From Trinkets to Turbines: Has Additive Manufacturing Reached a Tipping Point?

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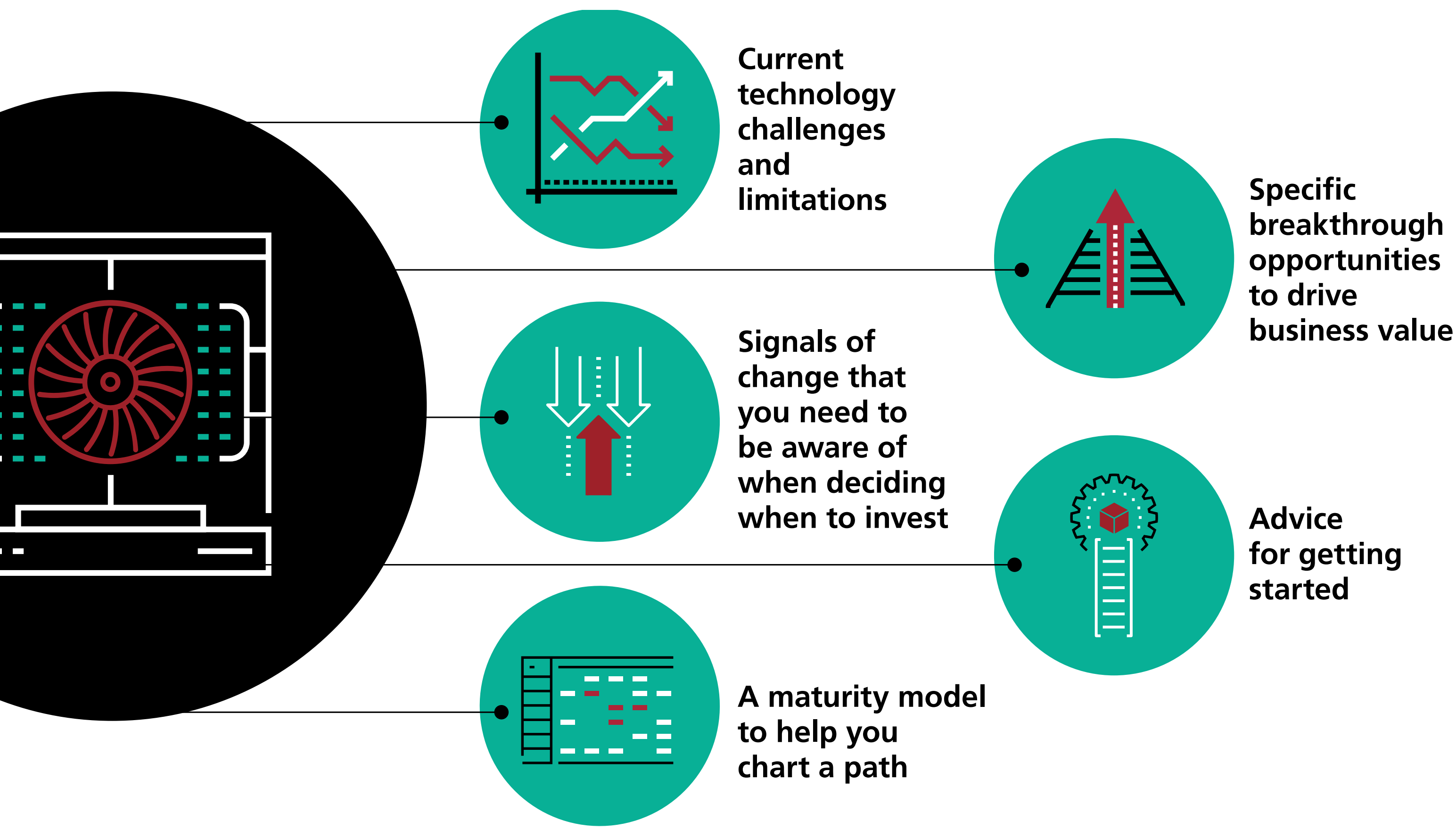
In the past 30 years, 3D printing (3DP) technology has gained traction for rapid prototyping and industrial tooling. Recent advancements in metal printing brought forth industrial applications for 3DP, yet finished parts formed by 3D printers are still limited.[1,2]

Just because something can be additively manufactured, *should* it?

This eBook explores:



1 https://www.sciencedirect.com/science/article/pii/S1369702117301773
2 https://www.forbes.com/sites/forbestechcouncil/2018/03/28/challenges-associated-with-additive-manufacturing/

Current Technology Limitations

The challenge when selecting a processing method is balancing all the factors that need to be met, including cost, speed, quality and part performance. While additive technology can produce parts quickly, there is still a long way to go to fully match the strength of other available processing technologies for metal, thermoplastic, thermoset and elastomeric parts.

Limitations Related to Cost

Compared to traditional manufacturing methods, the cost of 3DP is not cost effective for high volume or large parts when compared to conventional casting methods.[3] For smaller batch jobs, metal printing can be costly if Design for Additive Manufacturing (DfAM) techniques are not applied (e.g. reducing Z height, increasing porosity, etc.).[4]

However, this undesired cost-to-batch-size ratio can be modified if intelligent topology optimization tools are used. This results in reduced material use and print time, which can significantly reduce overall costs.[5] Additionally, optimizing build volume and utilization to achieve batch printing (maximizing the parts produced in one print bed or vat) can be effective in lowering costs.[6]

Nonetheless, cost can also be reduced by incorporating cutting edge 3DP techniques to traditional manufacturing approaches. An example is Additive Pattern Investment Casting (APIC), which incorporates 3DP with investment casting to create functional metal parts. This is achieved by 3D printing resin patterns with a honeycomb technique that enables the creation of low-material-consuming, resistant structures that are then used to cast the final product.[7]

Limitations Related to Speed

Additive manufacturing speed is measured as build time – for example, cubic centimeters or inches produced per hour. When it comes to comparing the overall speed of 3DP, it can be difficult to assess the comparative advantages and disadvantages without factoring in the complexity, size, form and scale of the part being produced and the machine parameters selected to achieve the performance and quality requirements. For example, layer thickness, printing speed, and required post-processing techniques could play a role.[8]

3 https://www.sculpteo.com/blog/2018/08/14/the-battle-of-innovation-and-tradition-metal-casting-vs-metal-3d-printing/
4 https://www.3dhubs.com/knowledge-base/introduction-metal-3d-printing
5 https://www.vtt.fi/sites/SIMPRO/Documents/VTT/poster_Erin_Komi_VTT.pdf
6 https://www.sciencedirect.com/science/article/pii/S1369702117301773
7 https://www.stratasysdirect.com/applications/investment-casting-patterns/how-additive-manufacturing-changes-investment-casting-process
8 https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf

Current Technology Limitations

For large or unelaborate forms like a solid block or panel, the build time per part would be much slower than subtractive processes like CNC machining or laser cutting, and slower than traditional casting methods. Meanwhile, for complex forms requiring a significant degree of advanced subtractive machining processes, additive might offer greater speed as an alternative.

When considering speed, the overall lead time from engineering a part to producing the finished part must also be considered. Often, the upfront investment in tooling design and development can significantly delay lead times.

Sciaky, a metal 3D printer manufacturer claims their EBAM 300 model is capable of producing a 10-foot-long titanium aircraft structure in 48 hours at a rate of approximately 15 lbs. of metal per hour, compared to the standard 6-12 months required to develop forgings in the aerospace industry. [9]

Even within additive manufacturing approaches, thorough analysis is required to determine the appropriate 3D printing technology for the application. Is the engineer creating a final part or prototype? Will the prototype help evaluate function or form? What are the performance requirements of the part? What is the anticipated lifespan of the part? What materials are most appropriate? Have the supply chain and full product lifecycle been considered? How long do suppliers take to fulfill raw material orders?

Using advanced analytics, these factors can be analyzed in a more accurate way to provide meaningful insights from product data, formulate predictions and recommend specific improvements.

9 https://all3dp.com/1/3d-metal-3d-printer-metal-3d-printing/

Current Technology Limitations

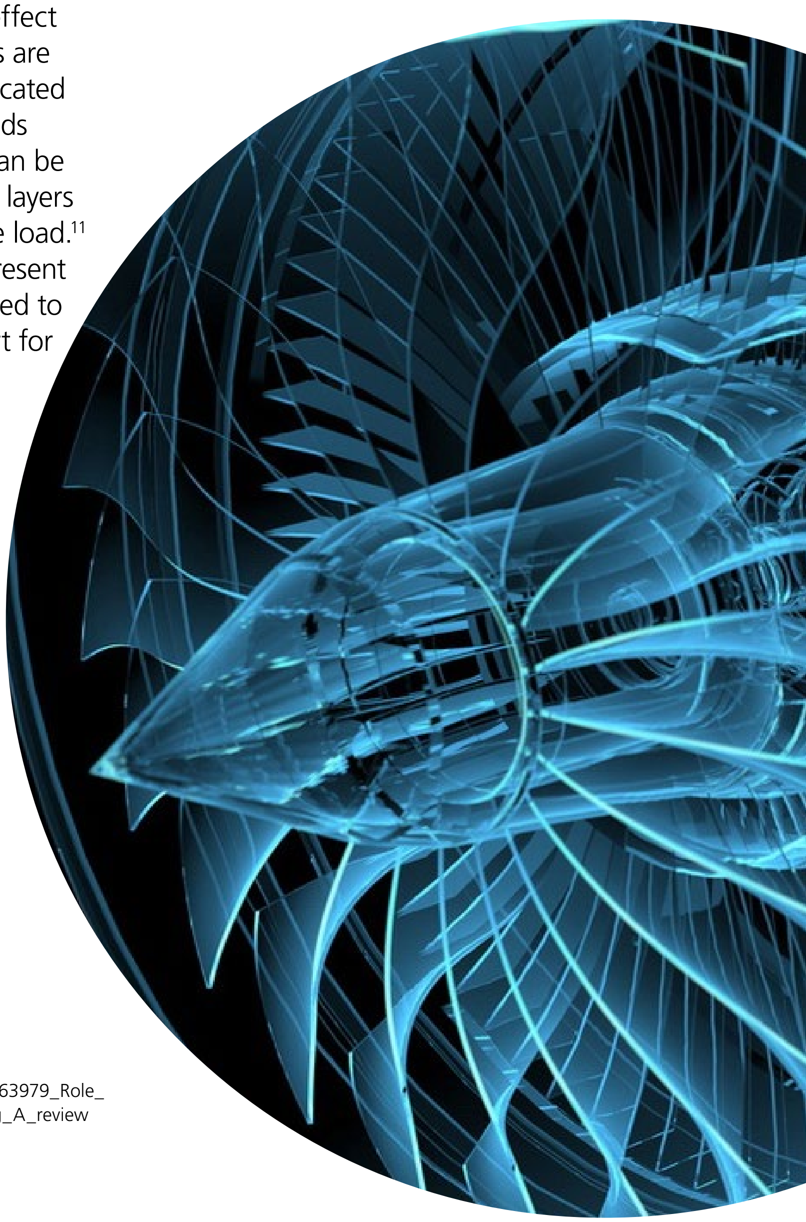
Limitations Related to Quality and Part Performance

Even though 3DP permits the creation of incredible structures that cannot be formed through traditional techniques, there are some scenarios where there is a downside to the newer approach.

For example, since parts are built through a layering technology in additive manufacturing, there is a laminate effect creating boundaries where the parts are not as strong as conventionally fabricated parts.[10] However, in cases where loads are static and predictable, this risk can be mitigated by orienting the part with layers perpendicular to the direction of the load.[11] In cases where dynamic loads are present and predictable, software can be used to identify the loads and orient the part for the most optimal product lifespan.[12]

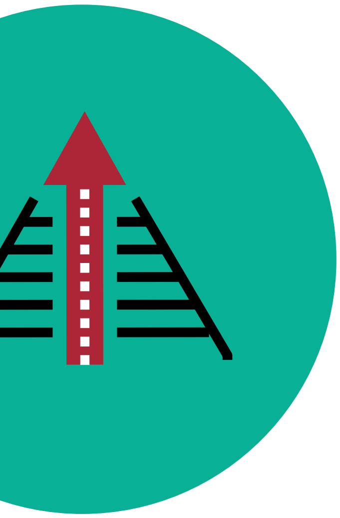
Another challenge with 3DP is shrinkage or warping. During the printing stage, it is possible the part will warp or shrink as a result of variables including temperature extremes, residual stress and material properties.[13] Due to the extreme thermal gradients present for metal printing via direct metal laser sintering (DMLS) or selective laser melting (SLM), there is a high risk of warping and distortion for this industrial application.[14]

To avoid this, more accurate parts can be achieved through part orientation and well-designed support structures. Additionally, part shrinkage can be anticipated and simulated using printer software, helping designers modify parts in advance.[15] For metal parts, heat treatment processes can be used after the part is built to relieve stress and prevent future failure.[16]



10 https://www.researchgate.net/publication/261363979_Role_of_build_orientation_in_layered_manufacturing_A_review
11 https://www.3dhubs.com/knowledge-base/how-does-part-orientation-affect-3d-print
12 https://blog.altair.com/designing-3d-printed-parts-to-withstand-dynamic-loads/
13 https://www.3dhubs.com/knowledge-base/dimensional-accuracy-3d-printed-parts
14 https://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/15202/7-Issues-to-Look-Out-for-in-Metal-3D-Printing.aspx
15 https://core.ac.uk/download/pdf/81540249.pdf
16 https://www.3dhubs.com/knowledge-base/dimensional-accuracy-3d-printed-parts

Breakthrough Opportunities



One of the main challenges when looking to additive versus conventional manufacturing takes place when comparing parts 1:1. Parts designed for die casting or injection molding will not likely thrive when produced as-is with additive techniques.

However, breakthrough opportunities in cost, speed and quality can be unlocked when parts are designed intentionally with additive manufacturing and the specific technologies in mind from the start.

1. Lightweighting and Material Reduction

Existing parts can be completely reimagined for additive methods with topology optimization tools. Most modern CAD programs include the ability to upload a 3D model and optimize the form. This is done by adjusting constraints to enable a new form that meets strength requirements while subtracting non-essential faces and shapes. The improved result often takes on a skeletal appearance that can only be produced through additive manufacturing technologies.

2. Generative Design[17]

This takes advantage of intelligent design tools to develop hundreds of thousands of possible designs on-demand in search of the optimal solution. Engineers can leverage generative design to solve design problems, driven by constraints and defined parameters. One could say it applies the evolution process to a product.[18]

3. Increased Flexibility of Operations

Low-volume, high-mix manufacturing can be achieved with additive manufacturing. Whether investing in 3D printers internally or working with external service providers, additive manufacturing can accommodate a range of materials, dimensions, and performance requirements. Compared to the extensive lead times and high costs of building an assembly line, small batch manufacturing can be achieved with minimal set-up required. In most cases, 3D printers can be left to complete parts unsupervised, allowing for overnight production. Taken further, automated 3DP solutions enable parts to be printed, cleaned, and treated with post-processing techniques without human intervention.[19]

17 http://kalypso.com/ptcforum2018
18 https://www.autodesk.com/solutions/generative-design
19 https://formlabs.com/3d-printers/form-cell/

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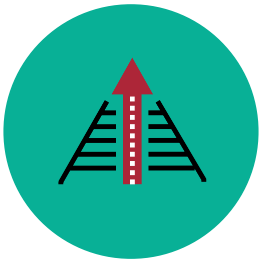


4. Inventory Management

Instead of holding a large inventory of a variety of parts, additive manufacturing can be used to produce parts just-in-time.[20] This can drastically reduce overhead costs by minimizing the space required for manufacturing and reducing unsold units.

5. Tooling

When tooling costs are high relative to product value (for example, stamping dies for low volume production such as prototypes), additive manufacturing is an effective alternative. When merged with different 3DP techniques, this can significantly reduce time and cost in this category.

6. Mass Customization for Small-Scale Parts

Whether it be personalizing upgrades to your vehicle's appearance or medical devices designed for a perfect fit, additive manufacturing is enabling a viable path for mass customization.

Since 2001, BMW Group's MINI brand has made vehicle personalization possible by providing options for style, features and comfort.[21] With the MINI Yours Customized online store, MINI owners can now design bespoke indicator inlays, interior trims, LED door sills and LED door projectors.

While traditionally handcrafted, custom-fit hearing aid shells are now primarily 3D printed. Hearing aid manufacturer Sonova produced 1,000,000 custom hearing aids in 2016 alone.[22]

Meanwhile, advancements in biomaterials are leading to new medical applications in various stages of testing and development. For example, custom medical implants are on the horizon with 3D printed bone-like implants that mimic a porous structure and are composed of a calcium polyphosphate powder.[23] Over time, the artificial bone is naturally replaced by native bone as it regrows.

3D printed bone-like implants

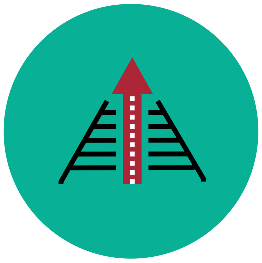
20 https://www.researchgate.net/publication/256986618_Additive_manufacturing_in_the_spare_parts_supply_chain

21 https://www.press.bmwgroup.com/united-kingdom/article/detail/T0277375EN_GB/mini-to-launch-unique-3d-printed-personalisation-upgrades?language=en_GB

22 https://www.tctmagazine.com/hear-and-now-enabling-mass-manufacture-hearing-aids/

23 https://www.3ders.org/articles/20160226-canadian-researchers-pioneering-3d-printed-bio-absorbable-bone-like-medical-implants.html

Breakthrough Opportunities



7. Hybrid Additive Approaches

To meet industrial requirements and address current gaps, hybrid approaches to additive manufacturing are being developed. While additive manufacturing can lay the foundation of metal parts, more traditional subtractive methods can be applied in post-processing. For example, CNC milling can be used to add threading, drill holes and achieve surface finishing in a reliable and reproducible way.

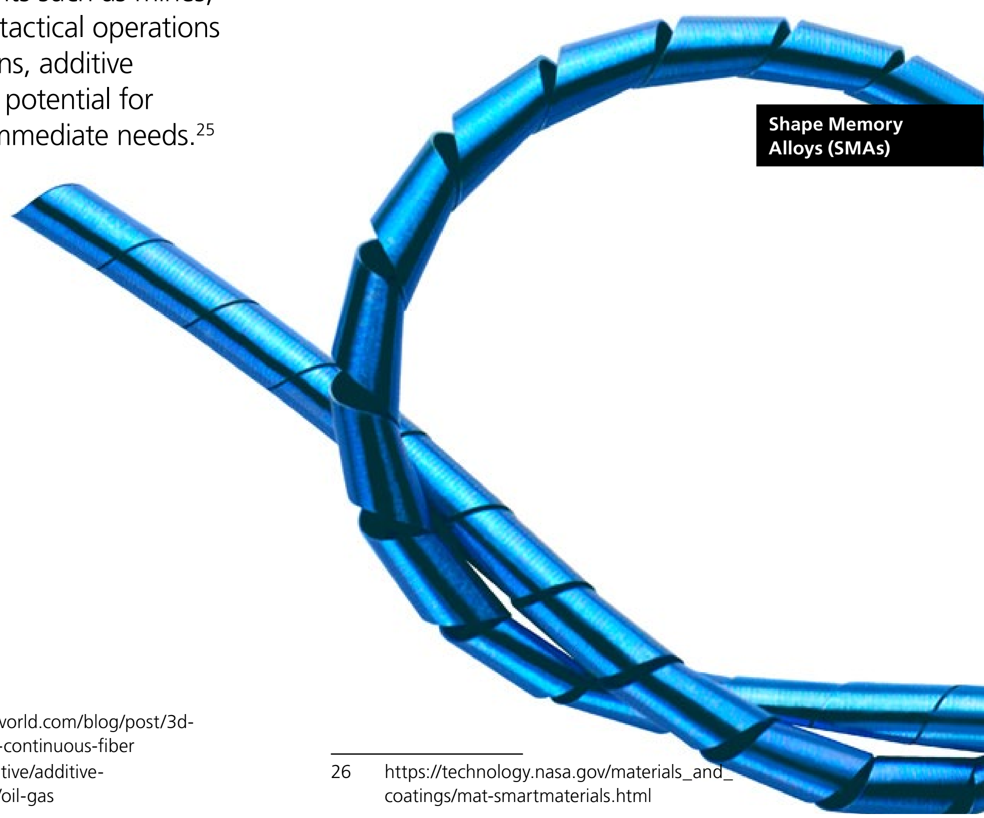
Hybrid materials are also being developed for additive applications. Continuous Composites is combining 3DP and robotic arms to enable multi-axis printing with continuous fiber.[24] With this technology, a range of properties including rigidity, fire resistance and conductivity can be controlled, combined and achieved in a single print. This technology will be a significant breakthrough for smart connected products.

8. Remote Maintenance & Repair

In remote environments such as mines, offshore oil rigs, and tactical operations for military applications, additive manufacturing offers potential for fulfilling short-term immediate needs.[25] Equipment breakdowns could be resolved in a matter of days instead of weeks. With a library of replacement part models available, parts can be printed on demand without requiring parts to be stored on-site.

9. Smart Materials

A wide variety of materials that reduce resource consumption are being created and improved daily. Some of these materials are Shape Memory Alloys (SMAs)[26], piezoelectric materials, photovoltaic materials, temperature-responsive polymers and self-healing materials, among others.



24 https://www.compositesworld.com/blog/post/3d-printing-composites-with-continuous-fiber

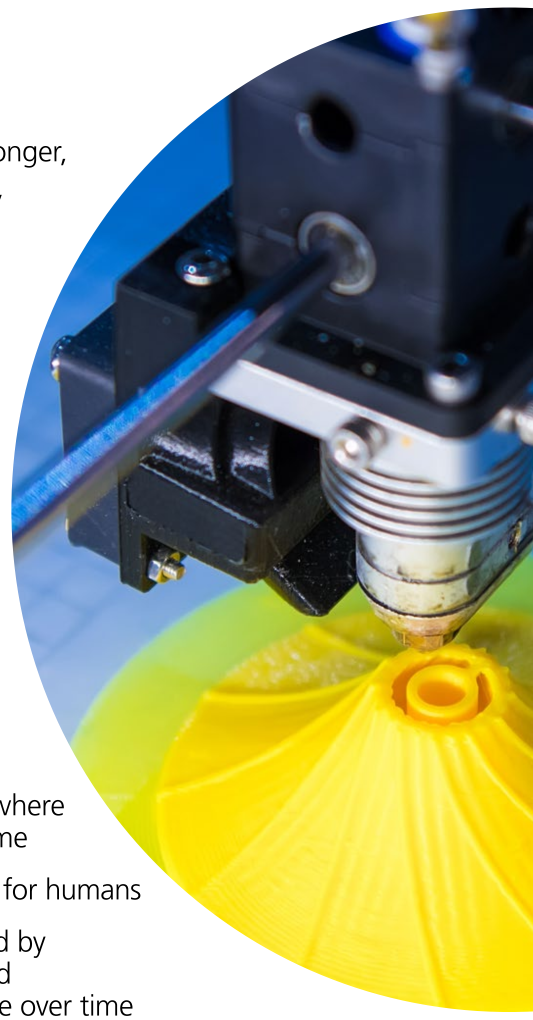
25 https://www.ge.com/additive/additive-manufacturing/industries/oil-gas

26 https://technology.nasa.gov/materials_and_coatings/mat-smartmaterials.html

Signals of Change

There are many use cases where additive manufacturing can relieve pain points and enable a cheaper and faster alternative to conventional methods. However, the technology is not yet universally parallel to these tried and true approaches.

What signals should organizations consider when monitoring advancements in additive? Which signals will help them determine whether it’s time to adopt this technology?



Expansion of the Processing Envelope

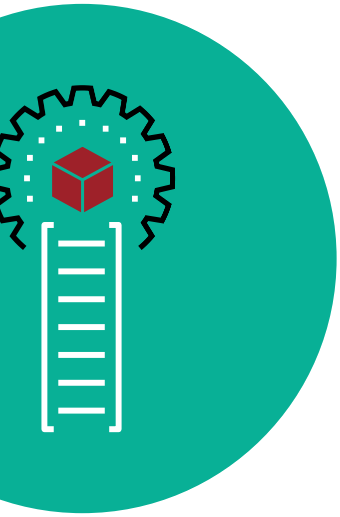
Look for the ability for additive to produce parts faster, stronger, larger and at a lower cost. The more this window expands, the more it will be the right choice for various applications.

Maturation of Emerging Additive Technologies

Depending on the use case, look to developments in emerging applications such as:

- **Lost-Wax Metal Casting** – a hybrid form of additive manufacturing technology where a high-fidelity master model is 3D printed then captured in a plaster mold where the part can be reproduced via injected metal
- **3D Printed Conductive or Sensing Materials** – enabling smart connected products
- **Nanoprinting** – ability to reach high-fidelity applications such as semiconductor manufacturing
- **4D Printing** – shift from concept to applied use cases where 3D printed objects can reshape or self-assemble over time
- **Bioprinting** – 3D bioprinted parts that are proven safe for humans
- **Liquid 3DP** – researchers are developing a new method by injecting water into silicone oil but have not yet achieved continuous liquid structures with an ability to hold shape over time

Getting Started: Understanding When to Move



While GE is already printing jet engine parts in commercial aircraft,[27] it can feel like your organization is being left in the dark ages by not adopting additive. Every use case will have specific pros and cons to be weighed before diving in full tilt. Contemplate additive before designing a part to explore whether specific forms, features or requirements can be better achieved with 3DP.

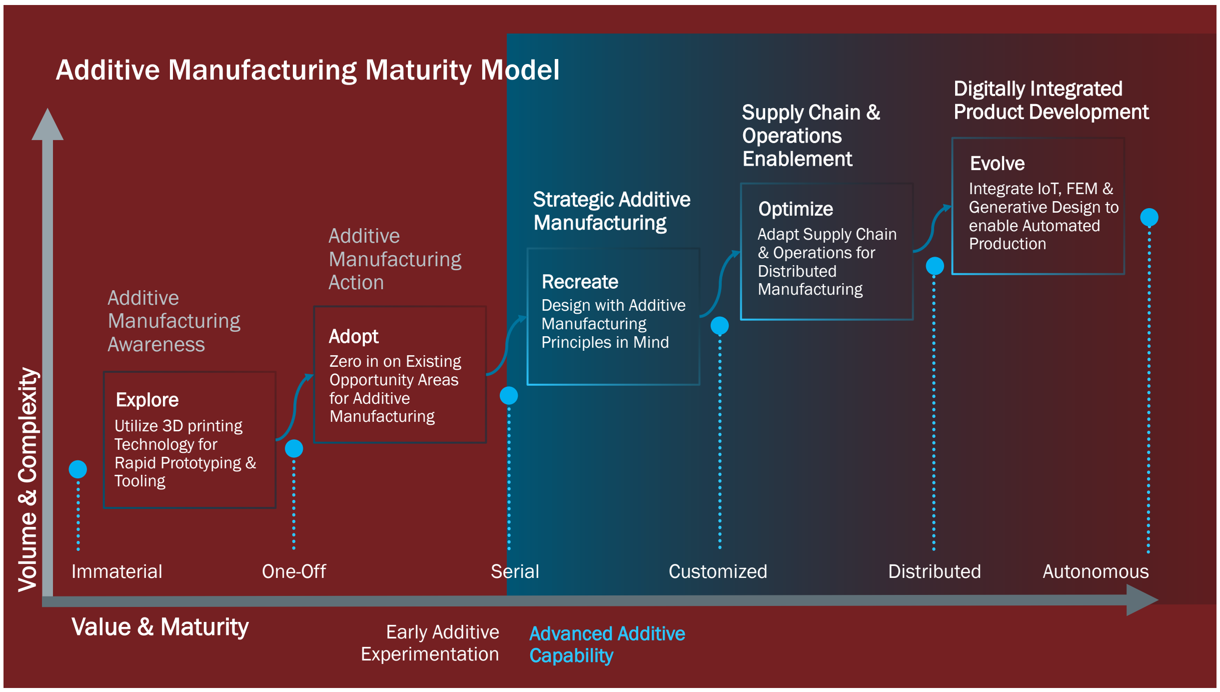
Start small. Consider working with an external service provider to assess whether additive is right for your application and outsource the skills required to bring your part to 3D printed fruition. Allow experts to be part of your product development innovation process.

In addition to this, implement advanced analytics to pinpoint areas in the value chain where you are lagging in comparison to competitors and/or that can be improved with cutting edge tech such as 3DP/AM. This way your organization can achieve benefits in any combination of speed, cost and quality.

27 https://www.ge.com/reports/future-manufacturing-take-look-inside-factory-3d-printing-jet-engine-parts/

An Additive Manufacturing Maturity Model

Becoming a digital leader means committing to transformation at scale. Kalypso's additive manufacturing maturity model helps our clients chart their path for additive and identify the optimal scale and opportunities where these technologies should be applied.



Explore	Adopt	Recreate	Optimize	Evolve
Utilize 3D printing Technology for Rapid Prototyping & Tooling	**Zero in on Existing Opportunity Areas for Additive Manufacturing**	**Design with Additive Manufacturing Principles in Mind**	**Adapt Supply Chain & Operations for Distributed Manufacturing**	**Integrate IoT, FEM & Generative Design to enable Automated Production**
• Use of rapid prototyping/3D printing service bureaus • Replace tooling with 3D printed parts	• 3D scanning and part replacement • Part consolidation for additive • Adapt existing parts/models with topology optimization techniques	• Design for Additive Manufacturing Approaches and Training • Customization/personalization of products • Intelligent engineering & generative design	• Distributed manufacturing strategy and network • Smart connected operations to enable just-in-time production of parts and tooling	• Automated 3D printing cells • Integration of IoT, FEM and generative design for product development

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About Kalypso

Kalypso is a professional services firm helping clients discover, create and make better products with digital.

We provide consulting, digital, technology, business process management and managed services across the innovation value chain.

We help clients build foundational digital capabilities that fundamentally transform the way they innovate and the products they bring to market.

3D Printing & Additive Manufacturing (3DP/AM) Offerings

3DP/AM Diagnostics	**3DP/AM Strategic Roadmapping**	**3DP/AM Process Optimization**	**3DP/AM System Integration**	**3DP/AM Product Development Integration**
Review product portfolio and identify opportunity areas for additive manufacturing. · Product Portfolio Review & Printability Analysis · Value Driver Identification	Define the strategic direction for an internal 3DP/AM capability. · 3DP/AM Roadmap Development · Business Case Analysis · Review Emerging 3DP/AM Technologies of Varying Readiness Levels	Design with Additive Manufacturing Principles in Mind. · Design for Additive Manufacturing Training · Process Design & Workflow Optimization	System integration across 3D Printing Workflow Software and enterprise tools. · 3DP/AM Workflow Implementation · System Integration to supply chain, sales and service systems (CRM, PLM, ERP, etc.)	Integration of advanced engineering solutions to automate an iterative and data-drivendesign capability. · Integration of IoT, FEM/simulation and generative design for product development

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