As raw material costs are rising and the Earth’s supply of certain ores is nearing depletion, the aircraft industry is looking for leaner and more sustainable manufacturing processes. While composite materials seem to be taking over the aerospace world, metals still play a crucial role and a major innovation is knocking on the door. Additive manufacturing is to be a replacement for machining and will reduce waste and increase design freedom.

Many aircraft parts today are made by milling. A billet is installed on a milling machine and material is cut away wherever it is not needed. This process is well-known, relatively simple and can produce high-quality parts. However, parts with a complex geometry are expensive and difficult (if not impossible) to manufacture. Also, milling inherently generates a lot of waste material which, especially in the case of aluminium alloys, is hard to recycle.

Additive manufacturing, commonly referred to as 3D printing, reverses the way of thinking: instead of starting with a solid billet and removing material to obtain the desired geometry, a part is grown from powder layer by layer and material is added only where it is needed. The result is nearly infinite design freedom (which can lead to significant weight savings through more efficient structural design), without generating any waste.

**HOW IT WORKS**
Additive manufacturing (AM) starts with a machine dispersing a fine layer of powder. A laser or electron beam then “draws” a pattern across this layer, melting the material together where needed. Next, a new layer of powder is dispersed and a new pattern is melted on top of the previous one. This process is repeated over and over, slowly but surely building up a product. When all layers are processed, the result is a block of loose powder with the solidified product inside. The unused powder can easily be removed and reused without loss of quality. The product can have nearly any shape — since each layer needs to be processed anyway, it does not take any more time (or money) to create a more complex geometry. This opens up a whole new world of possibilities: think hollow parts, microstructures and integration of multiple components that currently have to be made separately and joined with fasteners or an adhesive.

AM can be applied to a wide range of materials, from polymers and ceramics to aerospace grade steel, aluminium or titanium alloys. Obviously the process conditions vary by material, but the concept remains the same. This wide range of applicability makes AM an attractive process for aerospace manufacturers to research.

**CHALLENGES AHEAD**
There is still a long way to go before this new technology can be applied to commercial aircraft though. As always with innovations in the aerospace industry, complying with airworthiness regulations proves to be an immense challenge. Aircraft manufacturers must demonstrate that the new process delivers parts with a constant and predictable quality to ensure passenger safety. Several questions are raised. Are dimensional tolerances and surface roughness acceptable? Is the fatigue performance of parts predictable? What is the crystal structure of the material after processing, and how is it affected by changing the process conditions? Do the products contain any voids or porosities? While many parties (most notably EADS) claim excellent prospects for additive manufacturing, finding the answers to these questions and proving the reliability of AM will still take several years.

One of the major problems that must
Figure 1. The EADS Airbike made entirely with additive manufacturing

Figure 2. Cheek bone implant made from titanium using additive manufacturing

be solved is the surface roughness produced by additive manufacturing. Many aircraft parts require smooth surfaces for a variety of reasons: aerodynamic drag, leak-tightness of parts involved with the fuel system or hydraulics, or fatigue life of structural components (rough surfaces help crack initiation, deteriorating fatigue properties). The roughness of AMed parts (especially when using metal) is relatively high, because it is impossible for the laser or electron beam to melt the material where it should, without heating up the material right next to it. In fact, to reduce the required intensity of the beam and to speed up the process, the environmental temperature is often brought close to the material’s melting point. As a result, the powder that is close to the solidified component will stick to the surface, generating a very rough finish. Engineers believe the roughness can be improved by further developing the process (e.g. by letting the beam make a stirring motion instead of a linear one, or by adjusting the environmental temperature).

In terms of cost and cycle times, AM seems to be performing relatively well compared to milling. As explained above, a major advantage of AM is that complexity does not come at an extra price. This means AM – even if the process is still very much in development – can already compete with milling in some cases. For simple parts though, AM currently takes more time and is more costly than machining (due to high energy consumption and expensive equipment). However, there are more advantages that may outweigh the higher one-off cost. As explained above, AM can lead to lighter parts through more complex (more efficient) structural design and the integration of components – EADS claim weight reductions of up to 65% in some cases. This will improve fuel efficiency. Integrating multiple components into one will also reduce assembly time and improve reliability. Additionally, the supply chain is simplified as all parts can be made from the same powder, taking away the need for different billets of raw material for different parts.

EXAMPLES

One of the major aerospace players in the development of additive manufacturing is EADS Innovation Works, a division of EADS working on long-term Research & Development projects. Their focus lies in multiple areas: developing the manufacturing process itself, showing its potential by redesigning and producing parts for Airbus aircraft or for other industries (e.g. sports cars) and promoting additive manufacturing through showcases that appeal to a general public. In March 2011, ‘Innovation Works presented the ‘Airbike’ (see Figure 1), a bicycle made entirely from 3D printed nylon. The Airbike was made to demonstrate the potential of additive manufacturing, as can be seen in the lightweight truss structure integrated in its frame, the cushioning structure inside the saddle, or the cranks directly integrated with their bearings in order to reduce the number of moving parts.

The idea of 3D printing has applications that reach much further than just the aerospace industry. Hewlett Packard launched a 3D printer for home use in 2010, allowing artists or designers to create prototypes as they draw them. Additive manufacturing is also used to make jewellery and is set to find its way to the automotive industry and the medical world. For example, the Belgian company LayerWise made a custom cheek bone from titanium in June 2011 (see Figure 2), which was implanted in an elderly woman suffering from bone degradation. The benefits of AM in this case are obvious: the complex shape is relatively simple to make, customisation for each patient is easy and virtually free, while production can be started with a mere click on the button, resulting in fast delivery of the implant.

As so many industries and parties may benefit from additive manufacturing, financial efforts to support further research and development are booming and the technology is being improved rapidly. With their reduced waste, improved structural efficiency and enhanced supply chain flexibility, how long will it take before we can fly around in printed airplanes?

References

“The future of manufacturing...on two wheels”, press release, EADS, 2011