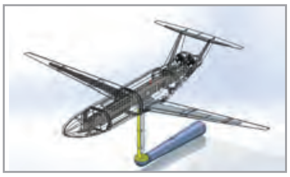

3D Printing Goes BIG

Stratasys®

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Technology for Optimal Design Engineering

The benefits of large-scale 3D printing is explained in this video.

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welcome

Bigger is Better

A majortiy of design engineers (61%) cited build volume/size as an extrmely/very important capability to consider in a 3D printing solution, according the "The State of the 3D Printing Market," a research paper based on survey results compiled by Peerless Research Group and *Desktop Engineering* on behalf of Stratasys. That's because larger build envelopes don't just mean all the benefits of 3D printing can be brought to larger prototypes and end-use parts, larger build envelopes also mean a greater number of smaller parts can be produced in less time.

But not everyone is aware of advances in the 3D printing industry that allow for larger build volumes. When asked about their perceived challenges/obstacles to using 3D printing, almost half (44%) of respondents cited print speeds and nearly a third (32%) cited build volume/sizes. Download the full research paper here.

The good news is that print volumes are indeed getting larger and larger. In the following pages, you'll find examples of how manufacturers are using large-volume 3D printing to speed testing, create more parts faster, build full-sized prototypes of cars and motorcycles, and even produce full-scale, running automobiles. Read on to learn how 3D printing size and speed challenges are being met.

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3D Printing Goes Big

Larger prints speed throughput along new paths of innovation.

By Brian Albright

The use of 3D printers in design processes has made it possible for engineers to quickly create models, molds, prototypes and even final end-use products at a relatively low cost and with multiple iterations. Many engineers, however, still work under the perception that 3D printing only has utility for creating smaller objects.

That was true in the past, but researchers, engineers and 3D printer manufacturers have continued to expand the potential build envelopes of these systems to the point that it is possible to not only print much larger objects, but also print large components and assemble everything from furniture to automobiles.

"These types of printing systems make it possible to print large car parts, such as one-to-one prototypes of dashboards, grills, rims, etc," says Mac Cameron, applications engineer at Stratasys. "You can also create large flat parts such as car mats, topographical maps, and large housings. Also this allows customers to print large mixed trays of big and small parts very quickly."

While printing an entire car is not necessarily an economically viable approach for large-scale production (yet), the concepts behind these big printing demonstrations can provide real operational improvements for designers in many industries right now. The availability of printing systems with large build envelopes makes it possible to produce much larger numbers of small parts, and to consolidate complex assemblies

The Objet1000 Plus has a 39.3x31.4x19.5-in. build tray.
Image courtesy of Stratasys Direct Manufacturing

into single print jobs. This not only creates new efficiencies, but also makes it possible for engineers to approach these designs unencumbered by the limitations of traditional production methods.

Printing Solutions for Big Jobs

Key to enabling these applications will be large-build printing solutions like the Stratasys Objet1000 Plus, the largest multi-material 3D printer on the market. The printer has a build tray measuring 39.3x31.4x19.5 in. (1000x800x500 mm), which can streamline production of 1:1 models, patterns, molds, fixtures and other manufacturing tools. It provides a resin capacity of 18kg in each of its six cartridges, and a high printing speed with no trade off in quality — it's 3% faster than Stratasys' previous model (the Objet1000) and produces 25% less waste.

The Objet1000 Plus offers Connex multi-material 3D printing capabilities to efficiently produce parts with diverse material properties; it can combine as many as 14 material properties in a single job, and is compatible with more than 100 Stratasys rigid opaque, rubber-like, transparent, and simulated polypropylene materials, as well as digital ABS and digital ABS2, rubber-like blends and other materials. It can be used for long, unattended jobs and produce cured parts directly off the printer.

With such a solution, engineers can print complete prototypes out of multiple materials, and generate fixtures as large as 1 meter long. What this means for designers is that not only is it possible to print large parts and products, but there are also opportunities to create even larger items, and to simplify the production of complex assemblies.

This type of large capacity 3D printing system is ideal for the automotive and aerospace markets because of the printer's ability to create large prototypes. Service bureaus and high-end or small- and mid-sized businesses can also use these systems to address multiple production challenges.

A fully functional motorcycle 3D printed via Fused Deposition Modeling. *Image courtesy of TE Connectivity.*

In fact, the large build envelope of the Objet1000 Plus is an effective solution for prototyping, jigs and fixtures, one-to-one scaled parts, high throughput applications, master patterns, surrogate parts, and orthopedic or orthotic production.

Complex Part Consolidation

In industries like automotive, aerospace and general manufacturing, complex assemblies are typically created from combining dozens (or even hundreds) of smaller parts via welds, bolts, screws and fasteners. This not only adds time and effort to the production process, it can also add weight along with multiple potential points of failure once the part is placed into service on a machine or vehicle.

What if those assemblies could be created as one single part? In the past, this was impossible because of the limitations of traditional tooling, machining, and mold and dye processes. By using additive manufacturing to create a complex component as a single piece, or generating a complex 3D-printed mold, manufacturers can eliminate weeks of pre-production work as well as hours of final assembly processes. Doing so can also make these parts lighter, stronger, more reliable and cheaper to produce.

In the case of a car or aircraft, 3D printing could also advance lightweighting efforts. A 3D printer with a large build envelope could turn sectioned parts of the vehicle that were previously held together by fasteners and welds into a single assembly. It could be printed using advanced design approaches that rely on honeycomb structures to provide strength while reducing the amount of material needed.

Mixed-Batch and Small Part Mass Production

A large build envelope also allows you to 3D print large batches of the same small part, or many different smaller parts in one simultaneous job, or even 3D print small detailed parts or injection molds in the free space around a large part to reduce the average print time and cost per part. Small parts added this way take no extra printing time, and don't appreciably add to material costs.

That makes it possible to build multiple different parts in a single job, or to produce a large batch of smaller parts at once. That's a huge boost to the economies of scale 3D printing can offer in certain applications that were previously limited by the number of items that could be printed.

For example, a service bureau with high capacity needs for a wide range of applications could use the Objet1000 Plus to rapidly produce high-quality prototypes, jigs and fixtures for automotive, aerospace or other applications very quickly. The same solution could be used for rapid prototyping of different parts for different projects at the same time.

Large Parts, Large Assemblies

Finally, large-format 3D printers can push further beyond the build envelope by allowing companies to produce large parts of an even larger end-use product. In 2014, Local Motors used an extremely large format 3D printing system developed at Oak Ridge National Laboratories to print an entire car (minus the powertrain, tires and a few other components) on the floor of the International Manufacturing Technology Show in Chicago using this approach. (See "3D Printing the Cars of the Future" on page 8.)

That's an extreme example, but other companies have used commercially available, large-format Stratasys printers to similar ends. TE Connectivity, for example, 3D printed a working motorcycle in roughly 1,000 hours using Stratasys printers. The frame was created via Fused Deposition Modeling on Stratasys equipment using ABS filament and Ultem 9085 resin. The bearings are made of plastic as well, while the metal parts were created from bronze using direct laser sintering.

The Urbee prototype vehicle developed by designer Jim Kor (of KOR EcoLogic) was designed from the ground up to be produced via 3D printing. In 2013, it was the first prototype car to have its body completely constructed from parts produced by additive manufacturing. Kor used Dimension and Fortus 3D printers available at service bureau RedEye on Demand, which is now part of Stratasys Direct Manufacturing. The Urbee was built using just 50 separate parts.

Aachen University also developed its StreetScooter C16 electric vehicle using the Objet1000 platform to print panels, bumpers and other components. That helped speed up the design and prototyping process immensely.

"The Objet1000 is the largest multi-material 3D Production System on the market and Aachen University was the first university in the world to have one," says Achim Kampker, professor of Production Management in the Faculty of Mechanical Engineering, Aachen University. "Being able to use it in the development of large and small parts for StreetScooter was exciting in itself, but the contribution the 3D printed parts made to the construction of the car was enormous. The ability to produce full-scale prototypes that perform like the final parts, accelerated testing and design verification, enabling us to bring to market a prototype electric car in just 12 months — something that is just unimaginable with traditional manufacturing."

Thinking Big

The 3D printing industry will continue to expand its large-format production capacity as manufacturers prototype and create end-use parts for aerospace, auto, construction and other applications. The availability of printing solutions such as the Stratasys Objet1000 Plus system will enable the production of larger parts, assemblies, molds and tooling, and will also provide the means to ramp up the production of larger batches of smaller items as well.

Whatever limitations remain for the use of 3D printing in these applications, build envelope size is no longer one of them.

—Brian Albright is a contributing editor for Desktop Engineering *magazine. Contact him via DE-Editors@deskeng.com.*

A fully functional electric vehicle was developed by Aachen University in just 12 months by replacing traditional automotive manufacturing processes with Stratasys 3D printing. *Image courtesy of Stratasys Direct Manufacturing and StreetScooter.*

Pros Roll with 3D Printing

Examples of 3D printing in the automotive and associated industries abound. The three videos here illustrate different aspects and strengths of 3D printing, from restoration, to creating one-of-a-kind works of art, to simplifying a complex, end-use part.

Click the images to watch the videos.

Watch a Shelby Cobra be 3D printed.

See how Joe Gibbs Racing uses a 3D printed duct outlet.

Check out Orange County Choppers' 3D printed Dragon.

3D Printing the Cars of the Future

A Local Motors demonstration points to a new way of making cars.

When attendees arrived at the International Manufacturing Technology Show (IMTS) in Chicago last year, the Local Motors 3D printing demo was a must-see exhibit. The design and manufacturing collective-produced car was printed directly on the show floor over five days using newly designed, large-scale 3D printing equipment. Potentially, this type of printing could not only open up new possibilities for vehicle design and manufacturing, but could also make it possible to produce lighter components and vehicles at a reduced cost.

Local Motors printed the chassis, body, seats and other interior components in several large pieces, then joined them to pre-existing drive components, tires, a steering wheel and other parts. The printed Strati was then driven off the show floor at the close of the event. The company used carbon fiber composite ABS from

SABIC Innovative Plastics to create the car.

The technology to accomplish this grew out of work at Tennessee's Oak Ridge National Laboratory. Oak Ridge initially created the large-scale printing equipment at the behest of Lockheed Martin, using a plastic extruder attached to a robot on an XY gantry system. Oak Ridge then teamed with Cincinnati Inc., an Ohio-based machine tool manufacturer, to commercialize the process.

"Local Motors initiated the concept of printing the car before we'd ever built a machine," says Rick Neff, manager of market development at Cincinnati Inc. "They had seen the prototype gantry at Oak Ridge."

According to James Earle, the engineer who supervised the work on the Strati at Oak Ridge, Local Motors CEO Jay Rogers immediately saw the potential for auto manufacturing when he visited the facility. Local Motors set up a design challenge for its members. "We also issued design rules, which are very different than for traditional auto manufacturing," Earle says.

Designs had to be modified so that they could be easily printable. For example, elements like overhangs, which are difficult to print without generating supports, had to be eliminated.

The winning design for the Strati came from Italian designer Michele Anoe, beating out 205 other entries. Cincinnati Inc. created the 3D printing system — dubbed Big Area Additive Manufacturing, or B.A.A.M., to print the car.

The B.A.A.M. has a build volume of 2x4x0.87 m. "The challenges you find with this type of large system are the same as you would find when printing small parts, but they are literally bigger," Neff says. "People say that complexity is free with 3D printing, but that isn't really the case. The more complex you make the part, the smaller the nozzle you need to extrude the plastics. You sacrifice speed for complexity. If we want to go fast, we need a larger nozzle at higher rates, and you lose complexity."

There is still typically post-processing needed for most printed parts. "We have to machine some areas of the part to provide accuracy or connection points for the drive system or suspension," Neff says.

Local Motors CEO and co-founder John "Jay" Rogers is quick to introduce a broader term to describe the way the Strati is manufactured. "It's direct digital manufacturing to us," he says. "It's not just 3D printing, but became known as that colloquially. It was really driven by the idea of reducing part

Urbee's 3D Printed Car Body

Henry Ford is attributed with the creation of the assembly line, ushering in a new era of mass manufacturing. Anyone with even a passing knowledge of business or history knows this innovation allowed Ford to create products that were less expensive to manufacture and easier to maintain. To use a frequently overused phrase, the assembly line was a game changer.

Now it appears as though the wheel is turning back toward crafted products, or as crafted as an additive manufacturing (AM) part can get. In collaboration with Stratasys, inventor Jim Kor is building a car using AM to produce the parts. The Urbee is intended to be an economy-sized, hybrid vehicle that can get over 200 mpg. The electronic portion of the car can be recharged at home by simply plugging it in, but Kor has ideas about using solar panels on garages or even mini-windmills to generate enough electricity to reduce the Urbee's carbon footprint even further.

"Other hybrids on the road today were developed by applying 'green' standards to traditional vehicle formats," said Kor, president and CTO of Kor Ecologic. "Urbee was designed with environmentally sustainable principles dictating every step of its design."

According to Kor, the Urbee could only be manufactured using 3D printing. The complex internal geometries and customization offered by AM allowed him to design every piece and panel, with the result that the Urbee has far fewer parts than other vehicles, and is lighter to boot. In place of the pile of parts usually required to construct a single piece of a car, Kor has used AM to combine the parts into complete sections.

— John Newman

complexity. We wanted to pit the capability of the computer, design software, printing machine and milling machine vs. the complexity of a car. ”

Local Motors created the first prototype Strati at Oak Ridge in May 2014, and it was on the road in June. It took 38 hours to build the first one. The drivetrain, suspension and other mechanical parts come from a Renault Twizy electric car.

Mass Customization

Originally, Local Motors planned to produce the Strati in one piece at IMTS, but the vehicle was actually printed in several parts and then joined together. “We have the space to print it in one piece, but the extruders we’re using don’t have the material flow rate to keep the thermal mass high enough on the part, and we ran into some deformation problems as the part cools,” Earle says. “We had to reduce the size of the parts we’re printing to maintain integrity.”

That’s a challenge that will eventually be overcome, he adds. Cincinnati Inc. also has the capability to produce much larger and smaller versions of the B.A.A.M.

3D printing an entire car has far-reaching implications on future vehicle designs. For one thing, printing can greatly reduce the complexity of the car by reducing the number of individual components needed.

“The world is on a hell-bent path that was accelerated by the internet, says Rogers. “That path leads to virtual design meeting physical manufacturing. Just like electric car was talked about since 1905, and has just become commonly available recently — sometimes takes 100 years for tipping point to happen. I feel a lot like there’s a tipping point going on now. You’re seeing design for manufacturing, design for additive manufacturing, or direct digital manufacturing … we’re finally, happily, moving past the word prototyping.”

Rogers says he hates the word prototyping because it means to the consumer that it’s a product they’ll never see. “Designers, especially in CAD, we want people to think ‘If you can design it, it can be real.’”

For members of the Local Motors community, the first step toward that reality often begins in Siemens PLM Software’s Solid Edge. Almost three years ago, the company introduced a special edition of Solid Edge, dubbed Design1, and made it available to Local Motors for a subscription fee of $19.95 per month.

“That gave us the ability to purchase professional-grade CAD software for basically the cost of a pizza each month,” Rogers says. “That was really important to us as a statement that ‘This is not beyond you.’”

Karsten Newbury, senior vice president and general manager of Mainstream Engineering Software for Siemens PLM Software, says the company’s move to a rental offering is about the “digital enterprise.”

“One of the key trends in the consumer world is mass personalization — accelerating the time people can get something real in their hands that is their own,” he says. “It’s not just about the 3D printed car. It’s really about the whole process … what we call the digital enterprise.”

In such an enterprise, if designers don’t have to

Local Motors’ Strati in Motion

See how Local Motors 3D printed its Strati vehicle.

Watch the Strati’s first drive.

consider the limitations of a traditionally more complex manufacturing model, it opens up all sort of possibilities when it comes to both styling and durability. Eliminating the need for multiple welds, bolts and clips, for example, also eliminates hundreds of points of failure on a vehicle.

"The way we make cars today, there are hundreds of stamped parts that are expensive to make, and they have to be primed and painted and welded," Neff says. "That involves lots of hours of machine time and labor to put them all together. The majority of that work can be done in one piece with 3D printing, and it opens up the possibility for mass customization in the future.

"I don't think Local Motors thinks this will replace GM or Ford anytime soon, but there are people who want to buy a very individualized car," Neff continues. "This can cut many labor hours out of the construction of the car, and make mass customization affordable for the average consumer."

In terms of lightweighting, printing also presents the possibility of reducing weight in non-load bearing components like seats. "You can tailor the material to the application in the car," Earle says. "You have high-strength material for the structure, and lighter weight, less-dense materials for other components. You can greatly reduce the weight of the vehicle by simply changing the material."

Neff cautions that just because the vehicle is printed from lighter weight materials doesn't automatically make it light.

"Carbon reinforced plastic is fairly light, but there is a lot of material in this particular car," he adds. "To meet the new Corporate Average Fuel Economy (CAFE) standards, cars have to be lighter, stronger and more aerodynamic. This would certainly, at a minimum, provide people with a way to prototype cars and test them aerodynamically in a much easier, faster way."

While large-scale vehicle printing is likely a few years away, both the auto and aerospace industries are interested in the technology for creating dies and tooling in a much faster and cheaper manner.

"When airplane manufacturers create parts, they have to get dies made for tooling, and that involves having a large piece of metal CNC-cut to a specific shape," Earle says, referring to the computer numerically controlled process. "That is expensive. In aerospace in particular, they may only make 100 parts off of a wing mold."

With 3D printing, he notes, the same mold can be made for a lot less money, and the turnaround is faster: "It's a few days vs. several months. The other benefit is you don't have to store those molds. You can reprint them later."

For the auto industry, there could be immediate application for cheaper, faster prototyping, in addition to creating small runs of custom vehicles. But if you can print a car that is durable, easier to manufacture, and weighs much less than a traditional model, what are the implications for repairability? If the entire body of the car is made from one piece, what happens when you crash and damage the rear fender?

"Right now, if you have to replace a panel, it can cost several thousand dollars," Earle says.

Local Motors 3D printed a Strati at the International Manufacturing Technology Show (IMTS) and then drove it off the show floor.
Image courtesy of Local Motors.

"We'd love to get the technology to the place where we can reprint the entire car for less than the cost of the panel repair." Conversely, different parts could be printed in different materials. A bumper made from a softer, more shock-absorbent material could be popped out and replaced quickly, for example.

Two factories, which Local Motors dubs "Factories of the Future" are under construction now and scheduled for completion by the end of the year.

—Brian Albright is a contributing editor for Desktop Engineering *magazine. Contact him via DE-Editors@deskeng.com.*

Article Reference:
deskeng.com/de/printing-car-future/

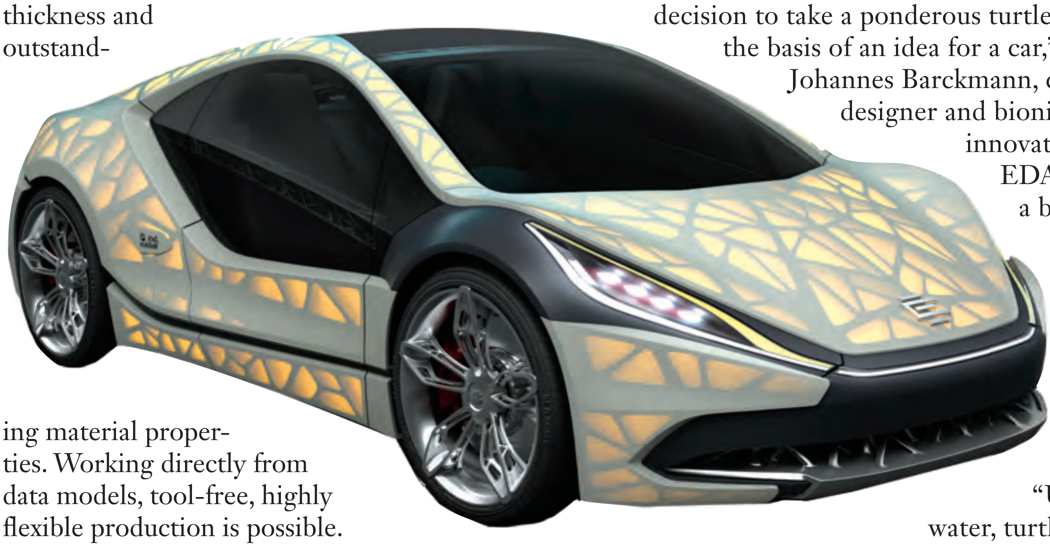
Engineering Firm Looks Forward to Full-Scale 3D Printed Auto Production

By John Newman

EDAG, a design and engineering firm based in Germany, is devising a path to the future for automotive additive manufacturing with its Genesis and Light Cocoon projects. They represent the results of a think tank that included experts from Fraunhofer, Laser Zentrum Nord and the DMRC Paderborn. The goal of the project was to examine the state of additive manufacturing and predict how the technology will impact automotive design and production.

The findings were published in an EDAG white paper titled, "EDAG Insights: Additive Manufacturing," and are summarized in the following passage from that paper.

"Additive manufacturing enables parts to be designed so that they are load-specific, multi-functional and bionic, while ensuring ideal wall thickness and outstanding material properties. Working directly from data models, tool-free, highly flexible production is possible. Weldable metals and plastics developed to be suitable for specific applications will pave the way to future applications."



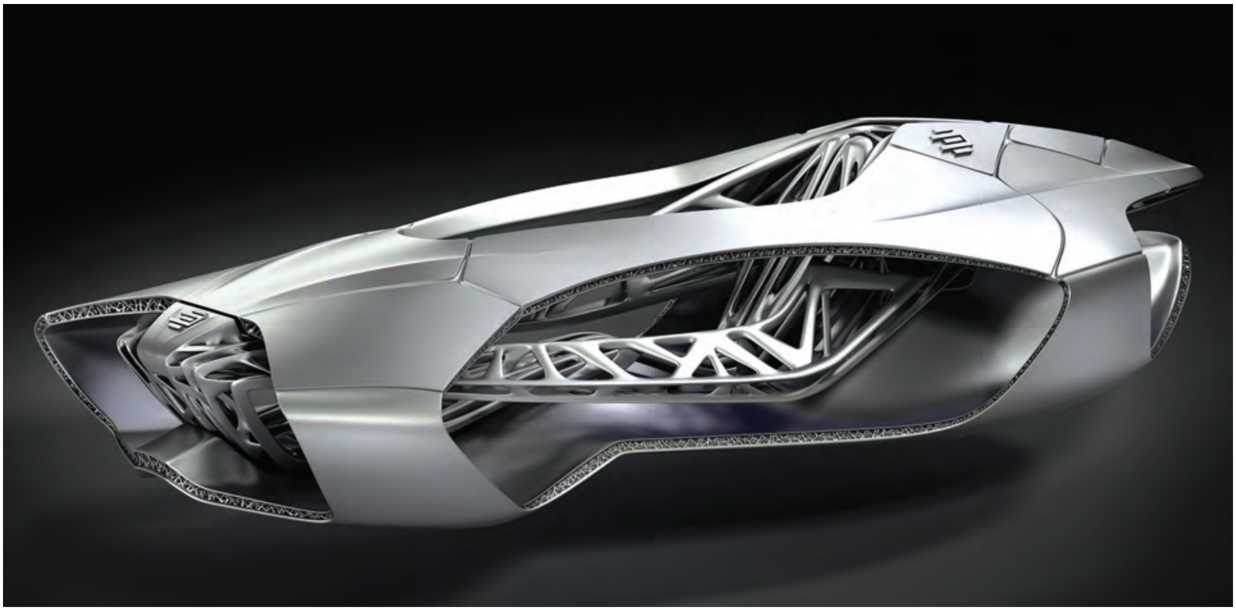
EDAG's group of experts is certain that new methods of designing for AM will evolve, as more designers embrace the freedom of design possible with 3D printing. This includes new and improved tools for design. Most CAD programs are still rooted in the old engineering and design philosophies developed for tool-based, traditional manufacturing methods. As more companies embrace AM for production, new tools will need to be developed to fully leverage the flexibility of 3D printing.

Proof of Concept

Rather than stand on the sidelines, EDAG stepped up to its own challenge and developed a proof-of-concept model. The ultimate aim of project Genesis was to design a vehicle using new design philosophies and manufacturing techniques. In this case, EDAG's team looked to nature for inspiration — the humble turtle to be specific.

"At the very beginning, we had to justify our decision to take a ponderous turtle as the basis of an idea for a car," said Johannes Barckmann, chief designer and bionics innovator at EDAG, in a blog post.

"Under water, turtles are skilled swimmers, but on land they are not the fastest of creatures. But what really persuaded us to take the turtle's shell as the inspiration for Genesis was the simple fact that what we are talking about here is a kind of passenger safety that nature has perfected over



The Genesis (above) and Light Cocoon (left) projects from German design and engineering firm, EDAG, are intended to explore the current and future impact of additive manufacturing on automotive design. *Images courtesy of EDAG.*

the course of millions of years. No engineer could come up with an idea like that!"

Less Weight via Part Consolidation

Basing the design on the structure of a turtle's shell offered a chance for significant lightweighting. Earlier testing by EDAG and Laser Zentrum Nord had shown that AM can reduce the overall weight of a part even if that part wasn't originally designed to be built with 3D printing. A joint effort at building a lighter multi-functional housing part for an electric vehicle resulted in a weight reduction of 1000 g. Project Genesis took that idea forward by applying AM design principles from the ground up to develop an entire vehicle body to be built in one part.

With a design in place, it then fell to EDAG to determine which AM process and material would best fit its needs. EDAG's team found that Fused Deposition Modeling (FDM) may well be the AM process best positioned for large-scale 3D printing, both now and in the future.

The resulting Genesis concept vehicle is part FDM shell, part artistic sculpture. It proposes that AM will be a major factor in the future of automotive manufacturing, and provides a glimpse into one way to create lightweight, yet robust, parts of all sizes while keeping material costs low. The project also highlights the idea that weight and material savings begin in design.

Following the success of the EDAG GENESIS, engineering specialists at EDAG expanded their vision of a bionically inspired body structure via additive manufacturing. The EDAG Light Cocoon concept study is "an unprecedented projection of the ultimate in future lightweight construction," according to the company. The vehicle structure is combined with a weatherproof textile outer skin panel that is backlit to illuminate the skeleton-like, organic structure.

—John Newman is a contributing editor to Desktop Engineering *magazine. Contact him via DE-Editors@deskeng.com.*

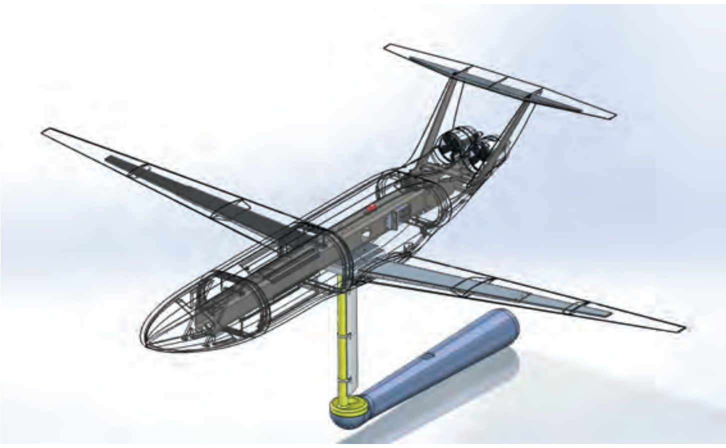
Article Reference:
deskeng.com/de/3d-printing-advances-design/

3D Printed Plane Propels Wind Tunnel Testing to New Heights

By Beth Stackpole

Fast forward 20 years and try to picture the state of air travel. Thanks to a growing world population and maturing developing economies, air traffic is expected to double in the next 15 years. That will create new levels of congestion and raise concerns about limited runway space, rising fuel costs and a surge in noise and pollution emissions.

As part of an exercise to explore innovations that would address these challenges, NASA embarked on a multi-million dollar Aeronautics Research Mission Directorate concept study to evaluate design approaches for a next-generation aircraft, akin to today's 737-class fleet,



In this full CAD model view of the integrated tail assembly, 3D printed parts were made transparent to show internal metal support structures.
Images courtesy of Aurora Flight Sciences.

that would go into service in the 2030 to 2035 timeframe. Central to the design study was identifying technologies that would reduce fuel consumption by as much as 70%, significantly cut back on noise and pollution emissions, and enable operation from 3,000 ft. runways that are common to secondary airports outside of major metropolitan areas.

A key phase in the project was a wind tunnel modeling effort that would assess the aerodynamics, propulsion, operation and structure of the proposed concepts. Led by one of the partners on the study, Aurora Flight Science's Research & Development division, the team took off with Stratasys' Fused Deposition Modeling (FDM) additive manufacturing technology as a way to shorten its design cycles and maximize limited time slotted in NASA's wind tunnel facility.

"Typically the turnaround on projects like this is weeks, if not months," notes Roedolph Opperman, a spacecraft systems engineer at Aurora Flight Sciences. "Because we were working with NASA, we had to schedule time in their wind tunnel months ahead of time and we had to meet our deadlines. With FDM, we were able to get everything done and have an assembled tail in the tunnel in just under a month. That's unheard of in this industry."

The "Double Bubble" Design

The concept study for the N+3 subsonic fixed wing transport aircraft — or a jetliner in layman's terms — called for the project partners to explore three areas of innovation: An aircraft design that could harness liquid natural gas, use a distributed, multiple-engine propulsion system, and would fly about 10% slower than current-day aircraft in order to take advantage of emerging technologies that aren't supported at current commercial flight speeds.

The team, led by MIT, which included Pratt & Whitney in addition to Aurora Flight Sciences, came up with a radically different design concept for the aircraft, intended to fill the seat of the B737/Airbus A320 class, which accommodates 180 passengers for travel ranging from 500 nautical miles to a transcontinental range trip. Referred to as the D8 series, the concept

In one test, an FDM wing with an aluminum skeleton was mounted upside down and loaded with 340 pounds to simulate a 300% loading of maximum lift force in the tunnel, resulting in a wing tip deflection of 8 inches.

aircraft took on the shape of a "double bubble" or double-tube and wing, Opperman explains, a design intended to increase lift while allowing for more room to accommodate additional passengers.

The other big change in the design was the placement of the engines — from under the wings where they typically reside, to the back of the plane, riding on top of the aft end of the fuselage. "That was done to take advantage of boundary layer ingestion — a concept that essentially reduces the drag created by the airplane," Opperman says. "It's better for the engine."

Once the primary design concept evolved and was validated with robust simulation testing, it was time to move on to the wind tunnel stage to put the proposed "double bubble" plane model through its paces and prove out the simulation results.

Aurora's role was to develop a scaled-down model of the plane design that would attach to the wind tunnel. The bigger the model, the closer the team could get to resembling the actual aircraft for evaluating drag, the effect on engine placement as well as other capabilities. Initial testing was done at MIT with truncated wings on the 1:11th scale model in order to have it fit in the tunnel. Eventually, the project was moved to NASA's 14×22-ft. wind tunnel facility to test the full-length wings because the larger tunnel reduces the negative impact of tunnel boundary effects on the measurements, Opperman explains. The team had to schedule the testing period for the NASA facility months in advance and had only a limited amount of time to conduct its wind tunnel verification work, he adds.

FDM Puts Test Model in Flight

Facing those requirements, and with a heightened interest in 3D printing as the wave of the future for manufacturing, Opperman and his team decided to engage Red Eye by Stratasys, now part of the Stratasys Direct Manufacturing service bureau, to create the test model in an effort to meet its rigorous timelines.

In one test, an FDM wing with an aluminum skeleton was mounted upside down and loaded with 340 pounds to simulate a 300% loading of maximum lift force in the tunnel, resulting in a wing tip deflection of 8 inches. Image Courtesy of Aurora Flight Sciences.

The typical model used in wind tunnel testing is machined out of aluminum, with foam parts used intermittently. It can take as much as a month just to get the machined part — a timeframe that would negatively impact the schedule, he explains. Using the Stratasys Direct Manufacturing service, the team submitted designs and received the finished 3D printed versions ready for assembly and finish work in just a few days, which enabled it to meet its aggressive deadlines.

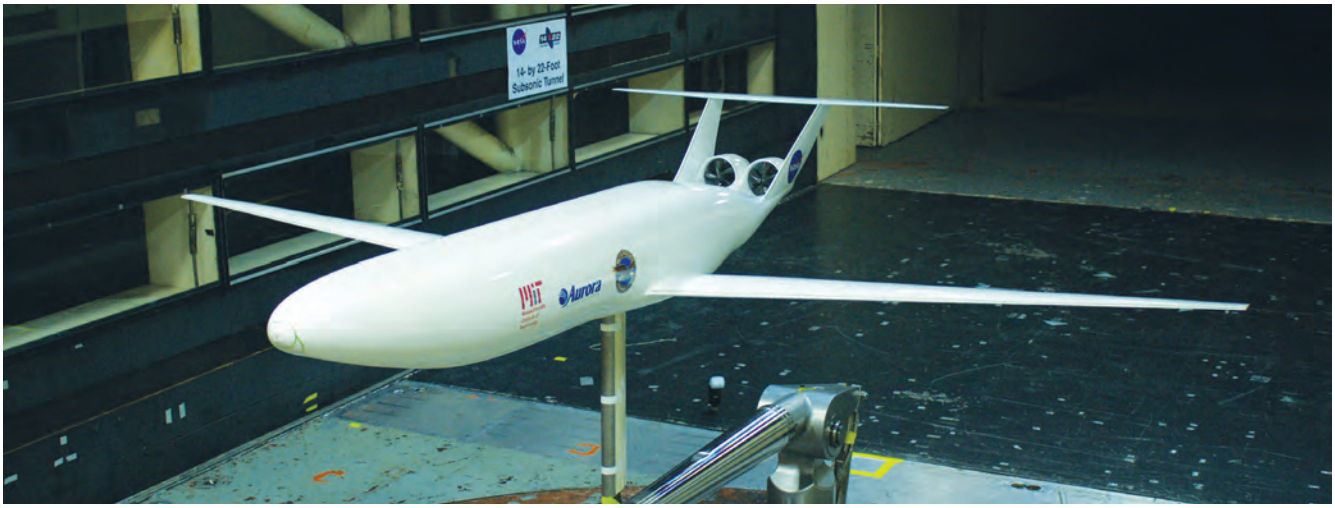
Evaluating possible engine placement and the different variations of the engine nacelle design were also much easier with an additive manufacturing approach, Opperman says. Stratasys Direct Manufacturing was able to very quickly print out eight different nacelle shapes during the test period in the wind tunnel, allowing the team to switch out variations and zero in on the optimal shape, he explains. “The clock was ticking — we had six weeks to do all the testing …” he says. “Because everything was changing so rapidly, we wouldn’t have been able to do it if we went the aluminum route.”

Another benefit of FDM is the flexibility in quickly manufacturing complex surfaces,

Fused Deposition Modeling additive manufacturing services from Stratasys Direct Manufacturing were engaged to produce engine nacelle parts for the wind tunnel model.

especially when it comes to the aerodynamically blended shapes of the fuselage, particularly around the integrated engine nacelles of the tail as they are difficult, expensive and time-consuming to machine, Opperman says. The smaller weight also minimizes the support structure required, so it simplifies the design and handling of the model in the wind tunnel.

Stratasys Direct Manufacturing could also provide expertise surrounding additive manufacturing practices that Aurora and its team of partners lacked, Opperman says. Stratasys



Aurora created a 1:11th scale wind tunnel model of a Subsonic Fixed Wing transport aircraft using Stratasys’ Fused Deposition Modeling (FDM) technology.

Direct Manufacturing is also the single biggest installation of consolidated FDM printers, so it can accommodate large jobs and handle the variety and size of parts and still deliver in a timely fashion, according to Jason Bassi, senior account manager at Stratasys Direct Manufacturing.

Because use of 3D printed parts in a wind tunnel was a relatively new application for NASA, due diligence was required in the form of a 400-page report and sample materials to prove that the materials and the process were structurally sound and wouldn't do damage to the NASA wind tunnel, Opperman says. "NASA wanted to ensure that nothing would break and that there wouldn't be pieces flying off the model and damaging the tunnel," he explains. "Because 3D printing is so new [for this application], we needed to show them the calculations and prove that it would be safe."

Aurora Flight Sciences' effort to validate the acroylonitrile butadiene styrene (ABS) materials and FDM additive manufacturing process for wind tunnel modeling will go a long way in convincing others of the merits of the approach for this and other serious simulation efforts, according to Bassi.

"The fact that Aurora took the proper steps to certify the materials and the process is crucial," Bassi says. "The more examples that are tested and validated, the more people have confidence in pushing the limits as to what additive manufacturing can do. Aurora is breaking new ground by validating that the materials work in these scenarios."

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Article Reference:
deskeng.com/de/3d-printed-plane-propels-wind-tunnel-testing-new-heights/

Case Studies

Diving into 3D Printing

Kirby Morgan has averaged a 50 percent decrease in time spent on product design since purchasing a Stratasys Dimension 3D printer.

Read the entire case study here.

APPLICATION STORY

Kirby Morgan Cuts Diving Equipment Design Process Time in Half with Dimension 3D Printer

"In the past, we were unable to fill custom product requests in such a short time period. The modified regulator we developed for the U.S. Military displayed the major speed and efficiency improvements you can achieve with the introduction of an in-house Dimension 3D printer."

— Pete Ryan Senior Engineer, Kirby Morgan Dive Systems

"At the extreme depths that many of our customers are required to work at, there is no room for error," said Pete Ryan, senior engineer, Kirby Morgan Dive Systems Product Development. "Divers require us to provide safe, reliable, underwater breathing equipment, sometimes tailored specifically to their needs."

With a rich history of providing cutting edge equipment, Kirby Morgan Dive Systems, Inc. thrives on delivering innovative, fail-safe products to the diving community. From commercial diving helmets to scuba regulators, Kirby Morgan dive systems are frequently designed to accommodate unique diving applications and extreme environments.

Kirby Morgan receives time sensitive requests from a variety of organizations, requiring rapid product design and redesign. Delivering the high-quality product Kirby Morgan has built its reputation on within a tightened time frame can be a major challenge. Kirby Morgan's dive systems are precision crafted to withstand the intense rigors of any diving environment. Designs must be thoroughly tested to ensure the highest levels of quality and reliability are achieved, regardless of deadline.

"Some of our new product designs and improvements require us to move ahead pretty quickly," Ryan said. "The designs ... and multiple 3D models before a final version has been approved."

... 3D models to service bureaus. The shipping and turnaround time ... through the design phase quickly and efficiently.

...ocess to build accurate, cost-effective 3D models used in the ...g capabilities in-house, they sought to cut model production time ... process. "Dimension was the obvious choice for us," Ryan said. ...eets our high standards and the purchase price of the Dimension

FASTER TO MARKET

PolyJet is a Game Changer for Accelerating Injection Molded Products To Market

"This is revolutionary…I estimate we've shortened our R&D process up to 35%, and this is on top of the 20% we're already saving on our design work. For me, it's fantastic."

— Patrick Hurst, Managing Director, Whale

These functional prototype diaphragms were made with Santoprene using a 3D printed injection mold (foreground). The CNC tool previously used to create the same part is shown in the background.

Tooling Obstacles Hinder Product Development

Based in Bangor, Northern Ireland, Whale Pumps designs and manufactures a diverse range of pumping and heating systems that include plastic and rubber parts for consumer and industrial applications around the world. The company employs an impressive in-house injection molding operation to manufacture the systems, but producing injection molds requires ordering costly CNC tools that typically take four to five weeks to create, are very heavy to transport, and cost tens of thousands of pounds sterling. Furthermore, Whale outsources its functional prototype parts from service bureaus often located in China. All of these factors greatly slow down the R&D process and substantially delay the launch of new products to market.

Patrick Hurst, Managing Director of Whale.

3D Printing is The Solution

Accelerating the time to market and enhanced product innovation are key drivers to Whale's success. To achieve this, Whale investigated the benefits associated with 3D printing.

"We saw 3D printing as a brilliant opportunity to change our business, reducing risk and the need for re-engineering. So we started looking at the most advanced 3D printing technology," explains Patrick Hurst, Managing Director for Whale.

The company purchased a Stratasys® 3D Printer which utilizes PolyJet™ technology. Soon corporate engineers were producing prototype parts in multiple materials and colors.

"Literally a week after we received the machine, it was being fully utilized. Then, because of the overwhelming demand, we bought another Stratasys 3D printer a few months later," recalls Patrick.

3D printed injection molds for various applications made with ABS material.

Stratasys
FOR A 3D WORLD™

Injecting New Speed into Molding

Whale Pumps is now 3D printing its injection molding tools with Digital ABS in less than 24 hours at a fraction of the cost of producing metal tools.

Read the entire case study here.