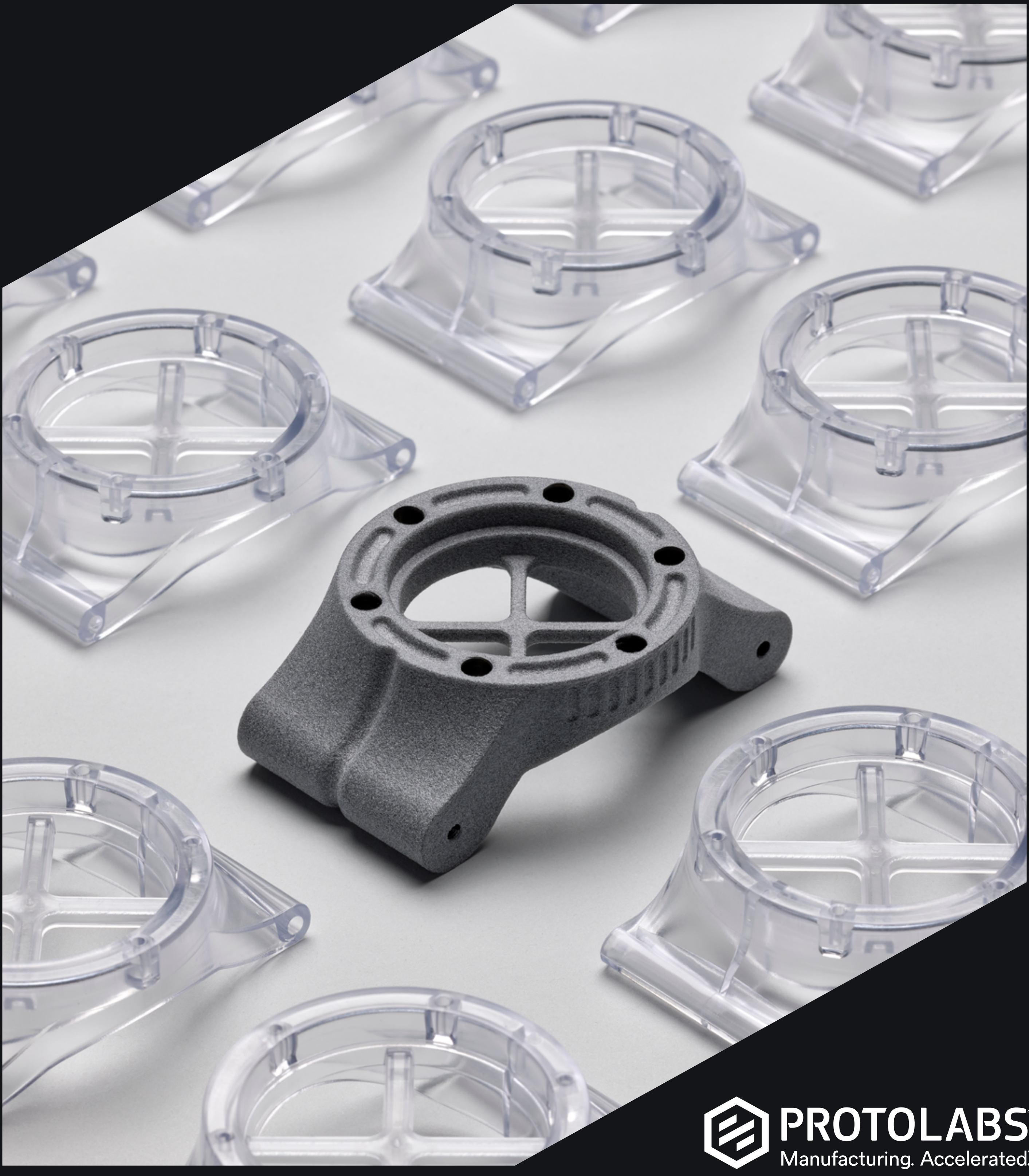
3D Printing for End-Use Production

An analysis of additive technologies that are redefining 3D printing as an end-use manufacturing method



PROTOLABS
Manufacturing. Accelerated.

Once considered a prototyping manufacturing method, industrial additive manufacturing is starting to make its traditional rivals sweat.

Over the past three decades, 3D printing has developed a reputation as an essential manufacturing process for prototype parts. Create a CAD model of your design, send it to your company's printer, and a 3D replica will be ready in hours. Historically, these parts were little more than conceptual show-and-tell models, not durable enough for long-term use, and in some cases prone to degradation by sunlight.

The winds of manufacturing have shifted, and industrial-grade 3D printing, or additive manufacturing, has encroached on machining, injection molding, and other conventional manufacturing processes. This white paper explores the new and existing technology leaders in this area and assesses the capabilities of production for each 3D printing process.

The Case for 3D-Printed Production Parts

Defining what is meant by production is an important first step. In a typical manufacturing scenario, prototype parts are produced for form, fit, and some function testing, and then either CNC-machined or injection-molded until quantities grow high enough to merit investment in high-volume production tooling. Production 3D printing shortcuts that process. Often, depending on the part and its intended use, it is possible to print parts that will perform every bit as well (and in some cases better) than conventionally produced parts, and do so cost-effectively enough that downstream investment is delayed or even unnecessary.

One notable example is GE Aviation's use of 3D-printed fuel nozzles in its LEAP engine, a move that saves aircraft owners roughly $3 million per plane annually. In the medical space, Johnson and Johnson is one of many suppliers using 3D printing for customized surgical tools and patient-specific implants, providing a better outcome for patient and surgeon alike. Oreck leveraged 3D printing to reduce the cost of its vacuum cleaner assembly pallets by 65%. Audio manufacturer Soundz used it to reduce tweeter grill lead-times from months to days. BMW lessened the weight of handheld assembly tools by 72%. Without 3D printing, all of these parts would have required lengthy, expensive machining or injection molding operations to produce.

Granted, 3D printing cannot compete with high-volume production methods in the majority of applications and probably won't for some time to come. However, it's important to note the willingness of these and literally thousands of other companies to embrace additive manufacturing technology for what it is—an effective way to produce precision components, which are often as capable as their machined or injection-molded counterparts when it comes to manufacturing end-use production parts.

An impeller, made using selective laser sintering.

Comparing 3D Printing Technologies

Much of this is made possible by a handful of 3D printing processes, all of which can be grouped according to the types of materials they use. Here's a short overview of each.

Plastic Production

Selective laser sintering (SLS) is a powder bed printing technology. It uses a laser to fuse tiny bits of nylon powder, tracing the geometry of digitally sliced CAD models layer by layer and working from the bottom of the part upwards. After each layer is complete, a roller spreads fresh material across the top of the bed and the process continues until the part (or multi-part assembly) is complete. After a quick brushing to remove excess powder and a light bead blast, parts are ready for end-use, although a range of finishing processes are possible. Because nylon is a durable, multipurpose material, and because the entire volume of the heated powder bed can be used to build parts, SLS is a favorite of many designers for production of end-use mechanical components and commercial products in low-volume quantities.

Multi Jet Fusion (MJF) is a relatively new 3D printing technology launched by HP. It is similar to SLS in that it uses a powder bed and is primarily limited to nylon polymers. There is no need for support material, post-processing is minimal, and the entire print chamber can be used to build parts. However, instead of a laser MJF employs an inkjet array to deposit fusing and detailing agents across the print layer, and an infrared heating element fuses them. The finished parts offer more consistent isotropic integrity than is possible with SLS, and because the entire bed is covered in each print pass (similar to a laser jet printer) build speed is predicated on the number of layers needed to build a part or batch of parts rather than on part volume.

Fused deposition modeling (FDM) uses a fishing line-like filament of heated thermoplastic, depositing it in ultra-fine, side-by-side beads. Here again, parts are built one layer at a time, starting at the bottom. FDM prints its own scaffolding during the build process to support the workpiece, but these structures are easily broken away once the part has been removed from the printer, after which the part is ready for use. A variety of commercial-grade materials such as ABS, nylon, polycarbonate, and PEI (Ultem) are available, and FDM can print multiple colors and even multiple parts within a single build.

Advanced Photopolymers (AP) is a newcomer to 3D printing and builds from the top down. It also images each layer with a combination of DLP projection and a laser for bordering, which projects a continuous sequence of part images into a UV-curable resin bath and literally "grows" the part in one fluid motion. When done, the parts are washed in solvents. Build speeds are substantially faster than competing processes (some say 100x that of stereolithography). The resulting parts can be used for production applications ranging from springs and gaskets to dental implants and manufacturing jigs.

Metal Production

Direct metal laser sintering (DMLS) is another powder bed printing technology. It uses a laser to fuse aluminum, cobalt chrome, stainless steel, titanium, and Inconel 718 into fully dense metal parts, "drawing" them layer by layer from the bottom up. Because of the stresses built up due to the extreme temperatures involved (rapid heating and cooling), support structures are required during the build to keep parts from curling or warping. When complete, parts must be heat-treated to remove residual stresses, after which the supports can be removed by machining or hand grinding. The GE fuel nozzles mentioned earlier are made using DMLS, as are an array of equally complex aerospace and end-use medical parts.

3D Systems units print plastic SLS parts at Protolabs' facility in Raleigh, North Carolina.

Each of these 3D printing technologies comes with its own set of rules, including design guidelines, accuracy and part-size considerations, surface finish and resolution capabilities, material selection, mechanical properties, and more. If you're contemplating using 3D printing for end-use production, or as a substitute for traditional low-volume manufacturing, take a close look at each technology, starting with the available materials followed by part cost and function. Of course, the success of any 3D printing project depends heavily on the part design, even more so than with injection-molded or machined parts.

Below is a comparison chart to get started, although all specifications should be verified with the specific technology supplier or 3D printing partner before making any final decisions on your project.

	Available Materials	Maximum Part Size	Minimum Feature Size	Layer Thickness	Expected Tolerance
Direct Metal Laser Sintering	Many commonly used metals and super alloys	9.68 in. x 9.68 in. x 10.8 in. (245.87mm x 245.87mm x 274.32mm)	0.006 in. (0.152mm) in high resolution	0.0008 in. (0.02mm) in high resolution	+/- 0.003 in. (0.076mm)
Selective Laser Sintering	Nylon-like PA850, PA650, filled nylon, and TPU	19 in. x 19 in. x 22 in. (482mm x 482mm x 558mm)	0.030 in. (0.76mm)	0.004 in. (0.102mm)	+/- 0.003 in. (0.076mm) plus 0.001 in./in. (0.0254mm/mm)
Fused Deposition Modeling	Similar to ABS, nylon, PC, PPSF, Ultem, and others	36 in. x 24 in. x 36 in. (914.4mm x 609.6mm x 914.4 mm)	0.019 in. (0.48mm)	0.007 in. (0.178mm) to 0.020 in. (0.508mm), depending on material	+/- 0.0035 in. or +/-0.0015 in. per in. (+/- 0.089mm or +/- 0.0015mm per mm), whichever is greater
Multi Jet Fusion	Nylon-like PA650 (Nylon 12)	11.1 in. x 14.9 in. x 14.9 in. (284mm x 380mm x 380mm)	0.020 in. (0.5mm)	0.003 in. (0.076mm)	+/- 0.004 in. (0.102mm) plus 0.001 in./in. (0.0254mm/mm)
AP	Similar to ABS, ceramic-filled, SLA resin	9.8 in. x 5.5 in. x 19.4 in. (249mm x 140mm x 499mm)	Varies by material, but 0.004 in. (0.1mm) is possible	N/A	Depends on material and part geometry but assume 0.2% +/- 0.01 in. (0.3mm) of feature size

Making Metal

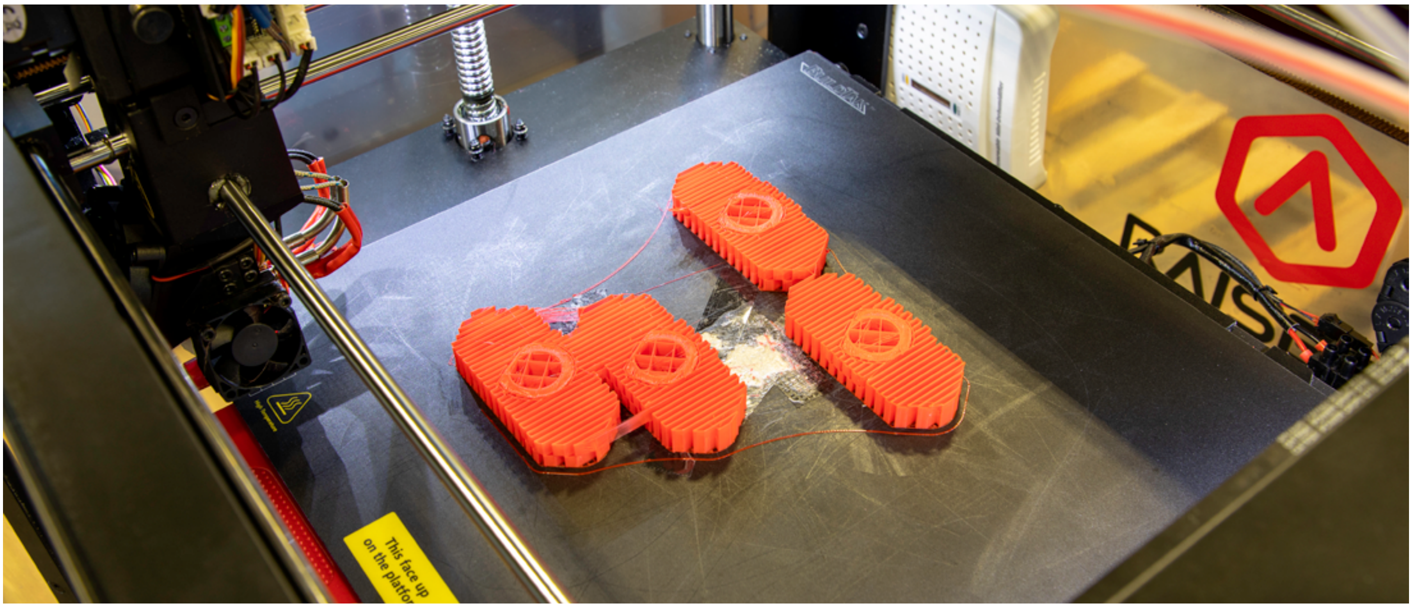
As GE has clearly demonstrated with its 3D-printed fuel nozzles, DMLS is exceptionally capable of producing high-quality, end-use production parts in metal, even in large volumes. In addition, until Metal Binder Jetting arrived, DMLS and comparable laser-based printing technologies were the only tech in town. Unfortunately, DMLS does suffer some drawbacks. The machines are expensive—spending $1 million or more on a system isn't unusual—so a low-volume part supplier is often used by product developers, designers, and engineers versus in-house 3D printing. Because DMLS-printed parts need support structures, a visit to the machine shop or grinding department for post-printing removal is required. So, too, is heat treating, to relieve the stresses induced during printing. Still, aerospace and medical companies alike have embraced DMLS in ways that few thought possible even a decade ago. The parts produced sit at the upper end of the 3D-printed cost spectrum, but this is easily offset by lower assembly part counts, lighter weight yet stronger products, and the ability to make "unmanufacturable" part designs that previously were never possible

Polymer Potential

Similar arguments can be made for and against the various polymer-based 3D printing technologies. For example, SLS produces very accurate parts with fine features and no need for build supports but is limited to nylon-like materials and TPU (thermoplastic polyurethane). MJF is more accurate (except on very small part features), is significantly faster, and has more consistent isotropic (Z-axis) strength, yet offers fewer material options (for now, just unfilled Nylon 12). Both processes also allow filling of the entire build chamber, an important point where large numbers of parts are needed. Either way, if you're looking for production parts for which nylon will do (covering many requirements), both technologies are a solid option.

FDM machines offer a greater number of material options than SLS and MJF combined. It's not quite as accurate, however, and surface finishes are a bit "stringy," keeping it firmly in the prototyping and low-volume part-making realm (although it remains the king of size, with build chambers large enough to fit a suitcase).

Then comes AP. It can print in many polymers and promises to build parts much faster than traditional SLA. Its accuracy is also quite good, and the surface finish is excellent. For many production parts, this is an excellent compromise, especially in light of its greater speed.



Parts produced using fused deposition modeling (FDM). FDM machines offer a greater number of material options than other 3D printing processes.

In any event, the advantage of 3D printing is this: It's very easy for designers to test the waters by sending their part designs out for prototyping, determining which process provides the best combination of price, accuracy, and material, and then easily segue into 3D printing production should that make the most sense. Just be sure the math still works as part volumes increase, and that your part design is manufacturable using traditional processes—too many designers paint themselves into a 3D-printed corner and end up paying dearly in redesigns and development time to get themselves out.

Traditional Thinking

Speaking of part volumes, what's wrong with injection molding? Absolutely nothing. A number of suppliers offer rapid injection molding services that allow for economic part production at virtually any quantity. The same can be said for machining services. Chances are good that if a metal part is easily and cost-effectively made on a CNC lathe or milling center, it's probably not a good candidate for DMLS. Remember, complexity is free with 3D printing. Not so with injection molding, machining, casting, and other traditional manufacturing processes, where complex part designs make production costs skyrocket.

Ironically, one of the biggest costs in 3D printing (aside from the price tag of many 3D printing machines), is the raw material itself. Most industry experts agree, however, that metal powder supply and demand is undergoing a sea change as 3D printing becomes more popular and an ever-increasing number of big name suppliers get on board. The same holds true for polymers, although probably to a lesser extent thanks to the relative maturity of the resin-based 3D printing industry. As companies such as BASF, Dow Chemical, HP, and others fight for market share of plastic and metal supplies, it can only spell lower prices for consumers of 3D-printed products.

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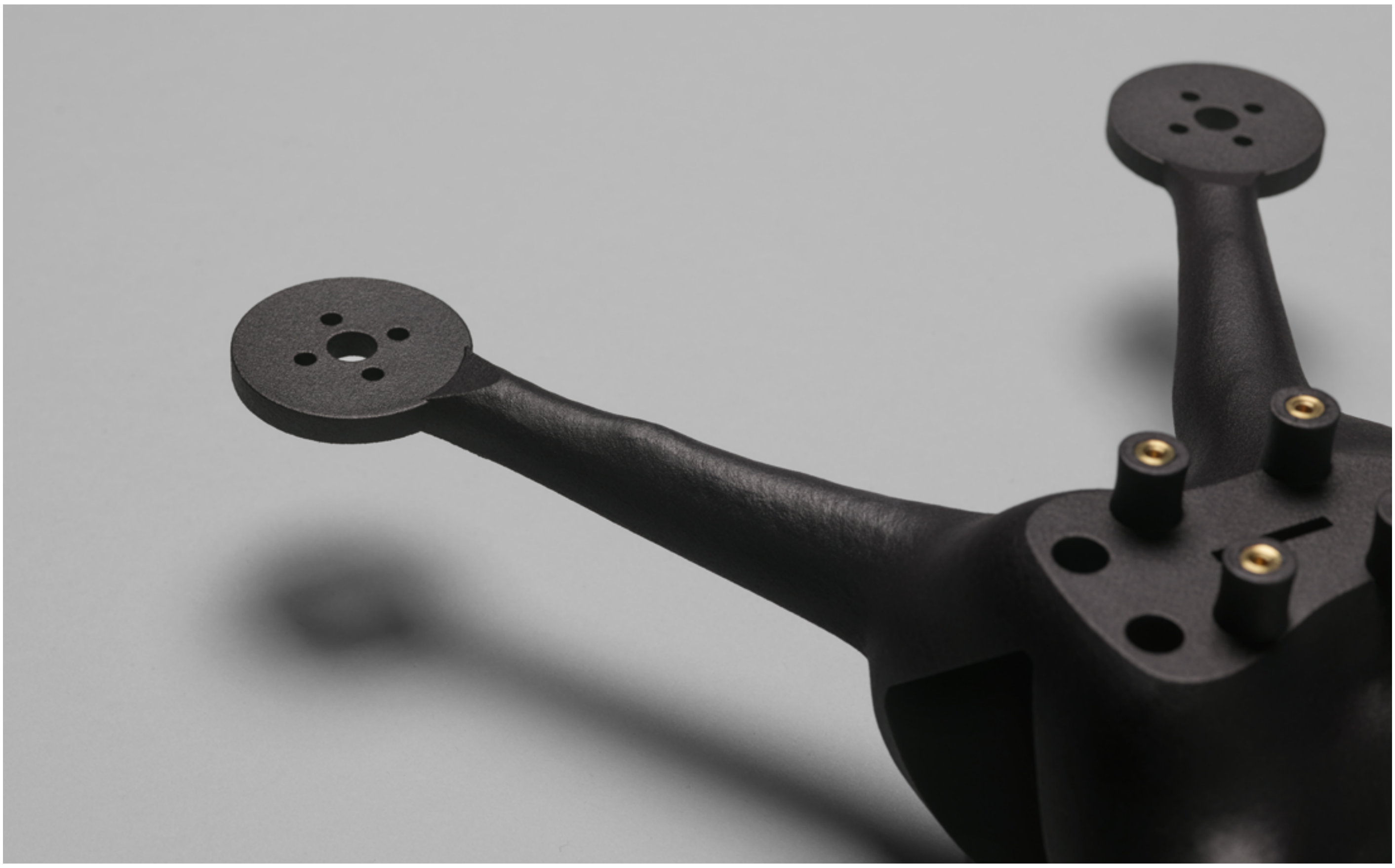

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