3D PRINTING

Another dimension

With huge leaps being made in additive manufacturing by aerospace and aviation engineers, *ETi* asks whether the automotive industry can harness the technology's potential to 3D print engine parts in high-volume production vehicles

WORDS: **JOHN THORNTON**

3D printing, or additive manufacturing as it is also known, is nothing new in the automotive industry. Engineers have been using the technology for rapid prototyping and modeling since its inception in the 1980s. In fact, in 1988 Ford purchased the third 3D printer ever made.

Since then, 3D printing has been widely adopted by OEM and Tier 1 R&D departments to quickly and cheaply produce prototype parts. It shaves months off the development time for individual vehicle components, such as cylinder heads, intake manifolds and air vents – or in Ford's case the engine cover for the new Mustang – and saves companies hundreds of thousands of dollars. Now, the wider world is exploiting the technology's potential in a host of innovative and forward-looking ways.

In the medical field, a survivor of a serious motorbike accident in the UK last year had pioneering surgery to reconstruct his face using a series of 3D-printed parts, including a medical-grade titanium implant printed in Belgium, while scientists in the USA have already successfully 3D-printed splints, valves and a human ear. Plans are even underway to eventually print a human heart for transplant surgery using the recipient's own cells. And, somewhat controversially, the world's first metal 3D gun has been printed by Solid Concepts, a 3D printing services company based in Austin, Texas, using a laser sintering process and powdered metals.

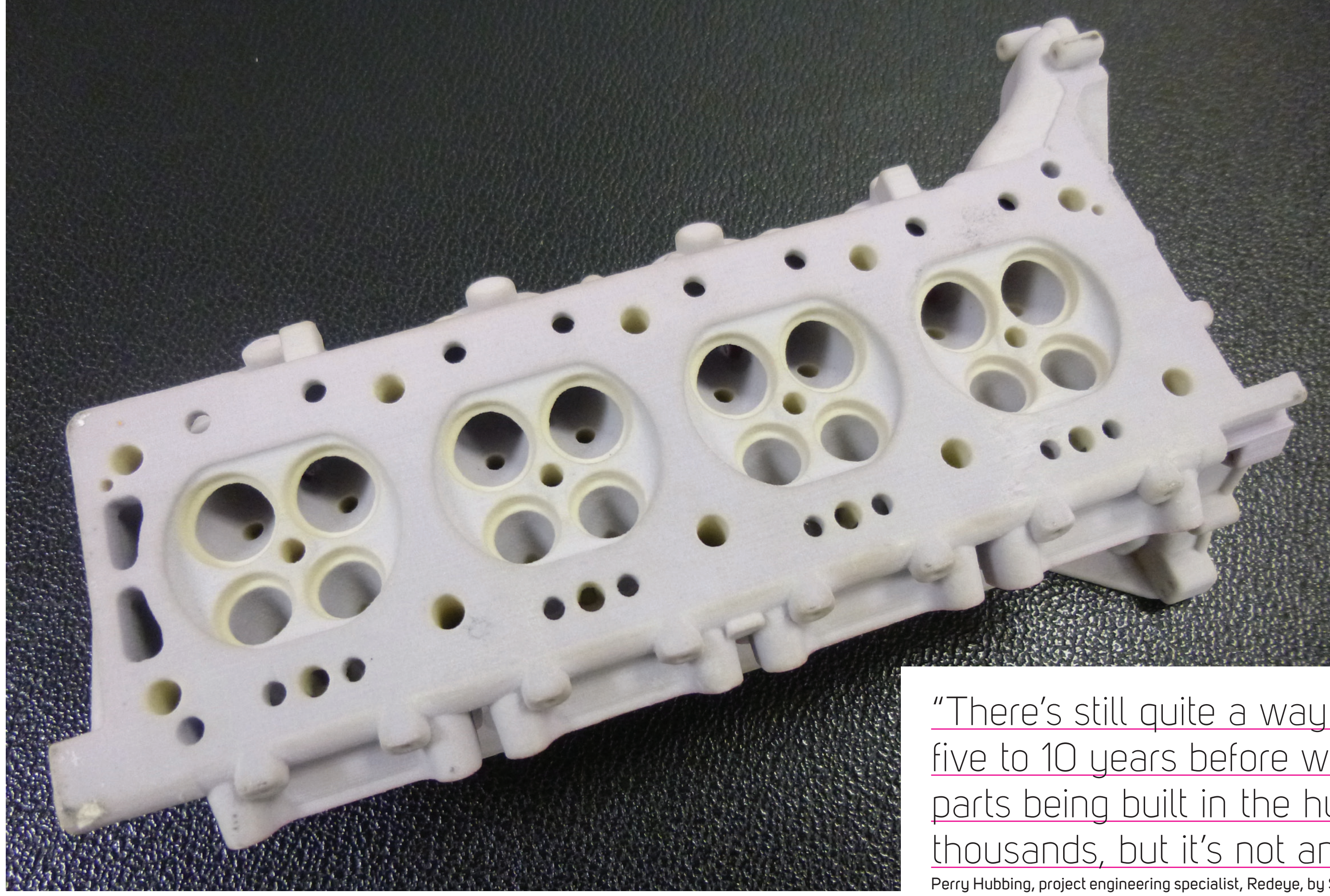
However, it's the aerospace and aviation industries that are providing perhaps the most relevant examples of how the automotive industry may further its own use of additive manufacturing.

Last year, General Electric (GE) announced its intention to 3D print up to 85,000 fuel nozzles for its new Leading Edge Aviation Propulsion (LEAP) turbofan engine family, while BAE Systems' combat engineering team is using additive manufacturing to engineer ready-made parts for supply to four squadrons of the Tornado GR4 aircraft. Meanwhile, Rolls-Royce's head of technology, Dr Henner Wapenhans, has been widely reported in the media as saying that the company was seriously considering using 3D printing to produce complex components for its passenger jet engines: "3D printing opens up new possibilities. Through the 3D printing process, you're not constrained by having to get a tool in to create a shape. You can create any shape you like." And that thinking counts for parts in end-applications, not just prototypes.

Furthest ahead in the race to develop engine components for use beyond the design review stage is undoubtedly NASA. Collaborating with California-based Aerojet Rocketdyne, in 2013 the US space agency's Glenn Research Center in Cleveland, Ohio, successfully tested a 3D-printed injector using selective laser melting (SLM). Although the part was smaller than it would be in a full-size rocket, it was still large and robust enough to withstand a record 9,080kg of thrust during hot-fire testing and "demonstrated the feasibility of developing full-size additively manufactured parts", says Carol Tolbert, manager of the manufacturing innovation project at Glenn. And according to Tyler Hickman, aerospace engineer at NASA, "the industry is three to five years away from routine production" of 3D-printed components for use in working rocket engines.

To infinity and beyond?

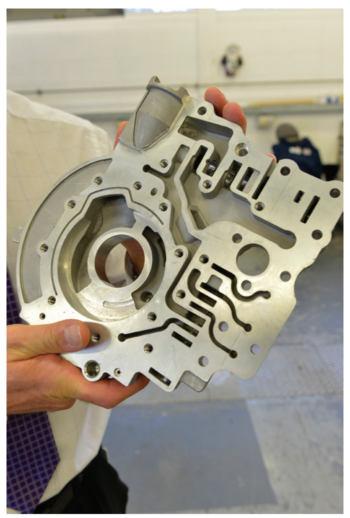
Naturally, such an exciting and imminent prospect begs the following question: When will the automotive industry start producing road-going light passenger vehicles that feature 3D-printed powertrain components or even an entire engine?



Left: Mahle Powertrain recently invested in a 3D printer that uses ABSplus material

Center: Simon Reader, Mahle Powertrain's engineering director, would like to see items such as crankshafts, cylinder heads and blocks 3D printed to reduce lead times during prototype development phases

Below: Ford's rapid product development (RPD) facility at its Dunton Technical Centre in the UK hosts an open day every two years to present the latest manufacturing capabilities of the RPD process – in particular 3D printing. The last event was held in November 2013



The answer is anything but clear cut. Ford's Detroit HQ claims, "One day, millions of car parts could be printed as quickly as newspapers and as easily as pushing a button on the office copy machine, saving months of development time and millions of dollars," and admits it is looking to what's next in its 3D printing strategy, including opportunities to print production parts in metal, rather than just plastic, for prototypes. However, the OEM's UK-based technical center is less sure.

"For a company like Ford, I think that scenario is some years away," speculates Nigel Dowsett, business manager for rapid prototyping at Ford's Dunton Technical Centre. "The technology is there, and I think the material selection is probably there. It's just that the volumes required at the moment in the auto industry don't really lend themselves to 3D-printed parts."

This sentiment is echoed by Mahle Powertrain's newly appointed engineering director, Simon Reader, who initially encountered the technology in his previous post within the company's design verification and purchasing department. "The only example I've seen where a 3D printer is used for parts on a proper road-going car is by very low-volume specialist manufacturers. You wouldn't see that happening on a volume where you need to make 100,000 vehicles. I can't see that it would ever make any financial sense, when you can have a permanent tool made and the price of making each part is quite small."

> "There's still quite a way to go, probably five to 10 years before we start seeing parts being built in the hundreds of thousands, but it's not an impossibility"
> Perry Hubbing, project engineering specialist, Redeye, by Stratasys

While conceding that current 3D printing technology is presently neither fast nor cost effective enough to cope with the rigors of high-volume automotive manufacturing, Perry Hubbing, project engineering specialist at RedEye, the manufacturing services unit of Stratasys and a producer of 3D printers, believes this could change as soon as the actual machines are capable of meeting demand. "Caterpillar is building 1,500 engines a year for a niche application in the trucking industry, and that's something we can certainly fulfill. Current 3D printing technology can build multiple parts at the same time, but essentially it works on one part at a time. So, it will work on one part and then move to the next. What we really need is a machine that is capable of working on 40 or 50 parts simultaneously and quickly. I think there's still quite a way to go, probably five to 10 years before we start seeing parts being built in the hundreds of thousands, but it's not an impossibility."

Unknown quantity

However, for both Reader and Dowsett, it's not just prohibitive costs and manufacturing volume limitations that stand in the way of 3D printing revolutionizing the way in which engine parts are produced. An inability to measure safety, accuracy and quality only adds to their apprehension. "Even if you drive down the cost and can get the range of materials, you've still got to decide how on earth you sign off on production of a part that is effectively a one-off every time you make it," questions Reader.

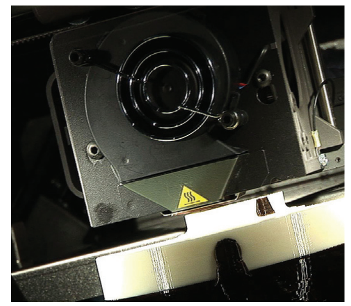
Dowsett adds, "There would be safety implications as certain components would have to survive certain crash test situations. The technology is good for a prototype and for running durability tests, but as for it passing more stringent health and safety standards, that's something else entirely."

Indeed, even Hubbing recognizes the technology's shortcomings. "Currently in 3D printing technology there isn't quite 100% repeatability and 100% accuracy part-to-part. That's something that's improving continually – the amount that's improved in the last five years alone is very impressive – and we're still working on it. There has to be a considerable safety margin engineered into a 3D-printed part because of that inconsistency."

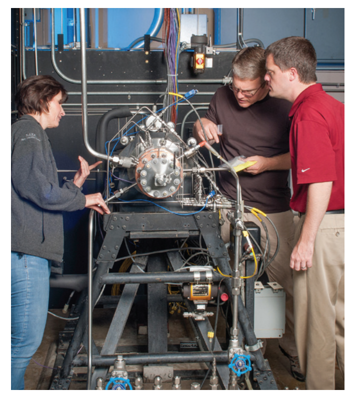
Interestingly, however, scope remains for 3D printing to make a bigger impact in the prototyping stage than it currently does, with the potential to print engine parts via processes such as continuous sand printing and direct metal printing with titanium and aluminum. And although Tolbert concedes that the test methods used by NASA on its rocket engine injector "are not directly applicable" to the automotive industry, that doesn't mean similar components can't be developed.

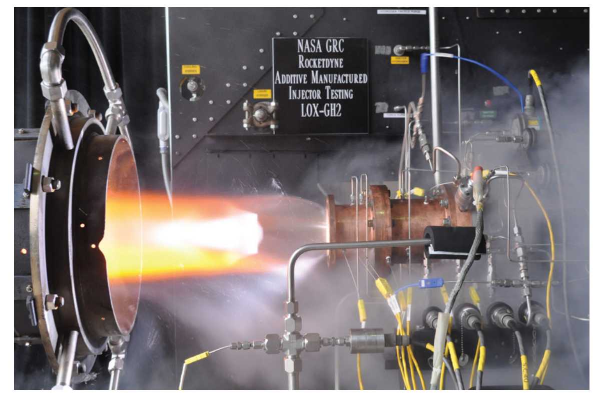
Mahle's engineering director, Reader, agrees: "As for printing useful parts that you could use on engines during the prototype development phase – I think that's almost here. Perhaps within the next five years we'll start to see that happening more and more. For us, the long lead items are things like crankshafts, cylinder heads and cylinder blocks. Typically, in a development phase we would need 16 weeks for any of those things once we've released the design and the drawing. So, they're the parts I'd most like to see printed. In the short-term though, the things most likely to be printed are plastic components – cam covers, sumps, front chain drive covers."

Hubbing, who has produced induction system components for motor racing applications, believes that brackets and fixtures for holding components are the most likely to be mass-produced first, but sees the technology getting into engine casings and even internal mechanical components, such as parts of oil pumps, valvetrains and rocker arms. And in the event that the issues currently



Below: The next generation of 3D printing machines will be able to print powdered metals, such as aluminum and titanium

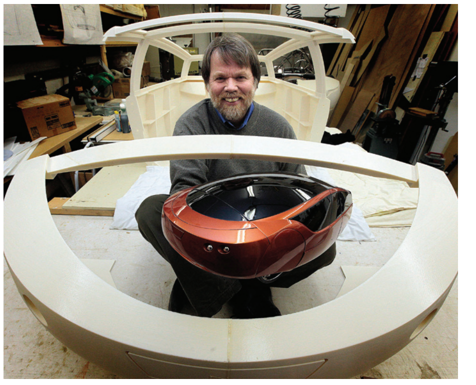




Below and right: Last year, engineers at NASA's Glenn Research Center in Cleveland, Ohio, successfully tested a 3D-printed rocket injector component using selective laser melting. The part withstood more than 9,000kg of thrust during hot-fire testing assessments

"The machine never comes back to you and says it can't make something. If that is a production machine, and you design for it, then almost anything goes"

Jim Kor, president of Kor EcoLogic



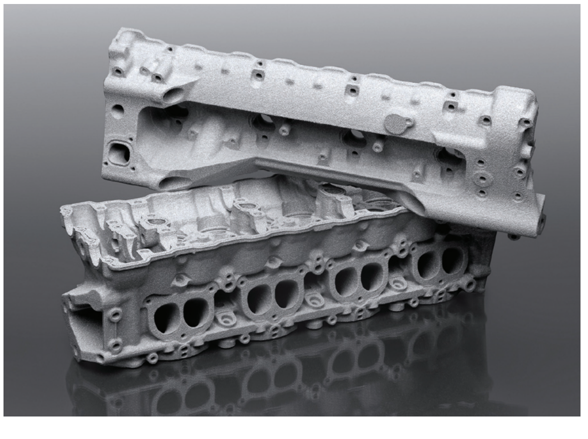
holding the technology back can be overcome, Hubbing believes the required materials are robust enough to handle the extreme temperatures generated inside IC engines. "The process that we use is fused deposition modeling. Typically, what we're using here for powertrain components is usually Ultem or PPSF plastics, which are high-temperature thermal plastics chemically resistant to solvents and oils. That means they will survive in contact with gasoline, oils and diesel fuels. Ultem goes up to about 190°C and PPSF to just over 200°C, so the material already handles the heat requirements. The powered metal parts will go well above what is required for internal engine components."

One step at a time

Yet the emergence of the world's first 3D-printed car suggests we may still see mass-produced vehicles that use 3D-printed powertrain components. The two-seater URBEE, which stands for urban electric with ethanol as back-up, is the first prototype car to have its entire body printed with an additive process. Designed by Winnipeg-based engineering group Kor Ecologic, and printed by Stratasys, URBEE's major body panels were built using acrylonitrile butadiene styrene (ABS) plastic. According to Jim Kor, president of Kor EcoLogic, and team leader of the URBEE project, the solution saved up to 10 months in comparison with traditional manufacturing methods.

Above: URBEE 2 is in the early stages of development, however the aim is to put the 7ps three-wheeled, rear-steering eco-hybrid on the road by 2015 and demonstrate its capabilities by crossing the USA using only 38 liters of fuel

Above right: Jim Kor, president of Kor EcoLogic and team leader of the URBEE project, with a downscaled model of the vehicle. The body and interior of the full-size URBEE 2 will be 3D printed on a set of Stratasys Fortus 900mc 3D production systems. The design includes more than 50 3D-printed components, which will require around 2,500 hours of work



Left: Toyota is a firm believer in the use of 3D printing for prototype development

Below: A manifold 3D printed at RedEye for the University of Minnesota's Society of Automotive Engineers' (SAE) Formula car

Although URBEE's powertain has not been manufactured using 3D printing, Kor claims that he would be more than comfortable doing so – if money weren't an issue. "When you're making an engine, you're casting it out of aluminum or another material, and there are all kinds of rules – you can't have the wall thickness vary, you've got to be able to pull the mold out, or if it's a sand molding then you've got to get the core in there. But with 3D printing, there's none of that. The machine never comes back to you and says it can't make something. If that is a production machine, and you design for it, then almost anything goes."

Having garnered much media attention, thanks to URBEE, Kor has subsequently attended a number of shows and conferences dedicated to showcasing the latest trends and advancements in additive manufacturing, and believes the technology is capable of producing engine parts in road-going light passenger vehicles. "I think the strength of the materials is there, and people are now asking how to measure 3D-printed parts and how to ensure they're all the same strength, which suggests its happening or is on the cusp of happening."

And as far as Kor is concerned, if the potential is there to use 3D printing as a way to manufacture low- or high-volume car parts in a fast, cheap and environmentally friendly way, then the technology has to be exploited to its fullest. "It will absolutely impact manufacturing. Not everything will be 3D printed, but a huge part of it might. When I hear the word 'engine' I think of complicated tooling and castings, and the technology will absolutely invade in there at some level."