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3D printing will disrupt the spare parts market. The question is how, how soon and what to do about it

BY TITOS ANASTASSACOS ON MARCH 3, 2015 • (LEAVE A COMMENT)

Spare parts account for the bulk of profits of OEMs' services business. Some companies are already using additive manufacturing (3D printing) to reduce spare parts inventories and maintenance lead times, improving profits. However in the not too distant future customers may be able to print and fabricate most of the parts on site, requiring a change of business model to sustain revenues and profitability. Past experience with digitization suggests that price pressures and margin reductions are a real and considerable risk

For example in the context of a project (MENTOR2 – funded by DARPA (http://www.darpa.mil/Our_Work/DSO/Programs/Manufacturing_Experimentation_and_Outreach_MENTOR2.aspx) US Defense Advanced Projects Agency) to reduce logistics supply chain costs and boost defense readiness by improving training and tools for operating, maintaining and adapting complex military equipment in low-tech environments – such as repairing unmanned aerial vehicles in austere locations or fixing ship systems at sea – the US Navy is beginning to install "Fab Labs" at various locations (http://science.dodlive.mil/2015/03/02/darpa-to-put-fab-lab-at-navy-ship-maintenance-center/).

Fab Labs are design and fabrication shops outfitted with modern digital tools and equipment—such as *laser cutters, routers, 3D printers, vinyl cutters for flexible circuit boards and digital design tools* that use open-source software. DARPA is establishing the Navy's customized Fab Lab through the Fab Foundation, a non-profit organization that oversees the international Fab Lab Network, a collaborative, knowledge-sharing community of more than 450 Fab Labs in 55 countries. "A Fab Lab is comprised of off-the-shelf, industrial-grade fabrication and electronics tools, wrapped in open source software and programs written by researchers at MIT's Center for Bits & Atoms (http://cba.mit.edu/)" (Source Fab Foundation (http://www.fabfoundation.org/)).

These are precisely the seeds for disruptive innovation according to Harvard's Clayton Christensen (http://www.claytonchristensen.com/): A method to achieve an acceptable outcome at far lower cost. Fab Labs (or equivalents) move from being something for academics and enthusiasts used mainly for experimentation or training purposes (Peer 2 Peer Production (http://p2pfoundation.net/Peer_Production), the Maker Movement (http://en.wikipedia.org/wiki/Maker_culture)) to something used experimentally by the military (http://3dprintingindustry.com/2013/03/06/u-s-army-deploying-mobile-fablabs/) and possibly soon, in specially packaged form, by the private sector and industry. For example Techshops (http://www.techshop.ws/) (a private sector initiative) are membership based shared facilities offering access to advanced tools -shared machine shops in fact- increasingly used by small local companies for prototyping and learning purposes.

3D printing is central to the disruption. Revenue growth in the industry has been explosive. According to the Wohlers Report (http://www.wohlersassociates.com/index.html), global industry revenues will grow from just over US$ 3 billion in 2014 to $ 21 billion in 2020, a compound growth rate of 32%. 3D printing remains expensive for mass produced items, mainly due to costs of materials. For example, acrylonitrile butadiene styrene (ABS), the most common 3D printing material, can cost up to US$ 80 per kg as bespoke powder or filament, whereas it might cost about $2 a kilo in the open market when used for plastic injection moulding. This is mostly because 3D printer manufacturers require users to buy materials from them at very high mark-ups. This strategy however is probably not sustainable in the long run as third party suppliers enter the market. In addition expiration of key patents and scale economies are bringing down the costs of hardware, while capabilities are expanding fast (see for example: Form 1+ by Formlabs (https://gigaom.com/2014/06/10/formlabs-reveals-the-form-1-a-faster-and-more-reliable-sla-3d-printer/): a stereolithography printer that uses lasers that are four times more powerful to print up to 50 percent faster than the previous generation printer Form 1; the Stratasys Objet1000 (http://http://www.stratasys.com/3d-printers/production-series/objet1000) -the largest multi-material 3D printer in the market to build large tools, fixtures and prototypes – or large batches of smaller parts – in one automated job, offers 120 material options, with as many as 14 distinct materials in any part or tray; products by SLM Solutions (http://www.stage.slm-solutions.com/index.php?index_en), the first to process reactive metal powders like Aluminum using selective laser melting; or the collaboration between the US Department of Energy's Oak Ridge National Laboratory with Cincinnati Inc., a major machine tools manufacturer, to develop a large-scale polymer additive manufacturing (3D printing) system (http://www.ornl.gov/ornl/news/news-releases/2014/ornl-cincinnati-partner-to-develop-commercial-large-scale-additive-manufacturing-system--): "Their design will combine larger nozzles for faster polymer deposition, high-speed laser cutters that handle work areas in feet rather than inches, and high-speed motors to accelerate the pace at which printer heads are moved into position. The result will be a system capable of printing polymer components as much as 10 times larger, and at speeds 200 to 500 times faster than existing additive machines". Further maker communities and service bureaus -whether units of manufacturers (e.g. Stratasys Direct Manufacturing (https://www.stratasysdirect.com/?_ga=1.26660990.2130803649.1425335759) service), attached to major store chains (UPS store (http://www.theupsstore.com/small-business-solutions/Pages/3D-printing.aspx), Staples (http://www.staples.com/sbd/cre/products/3d-printing/)) or independent service providers (3dhubs (https://www.3dhubs.com/), a 3D printer sharing community), – are strongly expanding the reach of the technology allowing also small firms to benefit.

Deloitte has a good primer on 3D printing, including technology, economics and managerial implications in the context of its 2014 Engineering and Construction Conference (http://www2.deloitte.com/us/en/pages/real-estate/articles/2014-engineering-and-construction-conference.html)

According to a study by McKinsey Global Institute (http://www.mckinsey.com/insights/mgi):

"3D printing, or additive manufacturing has come a long way from its roots in the production of simple plastic prototypes. Today, 3D printers can not only handle materials ranging from titanium to human cartilage but also produce fully functional components, including complex mechanisms, batteries, transistors, and LEDs. The capabilities of 3D printing hardware are evolving rapidly, too. They can build larger components and achieve greater precision and finer resolution at higher speeds and lower costs. Together, these advances have brought the technology to a tipping point—it appears ready to emerge from its niche status and become a viable alternative to conventional manufacturing processes in an increasing number of applications. Should this happen, the technology would transform manufacturing flexibility—for example, by allowing companies to slash development time, eliminate tooling costs, and simplify production runs—while making it possible to create complex shapes and structures that were not feasible before. Moreover, additive manufacturing would help companies improve the productivity of materials by eliminating the waste that accrues in traditional (subtractive) manufacturing and would thus spur the formation of a beneficial circular economy. The economic implications of 3D printing are significant: McKinsey Global Institute research suggests that it could have an impact of up to $550 billion a year by 2025"

The advantages of 3D printing over other manufacturing technologies could lead to profound changes in the way many things are designed, developed, produced, and supported. One of these involves profound shifts in the economics and profitability of spare parts services: A key challenge in traditional aftermarket supply chains, for example, is managing appropriate inventories of spare parts, particularly for older, legacy products. The ability to manufacture replacement parts on demand using 3D printers could transform the economics of aftermarket service and the structure of industries. Relatively small facilities with on-site additive manufacturing capabilities could replace large regional warehouses. The supply of service parts might even be outsourced: small fabricators located, for example, at airports, hospitals, or major manufacturing venues could make these parts for much of the equipment used on site, with data supplied directly by the manufacturers or through reverse engineering.

Aerospace

While a number of OEMs in different industries are using 3D printing to fabricate parts, aerospace is the most prolific user due to its particular economics. A key success factor throughout the aerospace industry is weight reduction and therefore a key indicator for products is the "buy-to-fly" ratio, the weight ratio between the raw material used for a component and the weight of the component itself. 3D printing can not only produce lighter parts, but also significantly compress the buy-to-fly ratio as much as 10- or even 15-fold, reduce material wastage (on high cost materials such as titanium) providing huge cost saving opportunities.

For example GE Aviation will start producing its first component through 3D printing –fuel nozzles for the new Leap engine in the Boeing 737 MAX and Airbus A320neo aircraft – from 2016. A fuel nozzle currently consists of 20 different components that have to be machined, cast and welded. With 3D printing, it can be made in one metal piece, have five times the lifespan and weigh about 75 per cent less. A number of other 3D printed engine parts could start to be mass produced from next year.

For this purpose in 2012, GE Aviation acquired Morris Technologies (http://www.businessinsider.com/ge-buys-3d-printing-company-to-make-parts-for-jet-engines-2012-11), a leading supplier of contract additive manufacturing services, in order to secure this company's capacity for its own use. According to Randy Kappesser, composites technology leader with GE Aviation in an interview with Modern Machine Shop (http://www.mmsonline.com/columns/why-did-ge-aviation-acquire-morris-technologies): "GE clearly views additive manufacturing as a game-changing technology. Morris is already committed to providing components within the combustion system of the LEAP jet engine currently under development by CFM International (a 50/50 joint company of GE and Snecma of France). CFM has received orders for more than 4,000 LEAP engines. Additional components for the LEAP engine as well as for other GE engines under development are being explored for additive production. By 2020, well over 100,000 end-use parts in GE/CFM engines will be produced through additive manufacturing. That's a huge change, and we believe a competitive advantage. With the acquisition, work on identifying and developing GE's other additive applications can be accelerated" and further: "Additive manufacturing gives GE Aviation opportunities for both cost and weight reduction on jet engines. Meanwhile, the acquisition will allow all GE businesses the opportunity to better understand the breadth and potential of new additive manufacturing applications. As manufacturing technologies and materials progress within the aerospace industry, jet engine suppliers are increasingly moving capability in-house. Pratt & Whitney, for example, has recently announced that it is moving its geared technology capability in-house. GE, for its part, has made strides in producing non-metallic parts, with GE Aviation leading the jet propulsion industry in the production of composite components. The additive manufacturing acquisition is another example. Jet propulsion represents one of the most attractive sectors of the aerospace industry, and the main suppliers will continue to build upon their internal capability".

Rolls-Royce, though behind GE, is also looking into 3D printing components for its jet engines, as a means of speeding up production and making more lightweight parts, such as brackets. However it has also announced that it will flight-test what it claims to be the largest 3D printed aerospace component to ever power an aircraft: a 3D printed titanium structure that measures 1.5m in diameter and 0.5m-thick. The front bearing housing contains 48 aerofoils and was manufactured using electron beam melting technology by Arcam (http://www.arcam.com/). The structure is incorporated into the company's Trent XWB-97 engine.

In the meantime GKN, the British automotive and aerospace engineering firm, is developing a 3 printed titanium bracket with Airbus. This bracket will reduce machining time from four hours to 40 minutes and cut material use by 30 per cent. Airbus is also looking at the potential to make larger, 3D printed titanium parts, several meters in length. In 2014, a component made using 3D printing made its first flight on a commercially operated Airbus aircraft. The varnished hard plastic component is a panel installed behind the crew seat, to keep the seat belt in place, measuring roughly 10 by 40 cm. This fairly simple panel represents a long-term paradigm shift in spare parts provisioning for aircraft as it enables the production of spare parts where only small quantities are needed on an 'on demand' basis cost effectively and rapidly (Sources: Financial Times, Forbes).

Other significant reasons for utilizing 3D printing in aerospace include the economics of spare parts lead times and inventories: Spare parts demand for aircraft is traditionally hard to calculate. For example most spares for the Airbus fleet are requested rarely or very rarely. Parts that are ordered on average as little as five times in two years are considered 'high runners'. Airbus must, however, keep every component in stock or at least be able to procure it at short notice – even after production is discontinued, as long as at least five aircraft of a given type remain in service: For example, the A300/A310 aircraft is expected to require spares until 2050 (production of this model ceased in 2007, today, there are still 415 aircraft flying), requiring the company to stock approximately 3.5 million spares. That requires gigantic storage space and binds significant capital. In addition some of these parts have very long lead times -12 months or more are not unusual due to the complex (and expensive) tooling processes required. 3D printing can very significantly reduce both lead times and inventories.

Virtually all major aerospace and defense companies, including Boeing, BAE Systems, Lockheed Martin, Northrop Grumman and Honeywell have major 3D printing programs. While 3D printing is not yet used to manufacture structural, load bearing parts this is expected to change over the next few years. A lab in China (State Key Laboratory of Solidification Processing of North Western Polytechnical University) working on the Comac C919 short haul passenger plane, is using giant 3D printing machines, one of them 12 metres long, to print parts (including wing spares and fuselage frames) in titanium. Airbus has partnered with this lab (http://sklsp.nwpu.edu.cn/New_Event.asp?bh=103) to manufacture test specimens of titanium alloy parts using its Laser Solid Forming technology, while also working towards spare part solutions or manufacturing larger aircraft parts with this technology, which is ideal for producing cost-effective, out-of-production aircraft spare parts on demand.

Automotive

Car manufacturers are extensively using 3D printing technology to make design samples and prototypes (achieving cost reductions of over 90% compared to traditional methods), but are a long way behind their aerospace counterparts in using it for mass production, mainly due to cost, which is too high for mass markets (lower cost materials compared to aerospace are used, therefore material wastage reduction plays a lesser role). Nevertheless Volkswagen is testing the latest printing methods, which utilise laser sintering of powdered metals to produce metal parts. Wohlers Associates believes that once prices of machines and materials fall, the automotive industry will begin to use the technology for manufacturing, probably within a few years. In the meantime however numerous on-line markets and communities are offering 3D printed parts for legacy automobiles and other vehicles (examples include Kazzata (http://kazzata.com/Home.aspx) and 3dlt (http://3dlt.com/)) providing an early indication of market direction.

However developments may come sooner than expected. For example, MTU, a German engineering company part of Rolls Royce, developed an economical high-performance turbocharger (http://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/8765/Can-3D-Printing-make-Economical-Auto-Parts.aspx) with a water-cooled casing and compressor that had inner channels to decrease surface temperature using Selective Laser Melting (http://en.wikipedia.org/wiki/Selective_laser_melting), an additive manufacturing process developed by Fraunhofer Institutes in Germany. This design resulted in a lower thermal load on the intercooler, which in turn could be reduced in size and weight. More widely reported however was the fabrication of a complete automobile using 3D printing technology by Local Motors (https://localmotors.com/), a low volume car manufacturer utilizing user or crowdsourced designs. Local Motors used the BAAM (http://http://www.e-ci.com/baam) (Big Area Additive Manufacturing) machine from Cincinnati Inc. which can lay down 40 pounds per hour of carbon reinforced ABS plastic, and is large enough to produce the body as one piece. Importantly an equivalent conventional car would have 5000-6000 parts.

Other industries (examples)

Siemens (http://www.siemens.com) is using 3D printing, in particular selective laser sintering, to make high temperature spare parts and other components of gas turbines within its power generation service and maintenance division. It can produce more than 100 different individual parts this way and claims to have reduced the lead time for burner repair from 44 weeks to 4 days because the replacement burner tip no longer has to be laboriously welded together. Instead, the new burner tip is simply printed onto the body of the burner, reducing repair costs by a considerable amount. Another example are gas turbine blades which must run for 25,000 hours, despite being subjected to temperatures of around 1,300 degrees Celsius. Siemens prints these from powdered steel and nickel-based alloys. These types of steel are especially durable and heat-resistant, though the printed products are not yet strong enough to be used under real operating conditions . However the company is already conceptualizing “spare parts on demand” with significant benefits for both supplier and customer.

ABB (http://www.abb.com) has invested in Massachusetts-based Persimmon Technologies (http://www.persimmontech.com/) to help develop its 3D deposition technology for motor component manufacturing. Since launching in 2011, Persimmon has been developing disruptive hybrid-field motor technology, a new approach to making motor components using a 3D deposition processes that aim to increase power density, eliminate manufacturing steps and reduce component costs. The company's first prototype motor concept increases the stator effective area and produces a higher output motor with comparable size and material cost.

There are numerous other examples and as costs reduce and capabilities of the technology improve the areas of application will expand fairly rapidly. Data from a PWC survey show that already 75% of large companies (> 500 employees) already use 3D printing in some way, while virtually all the rest plan to adopt the technology within 3 years. Small companies are not far behind: 59% already use 3D printing and over 20% plan to use it within 3 years.

For OEMs therefore a model of the future could be that parts are made "on demand", close to the customer, reducing cost of parts, maintenance lead times and even improving performance of the part or component while increasing Mean Time Between Failure (MTBF). All costs associated with spare parts inventories and logistics are reduced, even eliminated, benefiting both customers and suppliers. In this business model revenue generation is through the sale of proprietary 3D designs and perhaps certification of 3D printing and fabrication facilities.

Nevertheless a number of risks are also apparent:

- 3D printed components and products will have far fewer parts. In the Local Motors automotive example a full sized (compact) car was printed in one piece, whereas an equivalent conventional car would contain 5,000 to 6,000 parts. In the case of the GE fuel nozzles, 3D printing replaces 20 individual parts with one component printed as a whole. The net impact of reduction in part numbers on revenues and profitability is unclear.

- In this sense 3D printing may change the structure of supply chains. As conventional manufacturing investment becomes less relevant, materials suppliers may move to forwards integration supplying parts directly. For example Alcoa, a Canadian aluminium producer, plans to 3D print jet engine parts.
- Given the ability of 3D printers to produce virtually any product (economies of scope), it will eventually make economic sense for customers to print / fabricate parts themselves -notwithstanding safety or reliability standards and other issues. Differentiation through manufacturing becomes more difficult. As mentioned above, big users such as the US Navy are already experimenting with the idea -as are private companies, initially for not easily accessible environments or locations. For example Maersk Tankers is experimenting with using 3D printing to print parts on ships and oil services companies such as Halliburton, Baker Hughes, and Schlumberger as well as numerous oil and gas producers are beginning to utilize the technology to print parts used in drilling and production, mainly in areas with difficult access (in this context GE's Oil & Gas division very recently introduced the first metal 3D printers into their Japanese operations. Here they are using hybrid metal laser sintering 3D printers and milling machines to manufacture the company's Masoneilan control valve parts, which are used in various applications within the O&G industry). Other industries are following suit.
- Once customers (or third party service providers) start producing their own spare parts and components the spare parts business transforms from an inventory management and logistics business to a business providing 3D design services and supporting customers in improving part and component performance. In this context legal risks should not be underestimated: For example Autodesk recently introduced its 123D Catch App that can turn ordinary photos into 3D models. This type of underlying software could allow pictures of a product to be quickly transformed into the product itself. Alternatively, a company could use the 3D model to make 3D print molds for more traditional methods like injection molding or fiberglass production. This could allow a competitor to leverage its existing production techniques with 3D printing and gain significant cost savings over more traditional approaches. It becomes therefore essential (though difficult) to protect revenues through the necessary IP, including design patents.

3D printing and consequently on-demand, on-site manufacturing and fabrication is becoming mainstream. Given increasing R&D investment, both by users and 3D printing OEMs (including market entry announcements from major companies, such as Hewlett Packard (http://www8.hp.com/us/en/commercial-printers/floater/3Dprinting.html) or Epson, which may restructure the industry as well as accelerate innovation, capabilities and applications) and given current cost and capability trajectories, a significant number of products, components and parts will be manufactured using 3D printing over the next 5-10 years -initially in industries that make use of expensive materials and small production runs, later in others -even key component industries such as bearings. This creates the need to develop business models and strategies both for the new product market as well as for the after market, in particular spare parts, which account for a very significant part of OEMs service profits. What these business models will be like is still unknown, as is what role third party suppliers / designers or "platform providers" may eventually come to play with parallels to what happened in the book publishing or music industry (or what is happening in 3D consumer markets today), which were characterized by significant price pressures (on OEM equivalents) and therefore substantial reduction in margins.

These aspects will be investigated in a future post