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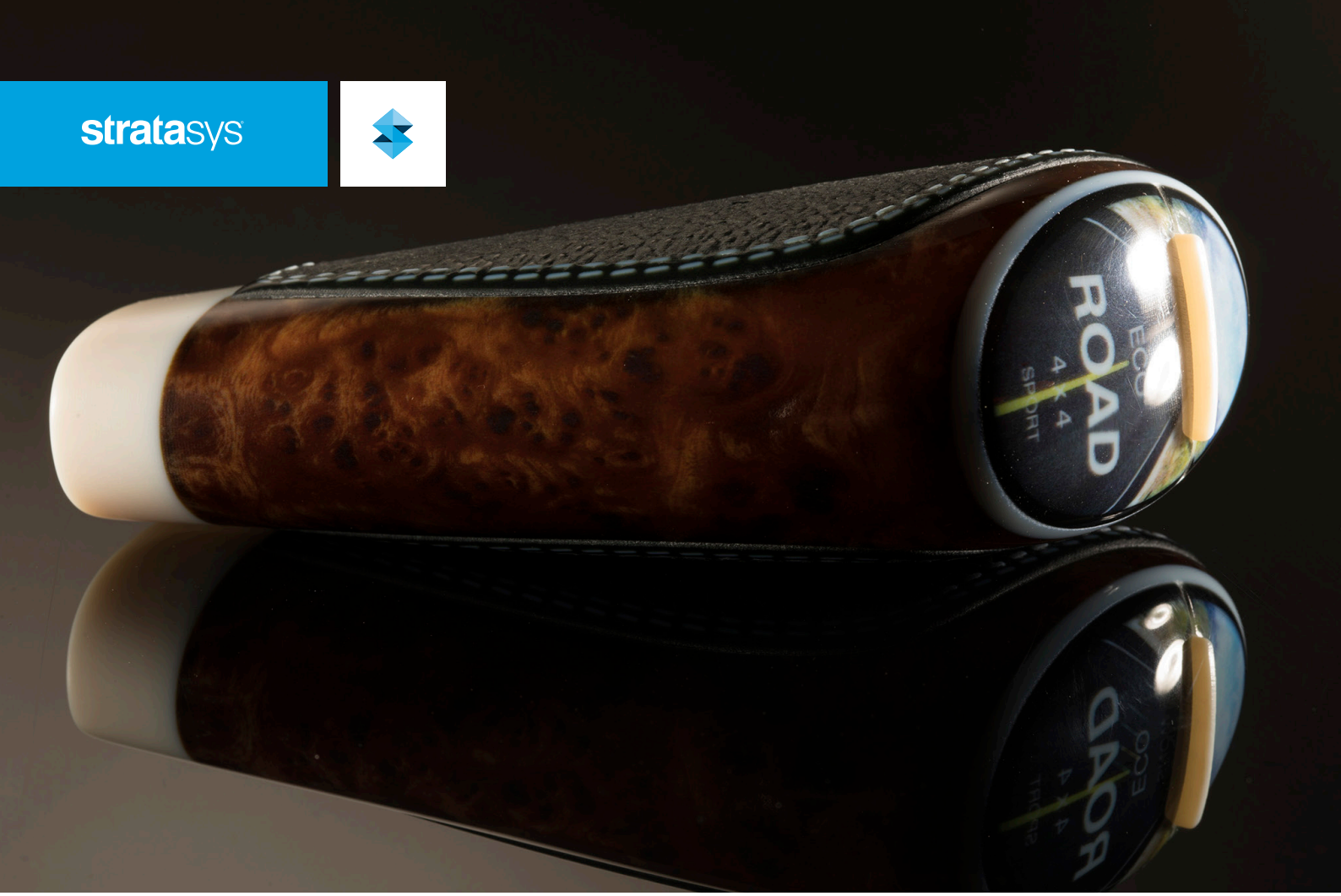

The Road Ahead

RAPID PROTOTYPING IN THE AUTOMOTIVE INDUSTRY

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PACE-SETTING AUTOMOTIVE DESIGN

Henry Ford may not have invented the automobile, but his pioneering spirit did transform the way cars were made. His assembly line process drastically reduced costs with standardized parts and greater efficiency which led to lower cost, higher quality and greater reliability.

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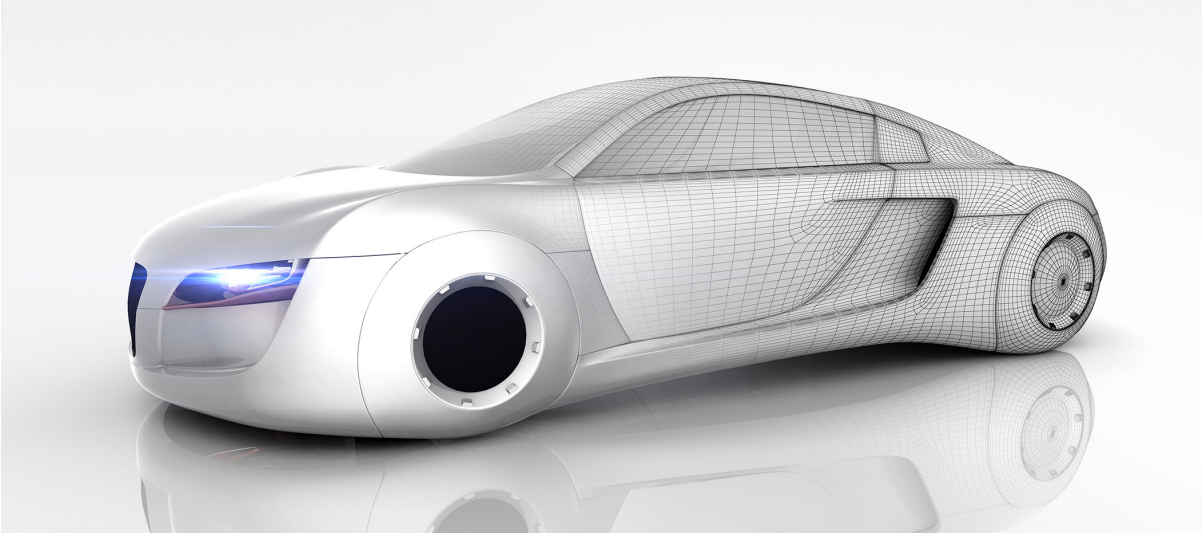

What Ford had no way of foreseeing was that sweeping changes to the auto industry in the 21st century would completely reorder sales drivers. While the auto industry was built on innovation, its continued growth depends on it.

Electric cars, car sharing and self-driving cars have meant what's under the hood is becoming less a consideration than how car interiors can and will be tailored to the changing needs and wants of consumers. In fact, according to Wards AutoWorld, "Interiors will be the number one differentiator in the age of mobility services, because the interiors will influence why someone picks a particular brand."

To keep pace, car designers will require nimble design and prototyping processes to carry innovation through to applications that will drive customer purchasing.

Futuristic Cars

If our cars are going to be driving themselves in the future, then what are we, as drivers, going to be doing? Will cars become entertainment centers, meeting rooms or sleeping pods? The point is that no one should be underestimating the increasingly pivotal nature of car interiors as unique brand differentiators.

Short design-cycle iteration is important in any industry, but none more so than the automotive arena. So what does this mean for the auto industry? It highlights the need for shortened design cycles and more seamless product design in order to shorten time-to-market. Low

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margins, due to the rising cost of development, make automotive a capital-intensive industry with the added challenges of constant innovation, customization and the need to bring designs to life efficiently and cost-effectively in order to stay ahead of the curve.

The importance of new design validation cannot be underestimated. The auto industry prototyping market is estimated to hit $5 billion by 2020, driving industry designers and engineers toward new ways to get their designs validated, quickly.

But the constraints inherent in many of the intricate and multi-material and fused parts, especially for interior and exterior parts that call for custom features and complex multi-material parts with separate elements, mean the demand for prototypes often exceeds the capabilities of traditional, multi-step processes. An exploration of how 3D printing for automotive can enable both rapid iteration and facilitate complex design, factors that lead to cost reduction and increased speed, are worth exploring.

anyone over the age of 16 can probably point to a particular car that just “felt” great, chances are that same buyer sat in many interiors that “didn’t feel right.”

Devices like cup-holders have long been a point of contention to consumers: which work, which don’t, which vehicles have enough, which don’t. But with the advent of driverless and electric cars and a proliferation of the sharing culture, interior design is going to take on a new level of importance. These intangibles undeniably contribute to a great or not-so-great user-experience and will necessitate a growing attention to morphing demands of the automotive industry.

ROAD-BLOCKS TO DESIGN

Car interiors are complex places. The elements of form, fit and function all play an important role in how user-friendly and aesthetically pleasing customers find a particular design. And, while

For the purpose of this white paper, we will examine the product design phase of one complex interior part and one complex exterior part and discuss the varied steps necessary in the design

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process, which can greatly impede speeding a product to market.

Interiors

The interior of an automobile is made up of instrument panels, seats, door trim panels, headliners and a steering wheel and gear stick, a complex set of interlocking parts that also typically require:

- Plastic and stereolithography (SLA) casting, wood veneering, leather cutting and gluing and rework.
- Roughly five prototype iterations before all the parts fit and function as a cohesive whole.
- Between two and several weeks per iteration, with a significant number of rejects for poor quality.
- Months of lead-time until the final design is approved.

Auto interiors are a complex mix of materials, which further complicates the rapid prototyping phase of design validation. Typically, each part needs to be produced separately, then glued together in a way that is both seamless and true to its final form.

The gear stick assembly, a combination of leather or textured fabric and the smooth plastic or wood surface of the console is a particularly complex interior part. Add in the ergonomic variables of a pleasing grip on the gear stick, which is most often made from multiple materials, and you have a large prototyping challenge.

The end result? A console prototype can take months of lead time before reaching the final approved design, depending on complexity.

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Cost

Costs for gear stick assembly prototypes are roughly $1,500 per iteration, and with an expected cycle of five to 10 iterations before final design validation, these costs mount quickly.

Additionally, multi-material prototypes are a necessity in the gear stick assembly, a process cumbersome, time-consuming and costly with traditional manufacturing processes.

Exteriors

Certainly at night, but also during the day, the light assemblies on the front and rear of a car are highly visible design elements as well as important safety features. Without clear, effective lighting covers, driving at night would be both difficult and very dangerous. But it's also impossible to overlook the aesthetic element at play. Head and tail light covers may be a safety feature, but their design is also an important element when it comes to the overall exterior aesthetics of a car, and getting the design just right takes many iterations.

Lighting lens covers are a complex part, comprised of different colors, textures and pieces that need to fit together seamlessly. Prototypes made by traditional means usually involve machining to create concept models, and prototypes are often an additional step. Creating a lighting cover prototype currently requires a multi-step process with separate manufacturing systems and a combination of traditional techniques which include:

- Vacuum casting molding that needs to be printed using stereolithography (SLA), then followed by multiple gluing stages of all parts.
- Milling from a solid acrylic glass block, followed by gluing and rework.

Costs

These steps add up to an expenditure of roughly $3,000 per lighting cover prototype (including labor, tooling, painting, hand finishing, machining and color matching).

Due to the complexity of the process, many companies outsource these steps, putting them at

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the mercy of a variable that's difficult to control – the vendor's lead time. This can also mean added cost in the form of skilled labor and the associated time and material that's involved.

Additionally, these delays work against getting the product to market as quickly as possible to begin generating revenue and to acquire or maintain leadership in the market.

There is little question that the multiple stages required to achieve a quality prototype can quickly take the "rapid" out of rapid prototyping.

AN ENGINE OF INNOVATION

Additive manufacturing allows rapid prototyping labs to quickly produce their designs, providing the ability to efficiently iterate, as well as produce prototypes that resemble the finished product. Cutting-edge 3D printing allows for printing in multiple materials so parts that would require separate production and assembly can be seamlessly printed in one run. These have numerous benefits for automotive manufacturers such as:

- Accelerating the product design phase.
- Allowing for printing in multiple colors.
- Printing with multiple textures.
- Eliminating time-consuming finishing steps such as assembly and painting.
- Facilitating a quicker design cycle which means quicker time-to-market.

Driving Efficiencies

The use of 3D printing for prototypes has sparked a rapid evolution in design, development and the manufacturing of products in many industries, including automotive. In industries where material weight is of importance, such as automotive, 3D printing has spurred advancements in both lighter-weight and more complex designs at a lower cost.

The use of 3D printing for prototyping also means designers are able to spot design errors or defects early on in the process, which also contributes to a reduction in both production timetables and overall cost.

3D Printing: How Does it Work

3D printing works by depositing material on a print bed, layer by layer, from the bottom up from a digital file. This "additive" process also contributes to cost savings due to its reduction in overall material waste.

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Designers and rapid prototyping shops can create products much faster than by traditional methods. Faster, easier production provides more time for refinements before arriving at the optimal design.

Having a tool that helps accelerate the product design phase is the main goal of rapid prototyping. Since designs usually take anywhere from a few to hundreds of iterations before arriving at a final design, having a cost-efficient, green, high quality process is invaluable. 3D printing has proved to be such a process for many industries, including automotive.

In addition to being able to spot design flaws early on, before expensive tooling or machining comes in, having an actual physical model that is nearly indiscernible from the real thing is also very helpful. Tactile feedback is proven to enhance product decision-making.

Currently, rapid prototyping is the largest application for 3D printing in the auto industry. But not all 3D printing is the same. There are tremendous differences between the available hardware, software and materials.

THE STRATASYS J750: A BRILLIANT PROTOTYPING MACHINE

The versatile capabilities of the Stratasys J750™ 3D Printer let users do what they do best in a more time and cost-efficient way. More significantly perhaps, it provides a platform to develop new solutions, better products and inspired design, all with a single step in only a few hours' time.

The Stratasys J750 produces the most realistic, efficient replication of the final intended product with near 100% final fit, form, and color and texture matching. No other technology is capable of prototypes with this level of color, design and seamless integration.

The Stratasys J750 with 500,000 vivid colors, transparency and multi-material capability.

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The full design approval cycle is now reduced from weeks or months to hours or days. This adds up to hundreds of thousands of dollars saved per year. This does not even take into account the additional value of better overall designs (by enabling more iterations within the same timeframe), earlier focus group and consumer validation, faster time-to-market, higher market adoption and improved profitability.

PolyJet Technology

PolyJet™ technology is an additive manufacturing process with the capability to make parts, prototypes and models in multiple materials, colors and color textures. A powerful 3D printing technology, PolyJet produces smooth, accurate parts, prototypes and tooling.

With microscopic layer resolution and accuracy down to 0.1 mm, it can produce thin walls and complex geometries using the widest range of materials available with any technology. All of these characteristics can be combined in one 3D print job, allowing complex parts with diverse properties to be produced quickly.

These gear shift prototypes showcase the Stratasys J750's ability to 3D print multi-texture, multi-color printing, all in the same print.

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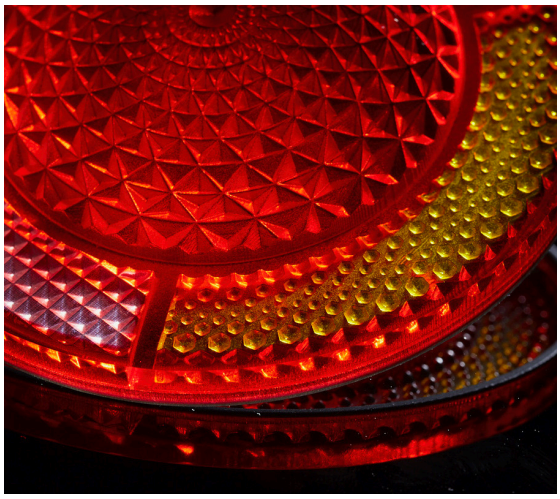
The capability to produce intricate, aesthetically pleasing parts with complete design freedom gives you the ability to rapidly iterate and speed your designs to validation in the automotive industry.

500,000 Colors

A hallmark of the Stratasys J750 is its true, full-color capability, a breakthrough in 3D printing technology. The ability to 3D print with various colors is not new, but previous offerings forced users to sacrifice either color range or part quality. The Stratasys J750 improves on this by producing smooth plastic parts with over 500,000 colors, and a range of texture capabilities. The wide range of textures includes leather, wood, woven materials, stitching, weave and more.

With this enlarged gamut of color, color range is 120% of SWOP (Standard of Web Offset 2D Printing), an increase of 40% from the current color range. Also, with the addition of two new transparent vivid color materials: VeroMagentaV™ and VeroYellowV™, simulating automotive lighting lens covers is as close to the real thing as is possible.

This color range is made possible because the Stratasys J750 can operate with a color range of: cyan, magenta, yellow, black, white, clear and



Simulated lighting lens covers with both vivid colors and transparency.

VeroMagentaV and VeroYellowV. With the capacity to use all of the primary colors in the CMYK color process including white, the Stratasys J750 has unparalleled color realism.

For cabin interiors, the new capabilities of the Stratasys J750 reduces this process to a single step, of a few hours, with near 100% brand color matching.

Color textures and gradients are also possible. Color texture capability means rigid opaque parts can be 3D printed with a variety of realistic patterns like wood grain and plain, for example. Gradients allow a transition zone between colors that blend seamlessly into one another.

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Multi-Material Capability

When a variety of material characteristics are needed, models can combine full color with a range of transparencies, or even different durometers. In practical terms, that means being able to produce a rigid model in multiple colors and gradients. Or, it might mean producing a tray of multiple parts, each with different characteristics, such as color textures, flexibility and transparency. Both scenarios are possible in a single print run.

Surface Finish

One of the drawbacks of existing color 3D printing processes is the relatively rough surface finish that results. In contrast, the Stratasys J750 achieves very fine layer thicknesses, as low as 14 microns in high-quality print mode, enabling high surface quality and the creation of models and parts with very fine, delicate details.

The availability of such a wide color spectrum, combined with fine-finish and multi-material capabilities, means the Stratasys J750 produces parts with an incredible array of characteristics. Prototypes that need to look, feel and function like the real thing are possible in a single print operation, with minimal to no finishing steps, such as painting, sanding or assembly.

Unmatched Versatility

The Stratasys J750 delivers incredible realism as well as unmatched versatility.

Its robust material capacity accommodates input of up to six base resins. Because advanced PolyJet systems create composite materials right on the build tray, the number of material options is far greater than the number of input materials. In the Stratasys J750, those base resins yield 500,000 colors, translucencies and durometer readings.

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Serving all your needs with one system enables rapid prototyping shops to:

- Reduce the amount of rapid prototyping equipment onsite, and its associated overhead and points of failure.
- Increase expertise and maximize use through familiarization with a single technology.
- Protect investments against changing business needs, both cyclical and unpredictable.

Print size with the Stratasys J750 is also generous, with a build area of 49 x 39 x 20 cm (19.3 x 15.35 x 7.9 in). This lets you create ample-sized parts or many smaller parts in one job.

For rapid prototyping programs, this versatility is an opportunity to meet the diverse demands of your operation without the inefficiencies associated with material changes or the need to invest in, operate and maintain a variety of technologies. You can print realistic prototypes, jigs and fixtures, promotional pieces or production parts – with one system.

The Stratasys J750 has the capability to print multiple materials in a single print with near 100% brand color matching, as well as produce parts from rubber-like material and functional under-the-hood parts for form and fit testing. Additionally, this workhorse also prints manufacturing floor aids, such as jigs and fixtures.

Reliability

The Stratasys J750 is capable of high output, repeatability and the highest-quality prototypes for automotive parts.

With extended-life print heads, you can print without interruption for 40% longer, thanks to significant engineering improvements.

Parts requiring thin walls and/or models printed in High Quality (HQ) mode, benefit from improved software parameters resulting in the highest model quality.

Completely updated software means smooth, uninterrupted performance from the Stratasys J750.

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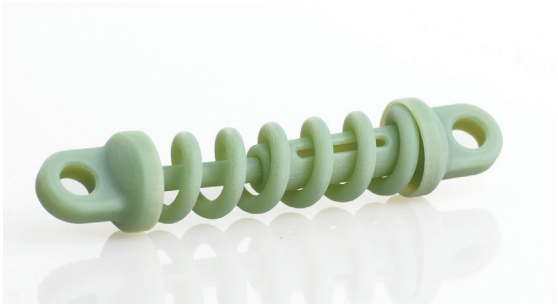
Advanced Materials

Agilus30™: Agilus30 is an enhanced flexible material for simulated rubber applications. Superior tear resistance makes it appropriate for tubing and other fluid-flow applications, as well as prototypes involving living hinges and other use cases that need rubber-like characteristics. For automotive use, this material enables functional door seals and gaskets and protective covers.

The flexibility and superior tear resistance of Agilus30 is a superior material for simulated rubber applications.

Digital ABS Plus™: For functional under-the-hood fit and form testing, Digital ABS Plus has proven to be a superior material specifically for rubber-seal mounting and functional testing of automotive door seals. Digital ABS Plus is also widely used for manufacturing aids and jigs and fixtures within the automotive shop.



A shock absorber 3D printed in Digital ABS Plus for high-impact resistance properties.

Jigs and Fixtures and Manufacturing Aids

While the scope of this white paper is limited to specific interior and exterior automotive prototypes, the Stratasys J750 is also a powerful tool for other areas of the automotive industry including:

- Jigs and fixtures, including rubber-like padding.
- Manufacturing aids.
- Production floor automation.
- Design teams and workgroups who work from concept models to final design iterations.

GrabCAD Print

The Stratasys J750 has an all-new GrabCAD Print™ slicer that enables the printing of a transparent core with VRML files. This slicer features full colors and textures (CMYKW + VeroClear). Also, the new colorimetric color

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profiler within GrabCAD Print ensures improved color matching between on-screen color and the printed part.

The ability to print 500,000 colors make lighting prototypes almost identical to the real thing.

USE CASES FOR RP IN AUTOMOTIVE

A number of automotive industry leaders are currently using the Stratasys J750 to create complex, liquid crystal display gear stick assemblies. With the ability to accurately simulate an LCD or digital display that features images, graphics and full-color text, the addition of a VeroClear™ overlay to simulate the actual device screen means the advanced gear stick's text and digital backgrounds can change to reflect the gear the car is in.

Also, using the same capabilities, auto manufacturers are 3D printing prototypes on the Stratasys J750 that are embedded in auto seat-backs. These "infotainment" devices have LCD screens, similar to those commonly embedded in the back of airline seats for informational video viewing and entertainment.

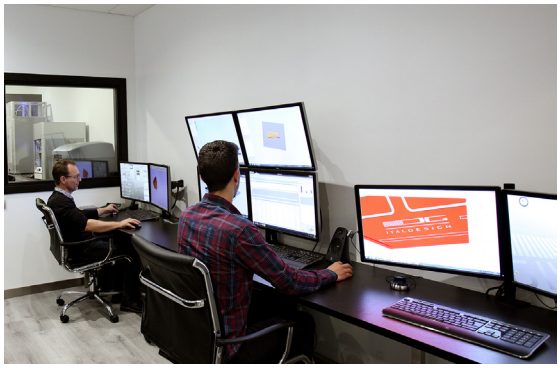
Audi

Luxury automaker, Audi, is currently developing taillight prototypes using the Stratasys J750, capitalizing on the 3D printer's ability to print in vivid red, with seamless color gradation integration and transparency, meaning the rear light prototypes are virtually indiscernible from the finished product.

Design iteration and validation are especially important in the luxury segment as consumers are both often willing to pay for innovation as well as demand it for brand initiation and/or brand loyalty.

Italdesign

Audi, Volkswagen, Lamborghini, Seat, Alfa-Romeo, Renault, Ford, Fiat. Pick a car manufacturer and chances are that design company, Italdesign, has undertaken work for it.



Italdesign's service bureau offers 3D printing services for automotive and a number of other sectors.

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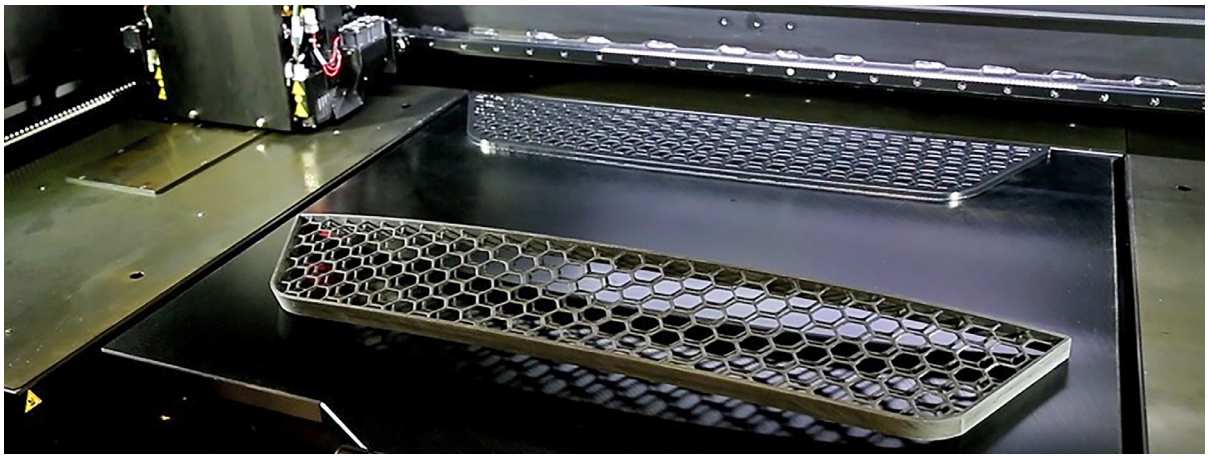

A grating for a car example, 3D printed in one piece.

Having worked on over 300 car models from more than 40 brands – a total of over 60 million cars manufactured worldwide – Italdesign is part of the very history and fabric of the global automotive industry.

Italdesign's newest foray into 3D printing is with the Stratasys J750, which allows them to expand their market and offer customers a new service. One of the applications in development involves the manufacture of the tuples of the pilots, so instead of having to paint them after manufacture, the Stratasys J750's Vivid Colors colorize these parts during the printing process. This saves untold time as well as cost.

A second venture under development at Italdesign is texturizing external parts, such as the mirrors, by 3D printing with carbon fiber. This would add tremendous value to this process. Also, the high-speed, high-volume capabilities of the Stratasys J750 include a notable increase in speed when printing using Digital ABS Plus material.

Thanks to its in-house 3D printing capability, Italdesign now enjoys savings on project times of as much as 50%, such that an out-sourced job that previously required a turnaround of between four to six days, can now be achieved in-house in only 40 printing hours.

"The time- and cost-savings are clearly evident and they have been achieved without compromising on quality," says Daniel Agulló, General Manager of Italdesign Giugiaro Barcelona. "This was not always something that we could consistently guarantee when out-sourcing, which did occasionally result in a few disgruntled clients.

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Ultimately, it's about being in direct control and having the peace of mind that jobs will be done quickly, cost-effectively and to a level of quality that will meet and even surpass client expectations," he explains.

Italdesign's service bureau

Italdesign recently opened a Spanish service bureau, PrintDesign 3D, to offer a 3D printing capability to other nationwide clients. The Spanish service bureau undertakes various projects, from small to large models, that Italdesign is currently commissioned to produce for customers like automotive giant, SEAT.

"Be it exterior components like lights, exhaust pipes and wing mirrors; or interior elements such as the steering wheel, gearshift and the numerous knobs and buttons, a car obviously comprises a multitude of different parts," continues Agulló. "Each of these requires its own individual design and testing process and 3D printing plays an important role across all of them," he adds.

"For example, the design of a headlight is extremely complex. We prepare the model and, using Stratasys' transparent material, 3D print each one of its lenses and small components, before bringing everything together.

"A couple of years ago, absolutely no provider could take on the level of work that we are currently doing. Previously, with traditional processes it would take us around four weeks to produce all the spare parts for six full-size cars. We can now 3D print these in as little as two weeks thanks to the ability to run the printer overnight and during the weekends without staff supervision," Agulló continues.

BMW

German luxury car manufacturer, BMW, uses 3D printing to build hand-tools for vehicle assembly and testing. Their goal was to design ergonomic assembly tools that would enable better worker performance, in addition to saving costs by not having to machine one-off designs. The result? The car manufacturer was able to reduce the weight of the tool by 72%, making it easier to use and increasing functionality.

Printing parts with complex shapes for reaching into difficult geometries has also proved successful for the German car manufacturer. The company 3D printed a tool to attach bumper supports, a design that produced a convoluted tube to bend around obstructions and places affixing magnets where needed.

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Jaguar Land Rover

Jaguar Land Rover (JLR) invested in 3D printing technology to broaden its resin-based rapid prototyping capabilities. The ability to create models directly from CAD data with elastomer, models directly from CAD data with rubber-like elastomer materials, and produce working mechanisms were other key benefits that would contribute to reducing development cycles. To prove its capability, the 3D printer was initially tasked with producing a complete fascia air vent assembly for a Range Rover Sport. It used rigid materials for the housing and air-deflection blades and rubber-like materials for the control knobs and air seals.

JLR printed the complete fascia air vent, as a working part, in a single process. Once printed, the model was taken from the printer, cleaned and tested, proving that the hinges on the blades all worked and the control knob had the right look and feel.

Over-molding is another part 3D printed at JLR. Two materials are used, but not mixed, to create a cover with a rubber seal. The assembly can be used directly for fit and functional testing. Other key areas for use include the development of door seals and protective gaiters where just the rubber-like material is used, and also the creation of parts for functional testing.

The styling department is the biggest user of PolyJet capabilities at JLR. More than half of everything on their 3D printer finds its way into the design studio to help finalize new design proposals. One example is a telescopic headlight washing system prototype that cleans headlights every fifth time the windshield is washed. JLR was able to prove this design before moving into an expensive tooling stage.

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THE VALUE TO YOUR RP PROCESS

The value of the Stratasys J750 to your rapid prototyping design process is exponential savings of both design validation time and material cost. The Stratasys J750 can:

- Reduce weeks/months into hours/days.
- Eliminate multi-step acrylic milling and molding processes and the gluing of separate colored parts.
- Perfect boundary separation between red/yellow/transparent elements of lighting lens covers.
- Easily scale new interior design elements to the entire cabin interior environment experience, including the capability to replicate wood, leather, carbon fiber and other texture effects with a high level of accuracy.
- Reduce cost per lighting cover prototype from roughly $3,000 to roughly $300.
- Enable a 10X cost reduction.
- Save $10,000-$15,000 per lighting cover for a full design cycle of roughly five prototypes. (This doesn't even include additional monetary value of time saved.)
- Save hundreds of thousands of dollars in multiple lighting and internal cabin designs per year
- Achieve ROI on a Stratasys J750 purchase within one year.

Conclusion

The advantages of 3D printing prototypes on the Stratasys J750 in the auto industry are numerous and compelling. Other applications and reasons include:

- Whether it's the fact that typically 60-70% of material in the fabrication process ends up as waste, there is nearly zero waste.
- While automotive OEM and suppliers primarily use AM for RP, the technical trajectory of AM makes a strong case for its use in product innovation and high-volume direct manufacturing in the future.
- Supply chain transformation: by eliminating the need for new tooling and directly producing final parts, AM cuts down on overall lead time, thus improving market responsiveness. It can also drastically reduce scrap and drive down material usage. When weight is an issue, 3D printing can lower handling costs, while on-demand and on-location production can lower inventory costs.
- Product innovation and supply chain transformation has the potential to alter the business models of auto companies.

Henry Ford's assembly line model cut Model T assembly time from 12.5 hours per car to just 93 minutes. Rapid prototyping with 3D printing on the Stratasys J750 has the capability to have the same degree of impact on the design validation process for certain exterior and interior parts.

Ford's assembly line drastically reduced costs through utilization of standardized parts and greater efficiency which led to lower costs, higher quality and greater reliability in products.

Rapid prototyping with 3D printing puts a 21st century spin on standardization, which is customization, and allows automotive manufacturers to quickly iterate design for customized parts as well as print with mixed materials and 500,000 colors.

Whether it's rapid prototyping, functional testing of parts or final part production that has the capability to disrupt the entire supply chain, 3D printing in the automotive industry is here to stay.

The initial investment required for the Stratasys J750 can be considered a barrier-to-entry. However, when considering the reduction in product development time and the capability to capture design issues early in the process, the return on investment makes perfect sense. Industry leaders would say automakers interested in leading the industry cannot afford to overlook the technology or settle for any 3D printer with lesser capabilities than the Stratasys J750 state-of-the-art 3D printer.

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