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Accelerating Engineering Innovation

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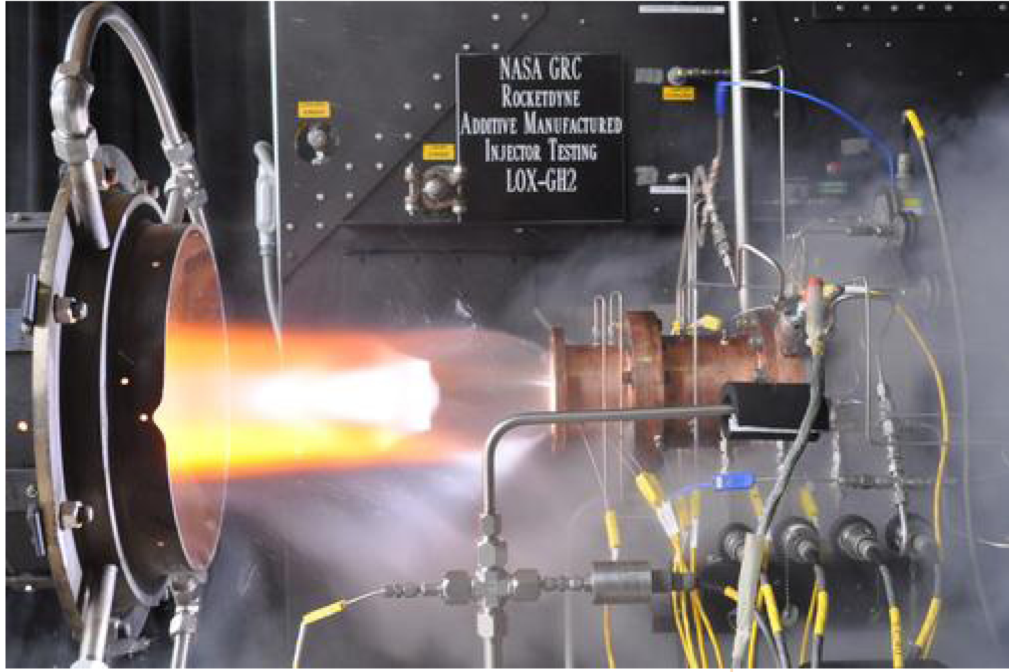

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3D Print Your Next Headphones

Rich Pell, *EDN*

These fully functional headphones were created using no manufactured parts—only 3D-printed parts and a few raw materials.

In an interesting technology demonstration, someone has created a set of headphones using no manufactured parts—just a 3D printer and a few raw materials. While the result isn't going to cause the likes of a Sennheiser or AKG Acoustics to lose any sleep anytime soon, it does hint at the amazing potential that affordable 3D printing promises to bring to end consumers.

In this case, the "Low Fi Hi Tech" headphones were created using only wire, tape, solder, magnets and of course 3D printed parts. The headphone drivers themselves were 3D printed - as thin printed parts with spiral slots in which copper wire thread was inserted - as was the headphone driver casing and headband. The latter was made using a flexible spring structured material.

In case you're thinking that the headphone's cable and connector must have been made using standard manufactured parts, think again. The cable is a **fabric conductive ribbon** from **fabrickit**. And the plug itself—designed to fit a standard 3.5mm headphone jack—is 3D printed, with wire coiled around the appropriate areas to enable a stereo connection.

Of course when it comes to audio it's all about the sound. The sound quality of these headphones is described as "very nice against all expectations," although it is noted that for portable devices a headphone amplifier may be needed.

VIDEO:
The following video (2:26) demonstrates how the 3D-printed headphones were constructed and shows them in actual use with an iPhone.

The designer of these headphones has made the files and instructions available on MakerBot Thingiverse (see **Low Fi High Tech Headphones**). For more, also see the designer's own **3D-printed headphone page**.

3D Print Your Own Personal Electronics

Ann R. Thryft, Senior Technical Editor, ***Design News***

If it's possible to 3D print **blood vessels, robots,** and guns, then why shouldn't you be able to 3D print your own personal electronics? Well, now you can—in the lab at least.

University of Warwick researchers have developed a **conductive plastic composite** material that can be used with unmodified, low-cost, hobbyist 3D printers to make functional electronic devices. The devices can even be custom-designed, such as tailoring a game controller to fit the shape of a particular user's hand.

The team, headed by Simon Leigh of the university's School of Engineering, says the inexpensive material, called "carbomorph," makes it possible to print out electronic tracks and sensors as part of a 3D-printed structure.

To date, the researchers have used

A conductive thermoplastic can be used with low-cost, hobbyist 3D printers to produce complete, customized electronic devices, such as this computer game controller. (Source: University of Warwick) the material to print objects with embedded flex sensors, such as a mug that can sense how full it is, or those with touch-sensitive buttons, such as a working computer game controller. The results were published in an **article** in the open-access journal PLOS One.

The printer can create touch-sensitive areas in the structure that can be connected to a simple, printed circuit board.

The computer game controller was printed using a Bits from Bytes BFB3000, Leigh told Design News in an email. "It's designed to interface with an Arduino board, then it can be plugged into a PC and used to play any game on your PC," he wrote. "The idea behind it is that you could in theory customize the layout of the controller hardware to your own specification."

Leigh and his team envision the technology being used to 3D print functioning electronic devices, making those devices more individualized. This could, he says, reduce electronic waste by customizing products to make them closer to what users want, and fitting their unique needs. Another application could be embedding sensors in products and monitoring how people use them, so designers could better understand how people tactilely interact with products.

The most immediate, short-term use Leigh envisions is giving the next generation of young engineers the hands-on experience of designing and producing electronic products in the classroom with advanced manufacturing technology like 3D printing. According to Leigh, existing open-source electronics and programming libraries can be used for monitoring the printed sensors.

One of the biggest advantages to 3D printing electronics is the fact that sockets for connecting the devices to equipment, such as interface electronics, could be printed out, rather than using conductive glues or paints. That's the research team's next step: to print more complex structures and electronic components, including the wires and cables that connect the 3D printed devices to computers.

Ford Builds Metal Prototypes With 3D Printing

Charles Murray, Senior Technical Editor, ***Design News***

Ford Motor Co. is raising the stakes in rapid prototyping, making testable prototype metal parts ranging from brake rotors to transmission cases with three-dimensional (3D) printers.

Using technologies such as selective laser sintering, stereolithography, and 3D sandcasting, Ford engineers say they're able to build metal parts with the same material characteristics as those that are injection molded, and then employ them as "surrogate" parts in test vehicles prior to production. Doing so enables them to eliminate the time-consuming step of building an injection molding tool, thus cutting weeks from the process.

"With these technologies, we just build a part directly from a CAD file," Harold Sears, rapid manufacturing technology specialist for Ford, told Design

Ford engineers send CAD files between facilities, then build prototypes at workstations using MakerBot Thing-O-Matic 3D printers. (Source: Ford Motor Co.)

News. “There’s no tooling needed.”

To be sure, manufacturers have used rapid prototyping techniques for more than a decade, but Ford is said to be unusual in its use of 3D printing for metal parts in test engines, transmissions, and brakes.

Prior to the advent of such techniques, manufacturers typically machined an injection mold tool before building a metal part. Doing so took time—one to two weeks for simple tools and 10 to 12 weeks for more complex ones. By eliminating the need for those tools, they can now turn around a testable metal part in days or even hours. “In the past, we might have only been making one or two parts, but we still had to make an injection mold tool for them,” Sears told us. “But with processes like laser sintering, we can now build really testable and durable parts without the tooling.”

Ford has invested in what may be one of the industry’s biggest rapid prototyping efforts. Three facilities near its Dearborn, Mich., headquarters contain selective laser sintering and stereolithography equipment, while another is dedicated to rapid sandcasting. The sandcasting facility enables printing of sand molds that can be used to create metal parts with the same material properties as production parts.

The giant automaker has employed those techniques in rotor supports, transmission cases, damper housings, and end covers for its C-Max and Fusion hybrids. Four-cylinder ECOBoost engines, Ford Explorer brake rotors, and F-150 exhaust manifolds have also been built with the technology.

Ford’s expanded use of 3D printing has also swept across its research and development facilities. Engineers often send CAD files back and forth between the company’s Silicon Valley Lab and its Dearborn facilities, then use the files to build physical prototype parts on **MakerBot Thing-O-Matic 3D printers**. By doing so, they can quickly tweak the designs of shift knobs, gauges, display modules, and other plastic parts.

“Now, at the press of a button, you can have the product or component at your fingertips,” said K. Venkatesh Prasad, senior technical leader for Ford, in a company press release.

"With a model in one hand, you can then input your changes back into the computer model."

Ford is one of many companies across numerous industries that are ratcheting up their use of rapid prototyping. **Daimler AG recently funded development** of an additive manufacturing system for use in automotive production, and **NASA has used 3D printing for making rocket engine parts**.

Ford engineers believe the trend toward rapid prototyping is still growing fast. "We're going to see more development of these materials," Sears predicts. "As the processes become more robust, they're going to allow engineers to do even more with these parts than they do today."

MIT 3D Prints Tough, Bone-Like Composite

Ann R. Thryft, Senior Technical Editor, ***Design News***

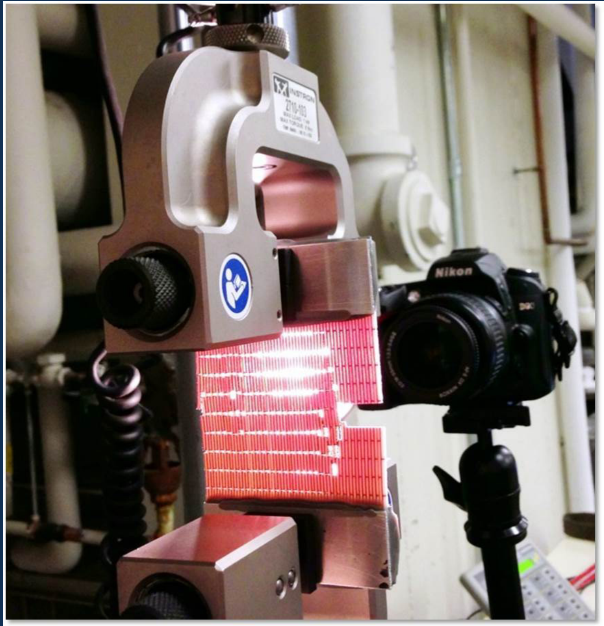
Printing composite materials from a 3D printer that engineers can actually use to build something may be closer than you think. A team at MIT has 3D printed bone-like composite materials on the **Objet Connex500** multi-material printer. But this wasn't just any old multi-material model using the Objet polymers. They were samples printed to test a computational model the engineers had created, based on three different bone-like, biological composite structures they designed.

The structure of mineralized materials such as bone itself, as well as the structure of seashells and certain marine sponges, combines soft materials with stiff materials in complex arrangements that have superior fracture mechanical properties. We've covered similar materials before, such as the **entirely new family of composites** invented by ETH-Zurich materials scientists that mimic the way an abalone shell's structure aligns strong, stiff elements within a softer matrix.

Another composite modeled after a biological original is the **complex fish scale architecture** we told you about that could be mimicked to provide flexible composites with a hard ceramic surface for applications like body armor or prosthetic devices. That architecture's very hard exterior protects a tough, flexible internal structure that helps the scales of the Amazonian Arapaima gigas fish resist razor-sharp piranha teeth.

But using a 3D printer to print out test samples for verifying the models is a new idea. The MIT team, led by professor of civil and environmental engineering Markus Buehler, designed three different synthetic composite materials that emulate bone, bio-calcite, and a rotated bone-like geometry. All of them take advantage of the combination of stiff and soft materials typically found in composite structures, but their topologies vary. One of the project's main objectives is to show that it's possible to design materials that have specifically tailored fracture mechanical properties, using computational models, and then make those materials using 3D printing.

Click on the photo to view an image gallery.



In an **article** published in Advanced Functional Materials (purchase or subscription only), Buehler and his group describe their work and the results of the tests on the samples printed on Stratasys's Objet Connex500 printer. First the team tested the two photopolymers—the stiff Vero White Plus and the softer Tango Black Plus—for their individual fracture response. Next, the team printed out samples of the three different materials. The deformation and fracture mechanisms of each material sample was then tested against its corresponding simulation.

Like the Amazonian fish scale architecture or abalone shell structure, the arrangement of stiff and soft materials in a hierarchical pattern in these synthetic composites dissipates energy and distributes damage over a larger area when struck. This helps the material suffer less damage from a fracture, instead of experiencing a single point of failure, since the cracks are more likely to propagate through the soft material, not the hard material that forms the object's structure.

MIT's test results showed that the fracture patterns of the bone-like material and the material with a rotated bone-like geometry performed as expected based on the computational models. The bio-calcite material was not replicated accurately during 3D printing. Increasing the feature size during printing is one way this could be addressed, the researchers wrote. Like the others, though, it performed better than its constituent materials alone.

As predicted by the simulation, the bone-like material's geometry has by far the toughest topology of the three: This material's toughness modulus is more than 20 times that of its constituent materials. The researchers conclude the article by saying their work "can potentially pave the way for more refined computational models able to predict the response of 3D-printed systems with higher accuracy as well as more complex 3D-printed structures with further improved mechanical properties."

Other members of the team that co-authored the article are graduate students Leon Dimas and Graham Bratzel, and Ido Eylon of Stratasys. The US Army Research Office provided funding.

Trek accelerates design cycles with Objet 3D Printer

The fact that we were able to print multiple iterations quickly enabled the designers to experiment more and still make all their deadlines."
—Mike Zeigle, Manager of Trek's Prototype Development Groups Prototype

Award-winning bicycle manufacturer now produces 4x as many prototypes as before while speeding time to market

Trek was founded in 1976 with a simple mission: Build the best bikes in the world. The company has won multiple awards for design and innovation. Mike Zeigle is the Manager of Trek's Prototype Development Group, a group of nine pros with a number of tools at their disposal. It includes a machine shop with five CNC machining centers, a full metal fabrication/welding shop, and for a number of years, service bureaus to whom they outsourced their SLA jobs.

Prototyping plays a crucial role in all phases of Trek's product development cycles. Industrial designers, mechanical

engineers, graphic artists and marketing staff all utilize prototypes, so Zeigle's staff of programmers, machinists and welders keeps busy. In most cases, they are prototyping bike parts, but occasionally they also prototype tooling mockups and related accessories such as shoes and helmets.

When Trek's annual costs for service bureaus reached $275,000, Trek's Engineering and Design Manager decided it was time to consider purchasing an in-house rapid prototyping system, and asked Zeigle to come up with some options. Initially, he researched only SLA, SD and FDM tools. He quickly narrowed the field down to SLA, but still had concerns about the machines' cost, space and maintenance requirements. Then a colleague suggested the Objet Connex500 3D Printing System, a clean, office-friendly machine that produces parts that rival those made with SLA in terms of quality and finish.

Unlike the other technologies Zeigle considered, the Objet Connex offers the unique ability to print parts and assemblies made of multiple model materials, with different mechanical or physical properties, all in a single build. Parts produced on the Objet Connex have smooth and durable surfaces, with exceptionally fine details. The system can print living hinges, soft touch parts and overmolds that other technologies are incapable of prototyping. The superior productivity, high quality output and unique multi-material printing capabilities of the Objet Connex enable users to closely emulate the look, feel and function of an exceptionally wide variety of end products.

According to Zeigle, the fact that the Objet Connex could jet digital materials – meaning, mix two materials together in order to increase durometers – was a key selling point, as was the Objet Connex's ability to combine two materials in one part. "The Objet Connex was the only rapid prototyping machine we evaluated that would allow us to do one build with multiple materials and durometers," says Zeigle.

"You can't do that with SLA or other brands of 3D printers, and it really sold us. The Objet Connex changed my perception of 3D printing."

Zeigle and his team were also impressed with the quality of the parts produced on the Objet Connex. "The part quality and finish of the Objet Connex are as good as the SLA parts we used to get from our service bureau," he says. "And we can have a part in just a few hours, versus several days and lots of paperwork when we had to outsource."

Objet Connex enables breakthrough design for new Speed Concept bike

Zeigle's team uses its Objet Connex printer for virtually every bike Trek produces. Most recently, it played a key role in the company's launch of its new Speed Concept 9 Series bike —a time-trial bike used in the Tour de France and Iron Man Hawaii. Its unique frame design features aerodynamic cross-sections that lower wind resistance and improve speed. Virtually every part of the new design was prototyped on the Objet Connex and then shipped from Trek's Wisconsin headquarters out to a California facility for wind-tunnel testing – where sample frames would be tested at wind speeds of 30MPH or more.

"The designers had several ideas for the aerodynamic cross-section design in particular, and wanted to see the impact on wind resistance," explains Zeigle. "So we printed out multiple parts on the Objet Connex that they could snap onto the main bike frame and then test in the wind tunnel." The team even produced durable accessories such as water bottles and bento boxes

on the Objet Connex, to make the testing conditions more realistic.

"The fact that we were able to print multiple iterations quickly enabled the designers to experiment more and still make all their deadlines," explains Zeigle. The end result represented a true breakthrough in bike design called the Kamtail Virtual Foil that's garnered major media attention.

Prior to having its Objet Connex, the

→ Click here to view a video about how Trek accomplished their goals with the Objet Connex500 3D Printing System

Trek team would have produced prototype parts out of aluminum or dense foam using CNC processes in its machine shop and mixed them with SLA parts outsourced to a service bureau. The time frame, says Zeigle, would have been quite different, as it can take a week or more to get a CNC part and several days to get an SLA part. By contrast, lead time for a part made in house on the Objet 3D Printer is usually less than one day. Lupe Ollarzabal, the engineer who runs Trek's Objet Connex printer, says that having the Objet Connex in house has made a big impact on Trek's productivity. "Our Objet Connex enables us to either get a new product to market quicker, or to get a better product to market on time—and in many cases, it's both," says Ollarzabal – whom Zeigle describes as the "go-to guy" for designers who need a prototype part immediately. "Either way, we win and so do our customers. If we're crunched for time, it really helps us."

Trek's designers are thrilled with the Objet Connex—instead of waiting days or weeks for their prototypes, they can now hold a part in their hands in as little as 30 minutes. They are also prototyping a lot more frequently. "75 percent of the prototypes we create are things we never would have prototyped before," says Zeigle. "When we outsourced or had to rely on our in-house milling operation, it was just too expensive and time-consuming to do a lot of prototyping." Zeigle notes that the Objet Connex has also helped significantly reduce tooling mistakes that can add weeks or months to a product launch schedule.

Today, says Zeigle, Trek's Objet Connex printer runs almost continuously. "At first, we had one part time person who ran our Objet 3D Printer," he recalls. "Within six months, as designers starting prototyping more, it became a full-time job. If we get any busier, we will be at the point where we'll need to add a shift or purchase another Objet Connex, maybe both. Our current machine runs all day long, all week long, and sometimes into the weekend."

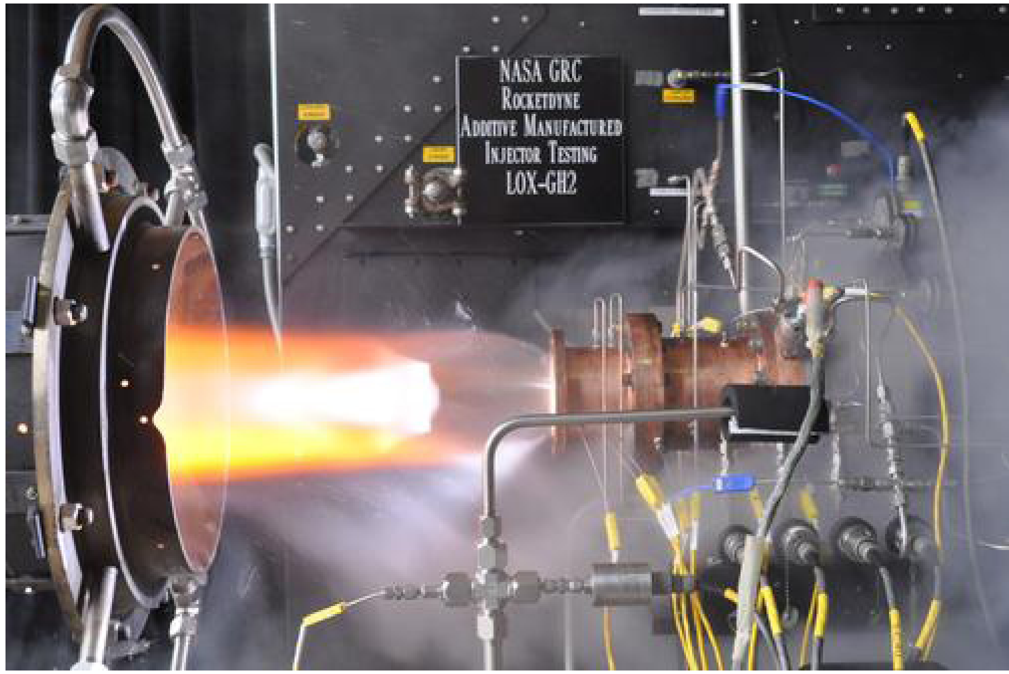
Stratasys's service has been excellent, says Zeigle, adding, "I wish all of our vendors were as responsive as Stratasys. On a scale of 1 to 10, they're a 10.

NASA Tests 3D-Printed Rocket Engine Part

Ann R. Thryft, Senior Technical Editor, ***Design News***

NASA and Aerojet Rocketdyne have completed **hot-fire tests** on a 3D-printed rocket injector assembly. The liquid-oxygen/gaseous hydrogen rocket injector assembly was built with a selective laser melting (SLM) process that uses high-powered laser beams to fuse powdered metals.

The tests were done at NASA's Glenn Research Center. Aerojet Rocketdyne, which produces propulsion systems, missiles, and launch vehicles, provided data about material design and the addi-



NASA and Aerojet Rocketdyne have completed hot-fire tests on a rocket injector assembly made with a selective laser melting 3D printing process and powdered metals.
(Source: NASA Glenn Research Center)

tive manufacturing (AM) process for the hot-fire tests to ensure reliability and safety. The manufacturer's engineers designed the injector as part of an effort to save costs by reducing the manufacturing lead times for complex rocket engine components. The injector can be produced in about four months, instead of more than a year using traditional manufacturing methods.

Aerojet Rocketdyne said in a **press release** that it's pursuing methods for achieving an integrated AM process, along with related analysis and design tools and component technologies, to make it possible to manufacture rocket engine components with SLM. The successful testing of the rocket injector was a first step in making this possible. Future steps will include scaling up the process and establishing production requirements. The company says on **its website** that it's also involved in developing new materials (including metallics), AM techniques, and powder metal technologies.

We've discussed several NASA 3D printing ventures previously. A program at the agency's Marshall Space Flight Center uses an SLM process to make **metal engine parts** for the Space Launch System, a next-generation heavy-lift rocket. The parts are being built with Concept Laser's M2 Cusing machine and powdered metals. Another NASA project aims to give astronauts quick access to tools, replacement parts, and instruments. The agency partnered with Made in Space to develop a **3D printer astronauts can use** on the International Space Station.

Aircraft engine makers are pursuing their own R&D projects. GE Aviation is using direct metal laser melting AM techniques to make production components for some of its engines. It expects new **in-process inspection technology** it is co-developing with Sigma Labs to reduce AM times and help assure build quality and repeatability. Pratt & Whitney has **opened its own lab** at the University of Connecticut to advance R&D for the AM processes that produce metal aircraft engine parts.

If the 3D printing of metal end-use production parts becomes integrated into regular manufacturing flows, it may happen first in aerospace. Manufacturing tends to involve low volumes and very high performance requirements. That means multiple iterations, which AM makes especially easy. And the **National Additive Manufacturing Innovation Institute** was launched to help revitalize research in areas like defense and aerospace.

National Additive Manufacturing Institute Funds First Projects

Ann R. Thryft, Senior Technical Editor, ***Design News***

The federally funded **National Additive Manufacturing Innovation Institute (NAMII)** has awarded funds to its first member projects in applied R&D. The seven projects include several different additive manufacturing (AM) processes and both metal and polymer materials.

Founded in August last year, NAMII is the first of 15 planned centers of excellence aimed at revitalizing US manufacturing in the defense, energy, space, and commercial sectors. As key components in the Obama administration's billiondollar National Network for Manufacturing Innovation (NNMI), the institutes are intended to encourage investment in US companies, and make US manufacturers more competitive. NAMII's formation highlights the fact that 3D printing and AM are now seen as major contributors to US economic health, as does the fact that they were featured in President Obama's **state of the union address** last month.

Centered in Youngstown, Ohio, NAMII is paying $4.5 million for about half of the projects' total costs, while members and their partners are contributing $5 million. Funds were awarded to proposals submitted in response to the institute's Project Call made last November at the Defense Manufacturing Conference in Orlando, Fla. Proposals had to target at least one of three technical topic areas: materials understanding and performance; qualification and certification; and process capability and characterization/process control.

Paramount Industries/3D Systems, Stratasys, and ExOne were listed among the 40 original member companies. Although none of them were mentioned in the list of winning project descriptions, three of the projects mention technologies specific to Stratasys: fused depositing modeling (FDM) and the high-temperature material ULTEM 9085.

Both of these technologies are featured in the winning project, "Maturation of Fused Depositing Modeling (FDM) Component Manufacturing," which includes small business part producer Rapid Prototype + Manufacturing LLC, the University of Dayton Research Institute, equipment manufacturers,

The National Additive Manufacturing Innovation Institute has funded its first projects. Three of the seven feature Stratasys' high-temperature ULTEM 9085 thermoplastic and its Fused Deposition Modeling (FDM) process, which Minimizer uses to produce truck fender prototypes.

(Source: Minimizer)

and system integrators. It will look at ULTEM 9085's properties, with the aim of providing a design guide, data about critical materials and processing, and certification for machines, materials, parts, and processes.

Both technologies are also mentioned in two related winning projects headed by Northrop Grumman Aerospace Systems and Missouri University of Science and Technology: "Sparse-Build Rapid Tooling by Fused Depositing Modeling (FDM) for Composite Manufacturing and Hydroforming" and "Fused Depositing Modeling (FDM) for Complex Composites Tooling." Other partners include the Robert C. Byrd Institute's Composite Center of Excellence. Both projects aim at producing tooling quickly and cost-effectively for manufacturing composites. Although ULTEM 9085 is mentioned, its role in both projects is not clear.

Interestingly, Stratasys has **already pioneered** the idea of using AM technologies for making carbon composites in aerospace applications in its joint work with Oak Ridge National Laboratory. That partnership aims to develop a process based on Stratasys' FDM for making production volumes of carbon fiber composite components entirely out of autoclave. Its goals are to develop carbon fiber-reinforced feedstocks for FDM, and in-process inspection methods for assuring quality of the parts created.

Another winning project led by Northrop Grumman is "Maturation of High-Temperature Selective Laser Sintering (SLS) Technologies and Infrastructure," which will focus on developing an SLS process that can manufacture air and space vehicle components from a lower-cost, high-temperature thermoplastic. The project will also explore materials recyclability and reuse.

Along with Arcam's Electron Beam Melting (EBM) process, EOS's direct laser sintering (DLS) process is featured in "Rapid Qualification Methods for Powder Bed Direct Metal Additive Manufacturing Processes," led by Case Western Reserve University. This project will target greater understanding and control of mechanical properties and microstructure in both of these powder bed metal processes, as well as process-based cost modeling for different production volumes.

Another project led by Case Western Reserve University is "Qualification of Additive Manufacturing Processes and Procedures for Repurposing and Rejuvenation of Tooling." The university will partner with the North American Die Casting Association, die casters, computer modelers, and several additive manufacturers to come up with and qualify methods for repairing and repurposing tools and dies using AM.

"Thermal Imaging for Process Monitoring and Control of Additive Manufacturing" led by Penn State University will look at thermal imaging as a method for providing process monitoring and control in two AM processes: electron beam direct manufacturing (EBDM) and laser engineered net shaping (LENS).

The seven projects were the ones among the many proposals submitted that "detailed highly innovative additive manufacturing project ideas, featuring applied research and development, efficient use of digital data, high sustainability, and aggressive education outreach and workforce training plans," said Ed Morris, NAMII director and NCDMM vice president, in a **press release**.

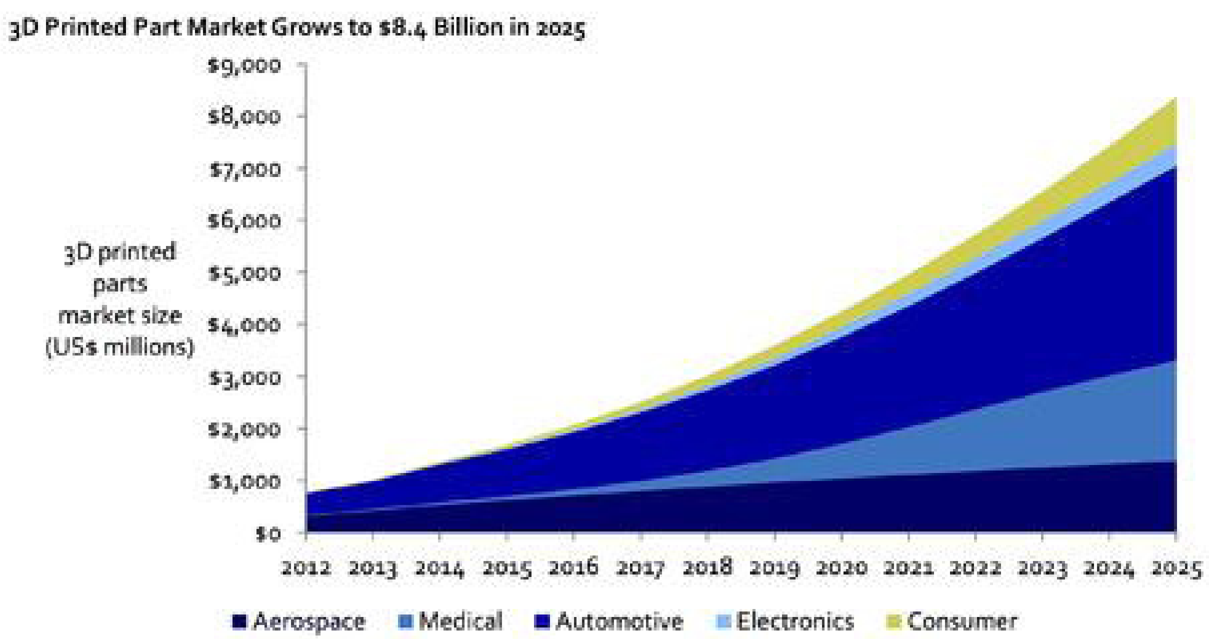
More details on the winning projects will be available after project kickoff meetings at NAMII on April 2 and 3. The projects span a range of technologies but appear to be focused on fine-tuning existing AM processes for a variety of different goals. This makes sense for the early stages of what is, in effect, a government-organized industry association. It will be especially interesting to find out what other 3D printing and AM manufacturers are involved, as well as which OEM manufacturers

The next project call will be announced during the **RAPID 2013** Conference and Exposition, June 10 to 13 in Pittsburgh, Pa. Any organization can respond to the project call if partnered with a member of NAMII on the proposed project and if that member submits the proposal. NAMII members include industry, universities and community colleges, non-profit organizations, and federal and state agencies.

Report: 3D Printing Will (Eventually) Transform Manufacturing

Ann R. Thryft, Senior Technical Editor, ***Design News***

Additive manufacturing (AM), including 3D printing, has the potential to upend manufacturing supply chains, according to the new report from Lux Research, "Building the Future: Assessing 3D Printing's Opportunities and Challenges." The catch is, it will take a while, and the results will depend on how quickly costs come



Although consumer applications have gotten a lot of attention, these will remain a small portion of the 3D printed parts market. By 2025, prototypes and production parts for automotive, medical, and aerospace segments combined will represent 84 percent of the entire market.
(Source: Lux Research)

down, and throughput goes up.

Although consumer applications—such as custom jewelry, toys, and art—have gotten a lot of attention, consumer products will remain a small portion of the 3D-printed parts market, Anthony Vicari, Lux Research associate and the lead author of the report, told Design News. These will grow $17 million from 2012's $777 million total to $894 million in 2025, when the total market value reaches $8.4 billion. Between now and then, the overall market will grow at an aggressive 18 percent per year.

Both prototypes and production parts for automotive, medical, and aerospace segments will represent 84 percent of the entire market by 2025. Today, prototypes represent about 90 percent of uses, and most of the major aerospace and automotive OEMs have some kind of 3D printing division to make prototypes in-house, said Vicari. By 2025, though, this proportion will drop to 47 percent.

The big growth will be in small-volume manufacturing, led by **automobile parts** and **aerospace engines**; this will jump from $1 million in 2012 to $1.1 billion in 2025. The production parts that will be most amenable to adoption of 3D printing will be those that need a lot of customization, don't require high volumes, and are somewhat less cost sensitive.

The report looked at nine different 3D printing technologies: stereolithography (SLA), selective laser sintering (SLS), selective heat sintering, powder bed inkjet printing, fused filament fabrication, polyjet, digital light processing, laminated object manufacturing, and electron beam melting. It did not include related technologies such as CNC milling or metal injection molding (MIM).

Although the $11 million medical 3D printing sector is small, it's growing fast, and will become $1.9 billion by 2025. Prices will drop for printers such as Stratasys's **Objet30 OrthoDesk** for dental devices, as well as for materials and scanning technologies.

Before the shift can happen to a majority of production parts in aerospace, automotive, and medical, the report concludes that several other changes must occur, primarily a rise in throughput and a drop in costs. “Currently, throughput is good for 1 to 10 pieces, but once you need to make more than few hundred or even thousand pieces of a part, 3D printing is not likely to be the most affordable way to manufacture something,” Vicari told us.

Methods for increasing throughput vary by specific 3D printing technology. For example, just increasing the build chamber and the number of nozzles only gets you so far, since the process is still limited by the time it takes to deposit the material. There’s been relatively limited development in machine throughput in recent years, perhaps because of the tradeoffs between throughput and minimum resolution. That’s why the report concludes 3D printing is not likely to penetrate the high-volume manufacturing segment.

The lack of improvement in throughput places even more pressure on manufacturers to reduce the cost of materials, which are highly specific to each machine. “Materials are being sold at very high margins right now,” said Vicari, “so there’s a market for independent material suppliers.”

Many different types of materials are involved in each printer’s materials set; for instance, various additives for polymers to control melting temperature and flexibility. For metals, this is less true, but they still require custom development.

Even so, printer companies are only offering a few materials with their machines, compared to what’s potentially available. By 2025, there will probably be a more open market with third-party materials suppliers selling many more materials choices. Meanwhile, some 3D printer companies, especially smaller and newer ones, are partnering with materials companies.

Users of printers often don’t have access to controls, like modifying the chamber temperature for a given material. But once these machines move into production, not prototyping, where every large company has their own process engineers, these customers will want to have more control over the process and the materials, said Vicari.

Business relationships and business models will also change. For example, last November, Morris Technologies, a service bureau that worked primarily with aerospace engine components, was **acquired by GE Aviation**, which makes aircraft, military, and marine engines.

This makes me wonder whether more aerospace companies might adopt 3D printing and other AM techniques by outright acquisition, instead of investment or monetary support of various kinds, such as **Lockheed's partnership with Sciaky**. I also wonder whether machines and materials sets will become more customized for first, specific markets, and second, for individual, very large OEMs.

Seismic Shifts in the 3D Printing Industry

Ann R. Thryft, Senior Technical Editor, ***Design News***

A Lux Research study **we reported** on a few months ago regarding the future of 3D printing and additive manufacturing (AM) suggested that business relationships among the makers of AM machines and their users will need to change. As the larger OEMs bring these technologies inside and want greater control over processes and materials, we speculated that some with specialized requirements might try to acquire 3D printing/AM companies, and invest in them as well.

That hasn't happened yet, although we have seen industry/university R&D partnerships between aircraft-engine-maker **Pratt & Whitney** and the University of Connecticut to develop processes and materials, and between **Optomec** and the University of Pittsburgh to train next-generation engineers in AM. I still think major-manufacturer ownership of 3D printing technology or materials is coming eventually.

But some other interesting developments have happened, and more are on the horizon.

In June, **Stratasys**, the high-end inventor of fused deposition modeling (FDM) techniques bought MakerBot, the low-end maker of desktop machines that use FDM. A few weeks ago, **3D Systems** acquired Phenix Systems, makers of equipment for direct laser sintering with metals and ceramics. Both purchases represent two ends of the industry coming together in ways that they haven't before, in terms of materials, users, or applications.

Will further consolidation happen? Probably. 3D Systems is already known for acquiring technology and markets by buying other companies, so this isn't new for the company. Stratasys has also made a few purchases in the last couple of years. Connecting the high-end metals part of the industry with the medium-to-high end of the industry that works only in plastics is a major change, as is merging the leading desktop 3D printer maker with one of the high-end 3D printer makers. I think there will be more partnerships or acquisitions, or both, as this industry continues to grow.

That's not all. Microsoft **said** in June that the Windows 8.1 update will have built-in support for desktop 3D printing via an SDK. The partners it mentions as helping to make this possible include 3D Systems, Autodesk, Dassault, Formlabs, MakerBot, and Stratasys, among others. 3D Systems was the first to demonstrate a printer driver for Windows 8.1, for its Cube 3D printer, at Microsoft's Build 2013 developer conference.

I think this development is huge —much bigger than Staples offering 3D printing services or Amazon selling 3D printers and supplies -- and at least as huge as the two consolidations we just mentioned. Giving engineers the ability to use their PCs to print out objects as easily as they do word processing documents (notice I didn't say design as easily) could be a sea change bigger than when desktop computers got direct access to 2D printers. Does anyone else remember waiting in line for the old printer server?

Self-Assembly Meets 3D Printing

Ann R. Thryft, Senior Technical Editor, ***Design News***

Two technologies at the edges of manufacturing are on the verge of coming together: self-assembly and 3D printing. In a recent talk given at the **2013 TED conference**, Skylar Tibbits, an MIT faculty member in architecture, demonstrated a new material and process that results in a 3D-printed object self-assembling underwater.

The new technology is a combination of Tibbits' process with Stratasys' materials and its **Objet Connex 500 Multi Materials** inkjet 3D printer, Daniel Dikovsky, digital materials team leader for Stratasys, told Design News. The idea for the material came when Dikovsky and Tibbits discussed Tibbits' self-assembly projects, which he had been activating via mechanical energy.

The material is a combination of two acrylic polymers, one water expandable and one an existing, static Vero black already used with the Connex 500 multi-material printer. “The combined material acts as a source of energy when placed in water, but it also serves as an actuator,” Dikovsky told us. “When exposed to water, it absorbs water, expands, and changes its dimensions.”

When exposed separately to water, the water-expandable material only expands and does not change its form, and the static material does not change at all. When they’re combined, the geometry of the 3D printed shape can be programmed to change form in predictable ways. You can watch a video **here** showing a cube shape self-assembling in water from a strand of the new combined material.

The key is in how they are programmed and combined at the particle level, which in the Objet Connex 500 is a very small 80-picoliter (80-nanogram) drop. These printers 3D print multiple materials, each a custom blend created from two out of several possible base materials. They are combined during printing from two separate cartridges. The mix is determined by a jetting pattern based on a software algorithm that integrates them in specific, programmed mixes to achieve certain thermal and mechanical properties.

Different combinations can be placed in different parts of the 3D model to provide varying degrees of hardness, flexibility, or thermal resistance.

In the MIT/Stratasys project, Tibbits used Autodesk Cyborg, and Objet used VoxCad simulation tools to predict the behavior of multi-material structures, including where to use the expanding material. VoxCad predicts the behavior of small structures, the links programmed to bend when exposed to water, and Cyborg predicts the behavior of the overall structure formed of those links, said Dikovsky.

Tibbits is the director of MIT’s new **Self-Assembly Lab,** which will develop the new technology jointly with Stratasys. Although the video of Tibbits’ 2013 TED Talk was not online at press time, the video of a 2011 TED Talk Tibbits gave on self-assembly of furniture and buildings can be found **here**. In this video, he says MIT researchers have worked on a MacroBot and a DeciBot, which are large-scale, 8-ft- and 12-ft-long reconfigurable robots made of mechanical and electronic components.

The energy required to initiate self-assembly in the MIT/Stratasys project comes from interactions of the water molecules with the molecules of the water-expanding material, said Dikovksy. Other energy sources could include humidity, sound, heat, or vibration. But before that, the next step could be generating energy by removing water, which will make the structure contract instead of expand.

In an **interview** on the TED blog about his 2013 TED Talk, Tibbits says potential applications for the technology are space systems that expand and self-assemble in orbit, activated by changes in pressure, temperature, or light.

Self-assembly of artificial systems is not a new idea. It's being pursued at the nano-level, using carbon nanotubes and organic or engineered DNA, as well as various methods for modular, self-reconfigurable robots.

We've covered mechanical, self-assembling robots such as the **Smart Pebbles** robotic cubes built by a team in the Distributed Robotics Laboratory (DRL) of MIT's Computer Science and Artificial Intelligence Lab (CSAIL). At the nano-device level, we've reported on synthetic DNA strands programmed to self-assemble into **2D tiles**, and more recently, into 3D bricks, by researchers at Harvard's Wyss Institute for Biologically Inspired Engineering.

Many of the developments in robotics are actually aimed at product manufacturing: The idea is to use robotic modules to make rapid prototypes, self-repairing systems, replacement parts for other systems, and self-reconfiguring systems like furniture that changes from a chair into a table. Adding expandable, programmable materials and 3D printing to this mix will give the development of this rapidly-changing field a big boost.

UK Elementary Students to Study Robotics, 3D Printing & Laser-Cutting —What About the US?

Carolyn Mathas, *EE Times*

I just read that, under a new national curriculum, students in the UK as young as five will study robotics, 3D printing, programming, and laser-cutting technologies. Why? The UK is putting muscle behind the desire to have more students study engineering, construction, and manufacturing. Addressing a 100,000 shortfall annually of math, science, technology, and engineering graduates, the new classes will replace such life skills classes as sewing and bicycle riding.

This makes sense (not just dropping the sewing and bicycle riding). Like any language, technology is best learned early in life -- just watching children with an iPad, smartphone, and computer is proof enough for me.

So, prompted by the new curriculum story in the UK, I began nosing around to see where we stand in the United States for this age group, and what is being done at what age to encourage children to study math, science, and engineering.

One study conducted by the National Center for Education Studies, their "Trends in International Mathematics and Science Study," compares 4th to 8th grade students in the US with other countries. The last year that data was collected was 2011, and the next report is scheduled for 2015.

Here are some highlights for the US in mathematics at grades 4 and 8 from the 2011 study:

4th grade

- In 2011, the average math score of the 4th graders was higher than the international TIMSS scale average, which is set at 500.
- The US is among the top 15 education systems in math (eight systems had higher averages and six were not measurably different) and the US scored higher on average than 42 education systems. The eight systems above the US include: Singapore, Korea, Hong Kong-CHN, Chinese Taipei-CHN, Japan, Northern Ireland-GBR, North Carolina, and Belgium.

(I'm not sure why individual states were called out in this study, as I would think they are part of the US score.)

What is interesting in the study's look at changes in scores over time are these statements:

- Compared with 1995, the US average math score at grade 4 was 23 points higher in 2011
- Compared with 2007 the US average math score at grade 4 was 12 score points higher in 2011.

8th grade

Comparisons of the math achievement of 8th graders in 2011 were made among 56 countries and education systems.

- In 2011, the average math score of US 8th graders was higher than the international scale average, set at 500.
- At grade 8, the US is among the top 24 education systems in math—11 systems had higher averages and 12

were not measurably different -- and scored higher on average than 32 education systems. The 11 systems with scores above the US were Korea, Singapore, Chinese Taipei, Hong Kong, Japan, Massachusetts, Minnesota, the Russian Federation, North Carolina, Quebec-CAN and Indiana.

In this case, changes in average scores over time note that compared with 1995, the US average math score at grade 8 was 17 score points higher in 2011, and there was no measurable difference between the US average math score at grade 8 in 2007.

Science achievement: 4th grade

Comparisons of the science achievement of 4th graders in 2011 were

made among 57 countries and education systems.

- In 2011, the average science score of US 4th graders was higher than the international TIMSS scale average, which is set at 500.
- At grade 4, the United States was among the top 10 education systems in science (six education systems had higher averages, and three were not measurably different) and scored higher, on average, than 47 education systems.
- The six education systems with average science scores above the US were Korea, Singapore, Finland, Japan, the Russian Federation, and Chinese Taipei-CHN.

Changes over time:

- There was no measurable difference between the US average science score at grade 4 in 1995 (542) and in 2011 (544).
- There was no measurable difference between the US average science score at grade 4 in 2007 (539) and in 2011 (544).

Competitively, the percentage of US 4th graders performing at or above the Advanced international science benchmark in 2011 was lower than three other education systems, was not different than six other education systems, and was higher than 47 other education systems.

8th grade

Comparisons of the science achievement of 8th graders in 2011 were made among 56 countries and education systems.

- In 2011, the average science score of US 8th graders (525) was higher than the TIMSS scale average, which is set at 500.
- At grade 8, the United States was among the top 23 education systems in science (12 education systems had higher averages and 10 were not measurably different) and scored higher, on average, than 33 education systems. The 12 education systems with average science scores above the US score were Singapore, Massachusetts-USA, Chinese Taipei-CHN, Korea, Japan, Minnesota-USA, Finland, Alberta-CAN, Slovenia, the Russian Federation, Colorado-USA, and Hong Kong-CHN.

Changes over time:

- Compared with 1995, the US average science score at grade 8 was 12 score points higher in 2011.
- There was no measurable difference between the US average science score at grade 8 in 2007 (520) and in 2011 (525).

Competitively, the percentage of 8th grade students performing at or above the Advanced international science benchmark in 2011: Twelve education systems scored higher than the US, 10 education systems were no different than the US, and 33 education systems scored lower.

More than 60 countries and education systems participated in this study. In the US, more than 20,000 students from more than 1,000 schools took the assessment, and 500,000 students worldwide participated.

I'm going out on a limb here, but I question what the word proficiency means from country to country. Having had two sets of children (but that's another blog for another site), I was frankly appalled at what was called "proficiency." For example, in the California high school exit test. I believe "proficiency" enough to graduate equated to an 8th grade education (not an 8th grade education decades ago, but one today).

Why are we expecting kids to get into college and study challenging subjects when they're closer to functionally illiterate than college material? When studies like the one above put the US doing better compared to 1995, all I have to say is that when you dumb down a system enough, of course it will look better. And when there's no appreciable difference over the last several years in scores, it seems we might not yet have dropped the bicycle riding and sewing-level classes. We surely haven't put in place exciting and motivating classes designed to capture these minds.

This subject is obviously a sore point with me. I consistently see articles on how we can get college level students to study math and science in our universities. I also see articles on bringing manufacturing back to the US. How? Interest doesn't start at the college level. And, until we stop dumbing down our education system here, I think we'll continue to drop shamefully in rank—and then gloss over it in these kinds of studies.