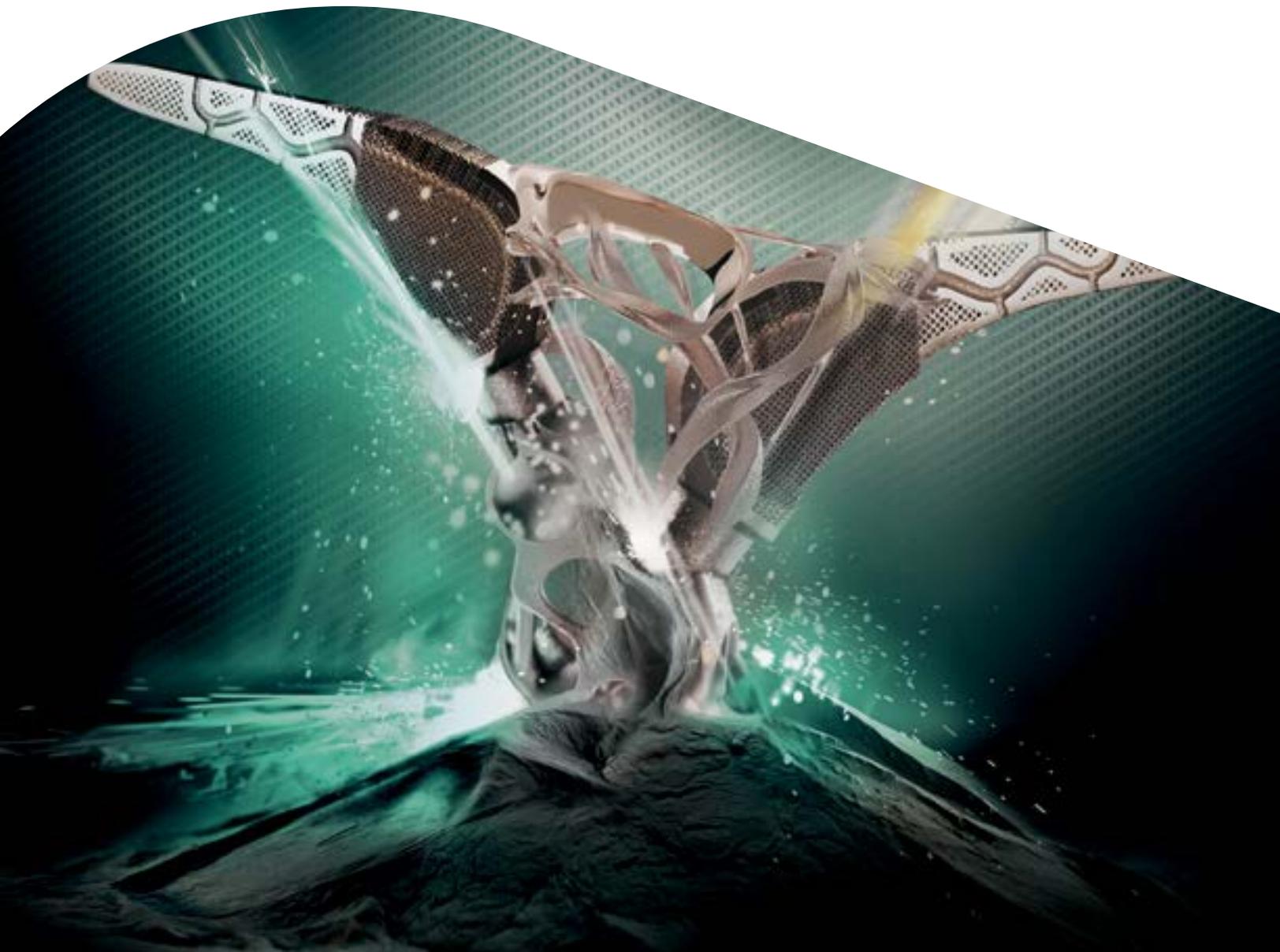


Unleashing additive manufacturing's full potential: the case for CT inspection

Harness the innovative power of additive manufacturing, made viable by CT inspection solutions



Executive summary

We have all experienced it. Both technology and its impact on humanity are profound, transforming our individual and collective lives in ways that are well beyond our imagination. The magnitude of these extraordinary changes, however, seems dwarfed when compared to the enormity of technology's impact in the engineering realm. In fact, as you read these words, one of our century's most innovative technologies is dramatically disrupting design and manufacturing processes in the engineering world. In ways never thought possible, one technological capability is silently shaping a better, stronger future for us all. Its name is additive manufacturing.

For engineers and manufacturers, additive manufacturing, also known as 3D printing, holds an unprecedented promise. It is an engineering marvel that enables the creation of highly complex, technically intricate and customizable three-dimensional parts.

With all this promise, where are additive manufacturing's emerging, innovative opportunities? We believe a key enabler is needed to realize additive manufacturing's full potential in sophisticated applications: Computed Tomography (CT) Inspection. In the highly integrated, intricate and complex parts that additive manufacturing produces, there has not been an adequate assessment tool to assure quality control, including internal and external part surfaces. CT inspection answers that unmet need.

So, to harness the tremendous potential of additive manufacturing, it must coexist with CT inspection: to facilitate full life-cycle quality control and to wholly enable rapid, real-time design iterations. Combined, CT inspection will enable additive manufacturing to unleash its full potential and give engineers and manufacturers a window to the future and beyond. These two interdependent elements will disrupt engineering design, obsolete manufacturing limitations and transform entire industries.

Why additive manufacturing is a game changer

A new frontier...

The holy grail in engineering is leveraging innovation and invention to solve previously “unsolvable” challenges that can improve life for us all.

That’s where additive manufacturing shines brightest, catalyzing innovation at new levels and expanding into new frontiers of possibility. Intricate parts that leverage highly complex geometries can now be produced in three-dimensions with additive manufacturing – faster and more cost effectively than conventional manufacturing.

Additive manufacturing uses modeling software to build physical, three-dimensional objects by adding layer-upon-layer of material. Materials, such as plastic or metal and often in powder form, are used to build successive layers and are subsequently melted to fuse and produce the final part.

“Additive manufacturing transcends traditional constraints in manufacturing and design and catalyzes creativity, exponentially.”

Josh Mook, Innovation Leader, GE Additive

In additive manufacturing, engineers must unshackle themselves from conventional design thinking and problem solving. “A new design mindset is required to fully embrace additive manufacturing possibilities. To think beyond the traditional constraints in manufacturing and design provides innovative ideation that catalyzes creativity, exponentially.”

Some of additive manufacturing’s unique and tangible benefits include:



Design freedom allowing engineers to approach challenges in an entirely new way



Inventory reductions through multiple part integration into one design



Sophistication on multiple dimensions such as form, fit and function



Minimized lead-time for manufacturing, including highly customized products



Fewer and faster design iterations during product development



Shorter time to market meeting customer demand more quickly

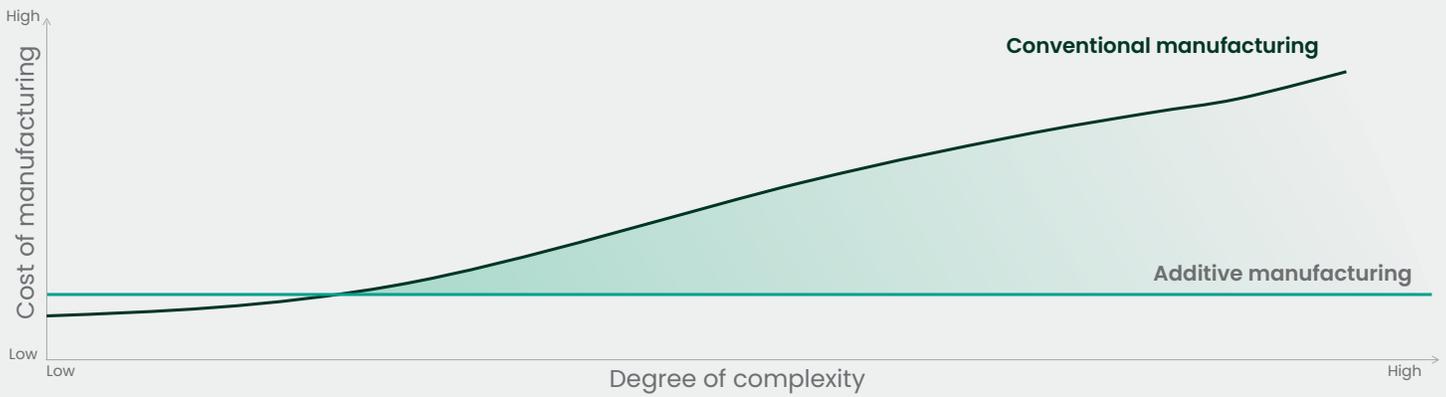


Individual manufacturing customization of moderate to mass quantities of products



Create on-demand spare parts where replacements are obsolete or in remote environments and a spare part is critically needed (military applications)

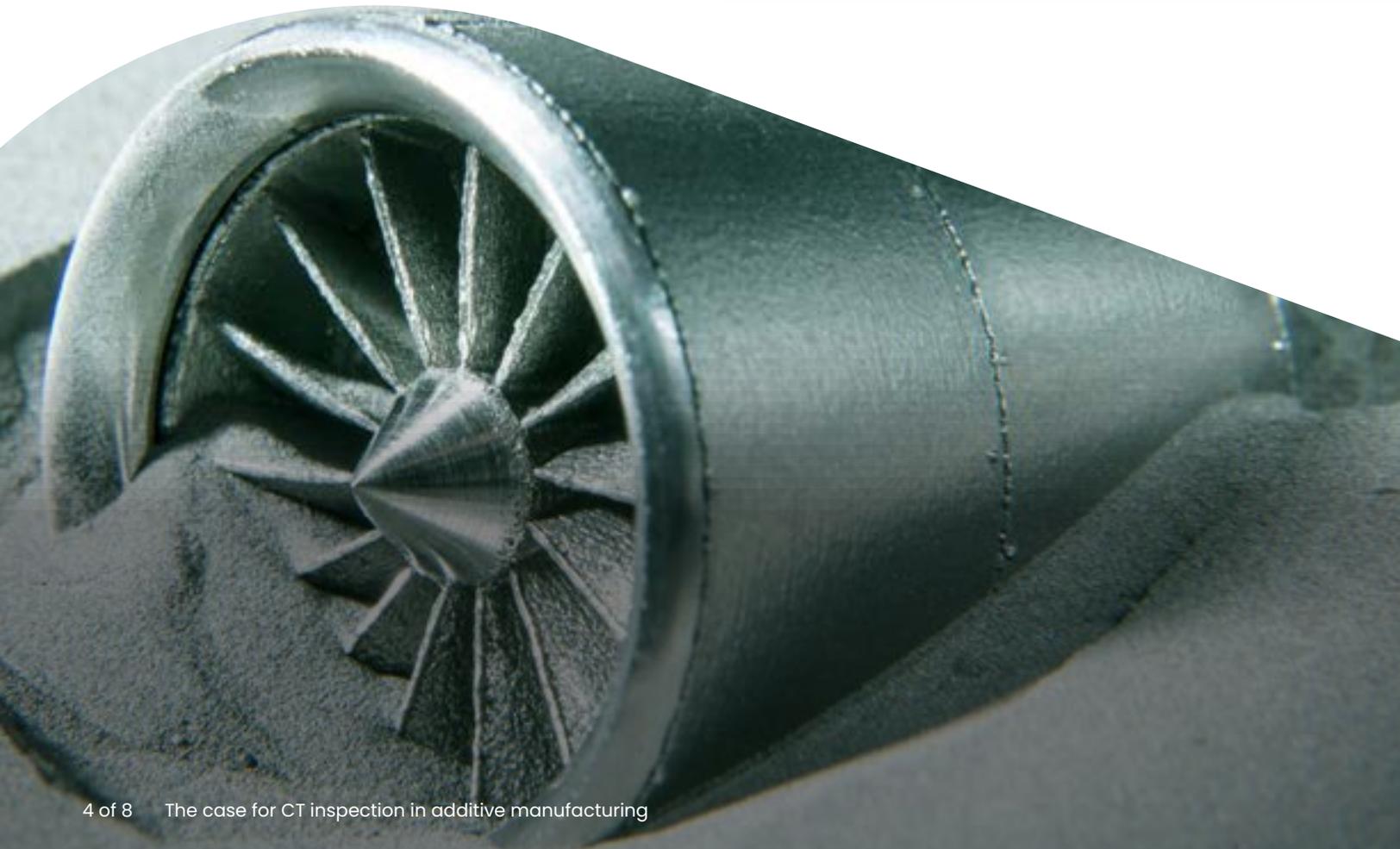
Design complexity with additive manufacturing



For design engineers, additive manufacturing significantly redefines conventional production and manufacturing paradigms. It enables design sophistication and part cost to be inversely proportionate to each other. In other words, as the complexity of a part increases, conventional manufacturing costs rise. With additive manufacturing, as part complexity increases, design innovation is free

because the cost of manufacturing is constant. Further, this relationship creates more than a cost advantage. It also enables impressive product development speeds that allow rapid step changes in product innovation.

Additive manufacturing enables design innovation that is inversely proportional to manufacturing cost.





Additive manufacturing in action: LEAP fuel nozzle

Let's look at an example to see how additive manufacturing works in the real world.

Design complexity in jet engines is – or rather used to be – expensive. By designing and producing a sophisticated cobalt-based alloy additive manufacturing fuel nozzle for LEAP jet engines, Baker Hughes is disrupting the jet engine industry. The LEAP fuel nozzle leverages additive's simultaneous benefits of lower costs with highly sophisticated design,

combining 20 parts into one single part that weighs 25 percent less and is five times more durable.

From design to manufacturing to real-world results, the LEAP success story is extraordinary. To-date, the LEAP fuel nozzle is powering planes that have carried more than five million passengers. More than 14,500 LEAP jet engines have been ordered – a \$210 billion value. Additionally, a 15 percent improvement in fuel efficiency was achieved for LEAP jet engines, thanks in part to the additive manufactured fuel nozzle.

Additive Example

LEAP Fuel Nozzle

This is just the beginning. Additive manufacturing's feasibility goes well beyond the aviation industry to include applications within the medical device, oil and gas and automotive industries (more on industry examples shortly). The key point is this: as additive manufacturing moves farther into industries to make sophisticated and highly accurate applications possible, its strongest ally, Computed Tomography (CT) inspection, becomes an essential, must-have enabler. The LEAP fuel nozzle, in fact, uses CT inspection throughout the production life cycle to ensure ironclad quality and inspection across materials, production and process.

Source: GE Aviation

*LEAP is a trademark of CFM International, a 50/50 JV between GE and Safran Aircraft Engines. Comparison versus TAPS fuel nozzle.



25%

Weight Reduction

20 → 1

Parts

5x

More Durable

30%

Cost Efficiency Improvement

95%

Inventory Reduction

How CT inspection makes additive manufacturing viable

Due to the sophistication made possible through additive manufacturing design, stringent quality control and measurable, repeatable consistency is crucial throughout the entire production life cycle—from raw materials to in-process manufacturing to final part inspection. For raw material(s), such as powder(s), and the intricacies of many additive designs, quality must be measured with nano-focused resolution in areas that are, for the most part, obscured, undetectable and/or unquantifiable with the naked eye.

Enter CT inspection, additive manufacturing's powerful partner and a key enabler for highly intricate additive applications. CT inspection uses radiation to scan and create three-dimensional images of the inside and outside of an object without cutting it. When used together, CT inspection increases the potential breadth and depth of additive manufacturing exponentially.

Raw Materials. For the most part, additive manufacturing utilizes raw materials in powder form, although liquid and sheet formats are also alternatives for some applications. Ensuring powder consistency – such as uniformity of particle size, shape and porosity – is the ever-important starting point and foundation for a quality final part.

CT inspection uses high resolution imaging to analyze powder characteristics such as grain size and distribution, homogeneity and detection of foreign materials.

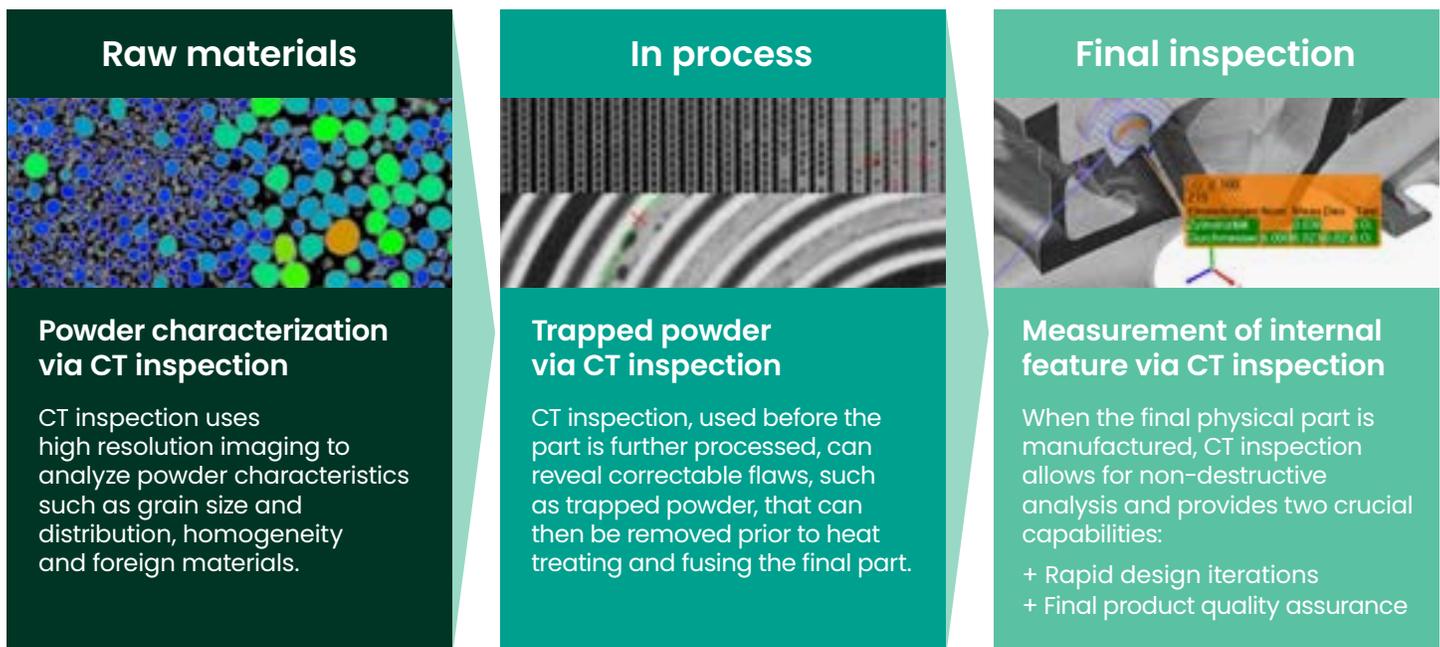
In-Process Manufacturing. Additive manufacturing builds a part layer-upon-layer, adding subsequent layers to achieve the final 3D part. Before the part is further processed, there is a quality control opportunity that allows for the correction of flaws. For example, CT inspection can reveal trapped powder that can then be removed prior to heat treating and fusing the final part.

Final Part Inspection. Assurance of a consistently replicable final part is achieved by ensuring that each part meets its stringent specifications. When the final 3D physical part is manufactured, CT inspection allows for non-destructive analysis and thus provides two crucial capabilities:

- Rapid design iterations: CT analysis allows you to peer inside the prototype to examine and evaluate the features without destroying the part, enabling quick design feedback and allowing for fast iterations. Answer questions such as:
 - Did you produce what you expected and intended from your design?
 - Are your support structures properly located and doing their job?
- Final product quality assurance: CT inspection provides dimensional analysis and measurement of critical internal features, such as wall thicknesses as well as the identification and location of porosity, inclusions and voids in the final part.

What CT inspection can do for additive manufacturing

Benefits throughout the entire additive life cycle



Catalyzing industry innovation via design disruptions

In industries ripe for design disruption, additive manufacturing, together with CT inspection, will revolutionize the way products look and the way they are designed and manufactured to catalyze innovation.

Let's take a look at applications in four diverse industries, all of which have a zero tolerance for any type of part defect, making CT inspection the must-have partner to additive manufacturing:



Aviation

In aviation, additive manufacturing is being used in critical and non-critical components and thus fostering innovations that are first-ever industry inventions at incredible speeds with simultaneous cost savings. Baker Hughes has disrupted design with their Catalyst advanced turboprop engine, using additive manufacturing to redesign and replace 855 parts with 12, achieve a 20% improvement in fuel burn and reduce the combustor test schedule from 12 months to six months.

Other aviation parts that leverage additive manufacturing techniques are being built by companies such as Boeing, Southwest Airlines and Delta Airlines for commercial airplanes. Applications include parts used in air ducts, stowage bins, furnishings and footrests.



Oil and gas industry

The oil and gas industry is incredibly ripe for design disruption. With sophisticated part designs, lengthy production time (especially for an offshore asset), costly supply chains, and the looming risk of expensive and damaging downtime, there is a clear need to streamline processes and reduce costs. Thus, the adoption of additive manufacturing with CT inspection is an ideal solution.

Baker Hughes is leveraging additive manufacturing in oil and gas today, with the production of metal end burners for gas turbine combustion chambers, control valve parts and nozzles. Oil and gas companies are likely to expand additively manufactured applications to include refining and processing equipment, on-demand spare parts and prototyping/modeling for exploration and operational equipment.

In addition to helping individuals, additive manufacturing and CT inspection can increase incremental revenue by million of dollars due to faster times to market. On the cost reduction side, an estimated 25 percent can be saved in development costs over more conventional methods.

The additive manufacturing revolution is gaining momentum. While the technology has been around



Automotive

Barriers to entry are high in the automotive industry, where sophisticated automation and scale are keys to competing globally. Additive manufacturing is introducing faster to market parts and rapid design development to enable more innovation. Currently, automotive applications are leveraging additive manufacturing for prototyping, tooling and increasingly for parts production as well. In China, the world's first automobile, called Urbee, was built using additive manufacturing.

The large automobile manufacturers and their OEMs are embracing additive manufacturing and expanding its' use and applications. For example, Ford uses 14 additive printers to produce 200,000 parts each year. Improvements in time and money saved are significant. In one example, Ford's design of intake manifolds has been reduced from four months at a \$500,000 cost to four days at \$3,000.



Medical device industry

When it comes to saving and enhancing lives, speed is essential, and outcome significance is high. Too often, cost is high as well. Orthopedic companies are taking the lead in adopting additive manufacturing to increase time to market, decrease costs and make products tailored for individuals.

Additive manufacturing is used to produce personalized orthopedic and cranial implants, dental restorations such as crowns, external prosthetics and customized surgical instruments.

for 20 years, initial growth was far slower. Today, additive manufacturing, together with CT inspection, possesses proven credibility. Additive's adoption in highly sophisticated engineering industries where its ability to reduce costs, improve performance and minimize time to market are creating the ideal scenario for the wide spread viability of additive manufacturing/CT inspection solutions across a number of industries.

Exploring what's possible

We invite you to explore where additive manufacturing might be right for your business or application. As the understanding of additive manufacturing increases, the adoption of it is rising dramatically. Helping companies understand the importance of integrating CT inspection to ensure safety and the production of consistent, high quality parts are top priorities. Our mission is to aid in that education and help facilitate the incredible transformations we have both seen and experienced.

To start, many engineers develop an application-based business case that quantifies feature geometry, cost, lead-time, performance and other tangible design benefits for additive manufacturing vs. conventional manufacturing.

The path forward is knowledge and innovation. Once additive methods are understood, then a business case for applications can be made. In our experience, the business case can show how additive manufacturing enables innovation in design that brings step changes to performance of products

and value to end users and customers. That's where exponential increases in value are made possible.

Additive manufacturing paired with CT inspection is redefining our world, obsoleting limitations and transforming entire industries to foster new levels of innovation. Together with you, we are committed to that journey toward a better future.

For more information, feel free to
contact us here: bakerhughesds.com/contact

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