volume and the ability to print parts up to 46 inches long. But there's more than just size here. Several key features offer valuable benefits that address the challenges raised earlier.

Generous Build Capacity

You don't need to worry about running out of material if you have a full material load. F770 material cartons provide 200 cubic inches of material, giving you up to 140 hours of continuous print time.

Soluble Support Material

An effective soluble support material means your large parts can be as detailed and intricate as they need to be. It lets you print the part you want and doesn't limit you to the part you can because of a less-capable printer.

GrabCAD Print™ and Insight™ Software

Good software gives you the tools you need to get the results you want. Print large parts with an effective blend of speed and favorable aesthetics using adaptive slice that automatically adjusts the layer thickness to optimize throughput and visual appearance. Dial in the right amount of infill where you need it to balance part strength and build time as well as material use. Easily create stability walls to ensure accurate parts. Incorporate perforation layers in your support structures for faster hand removal and quicker time-to-part.

Three Layer Thicknesses

Leverage the flexibility to tailor big parts for speed or detail with multiple layer thickness options. Or, rely on the adaptive slice capability for an optimized blend of both.

Fully Heated Build Chamber

An enclosed build oven and time-tested FDM® technology ensure a uniform temperature profile throughout the build volume. You'll build large parts that won't warp and curl, so what you model in CAD is what comes out of the printer.

When it comes to applications, the F770's value cuts across multiple industries including automotive, aerospace, heavy industry and agriculture, to name a few. Prototyping body panels and fenders is just one example of a typical use case for large agricultural vehicles.

Tooling is a particularly favorable application for agricultural equipment manufacturers. Typically large and heavy, these tools can be made lighter by replacing metal with plastic under the right circumstances. 3D printed tools can also be easily customized and made more ergonomic for worker comfort and safety.

It's not that you can't achieve these objectives with smaller 3D printers. You'll just have to make the parts in sections and fasten the pieces together, provided your printer is sufficiently accurate to achieve that. All of this requires more up-front design time and post-print processing. It's precious time most manufacturers are hard-pressed to spend.

Instead, the F770 offers the opportunity to avoid that time and effort. It precludes having to stay with the slower, more expensive status quo of machining large prototypes and tooling fixtures or piecing parts together with smaller printers. Virtually any manufacturer that deals with larger tools and components can benefit from the F770's capabilities.

Time for
big decisions

If you or your team already has experience with reliable 3D printing, you understand the positive impact it can have on your production schedule and your budget. Now ask yourself this: what if you could 3D print even larger items than you're making now – what opportunities would that open for you?

And what if you haven't adopted 3D printing yet? You simply need to determine if making large tools and prototypes in less than half the time it currently takes you, at a lower cost, is worth it. There's plenty of readily available evidence that supports 3D printing's value as a time and cost-saving supplement to existing manufacturing approaches. If the price tag of current large-format 3D printers has kept you from joining the additive manufacturing party, consider the F770 your open invitation.

Reliable, large-scale 3D printing is the F770's primary mission. And it's designed to do that so virtually anyone can initiate the print job – and then get back to their real job. Combined with its affordable price, it makes reliable large-format 3D printing, and the time and cost savings it embodies, much more accessible.

Find out how the F770 can scale up your operation.

To learn more, contact us today or visit the F770 printer page at Stratasys.com.

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