Sim Takes Flight

The use of simulation software allows GE Aviation to try out creative approaches to machining—without the risk of costly failures.

By Bryan Jacobs, CGTech

Using the latest CNC simulation software technology, R&D engineers at GE Aviation, Bromont, Quebec, are developing creative solutions to complex challenges. One such challenge was developing the manufacturing process for the titanium leading edges of 18 composite fan blades used in each GEnx jet engine, which will power the Boeing 787 Dreamliner and the Boeing 747-8.

The GEnx engine provides substantially improved operating economies over comparable current engines. With more than 1,100 GEnx engines ordered to date, it is the fastest-selling engine in GE Aviation's history. Composite materials and specialized coatings are used in the engine's lightweight, "super-high bypass" fan blades.

Super-high bypass refers to aerodynamic improvements in the design of the fan blades and other engine components, which help improve fuel efficiency and reduce engine noise by 30 percent compared with a baseline GE CF6 engine.

GE Aviation

The GEnx is GE's next-generation turbofan engine for medium-capacity, long-range aircraft, including the Boeing 787 Dreamliner.

The blades are made from a defect-free, carbon-reinforced epoxy composite, which means there are no wrinkles or voids in the fibers. Each blade includes 400 plies of prepregged tape with the plies thinning from the base to the tip. The blades help the engine generate 53,000 to 75,000 lbs. of thrust, depending on the model.

Leading Edge Manufacturing

A 6-4 titanium leading edge is attached to the fan blades to protect the sharp-edged composite from fraying or being damaged by foreign objects. Traditionally, GE Aviation has subcontracted machining of leading edges for its aircraft engines to an outside supplier that uses a patented machining process. However, due to high demand for the GEnx engine, GE Aviation needed to add machining capacity at its own operations to supplement that of its outside supplier.

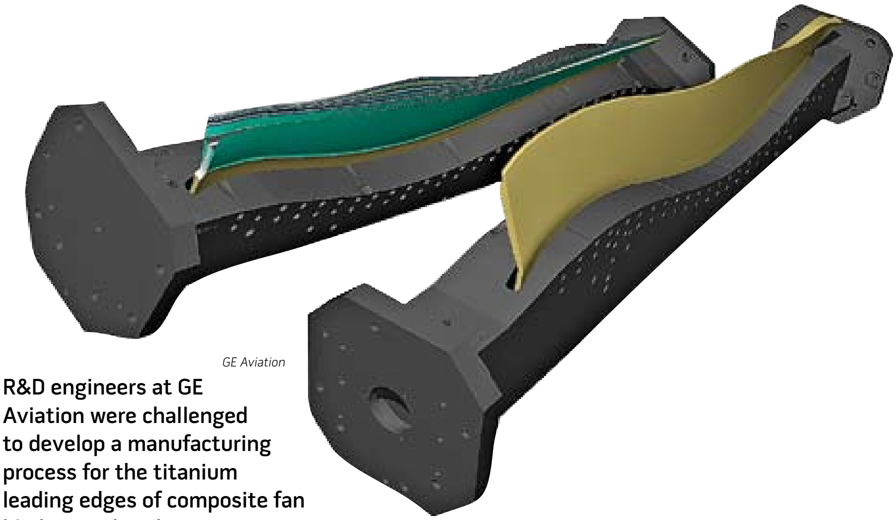
Alain Ouellette, new product introduction manager for GE Aviation, was tasked with developing a cost-effective solution to manufacturing the leading edges in-house, and in January 2005 he assembled a group of engineers, designers and programmers. GE Aviation planned to machine the blade's leading edge on its StarragHeckert 5-axis milling machine.

Benoit Courtemanche, NC programmer for GE Aviation, sought a way to machine the blades using a 5-axis milling program, but needed a way to prove to management that it could work. He decided to use Vericut 6.0 simulation software to prove the process. Prior to this project, GE Aviation had been using Vericut for collision checking only, but it now uses Vericut's ability to perform machine simulation, create videos and demonstrate the feasibility of machining new products.

"It would have been very difficult to verbally explain to management the proposed process," said Courtemanche. "I simply showed them a video of the Vericut simulation. It is a great tool for communicating with management and other departments." Vericut software, developed by CGTech, Irvine, Calif., simulates CNC machining to detect errors, potential collisions or areas of inefficiency. Vericut enables NC programmers to correct errors before the program is loaded on the machine, thereby eliminating manual prove outs.

Vericut shows material removal at the workpiece level and simulates entire machine tools as they appear on a shop floor. The program also simulates NC machine controls and supports advanced control functions to reduce the possibility of machine crashes. The program's machine simulation module detects collisions and near misses between all machining elements, such as axis slides, heads, turrets, rotary tables, spindles, toolchangers, fixtures, workpieces, cutting tools and other user-defined objects. A user can set up near-miss zones around various components to check for close calls, and detect overtravel errors as well.

To prove that the 5-axis milling process could work for the GEnx leading edges, every process element was tested in the Vericut virtual environment. The StarragHeckert machine available in the GE Aviation machine shop had a cylindrical work envelope 17" in diameter × 41" long, so Courtemanche's first step was to determine if it would be possible to machine the leading edge in the machine. The entire machine, fixtures and new tools that would have to be designed for the operation were all simulated in Vericut, which determined that it would be possible to use the StarragHeckert machine to produce the leading edge.



GE Aviation

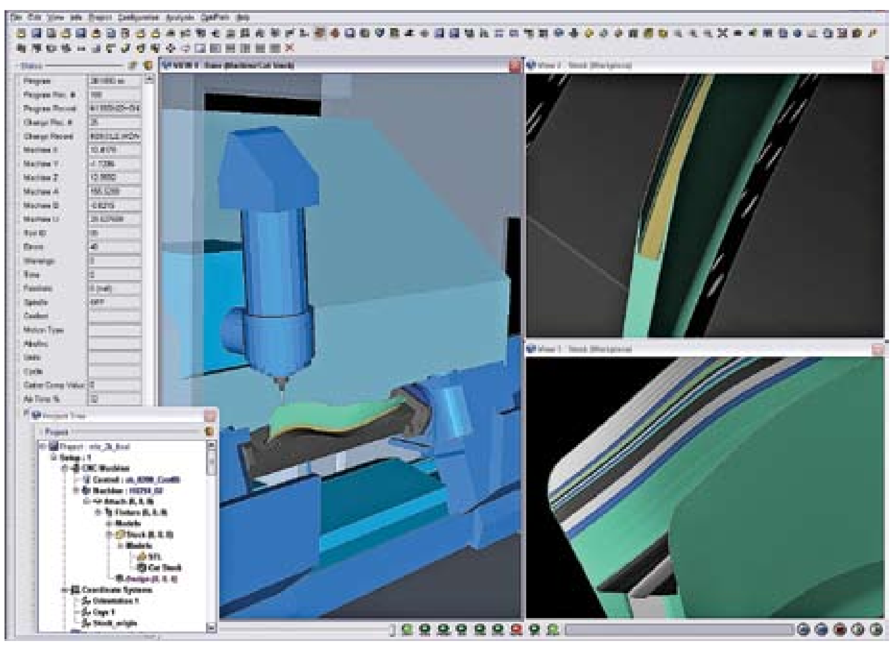
R&D engineers at GE Aviation were challenged to develop a manufacturing process for the titanium leading edges of composite fan blades used in the GEnx engine.

Flying V

The leading edge's final shape is a 3'-tall V with walls down to 0.010" thick. The inside of the V is up to 5" deep and its part width varies from 5/16" to ¾". As a result, the cutting tool must reach a deep cavity in a minimum amount of space, requiring a high depth-to-diameter ratio.

The inside and outside dimensions of the V-shaped part are cut in small levels from top to bottom, with each level receiving a roughing and finishing pass before the machine proceeds to the next level. There are more than 200 levels in each leading edge. Multiple tools of different lengths are applied to ensure the machine always uses the shortest, most rigid cutter possible.

GE Aviation's biggest programming challenge was that its NX4 CAM



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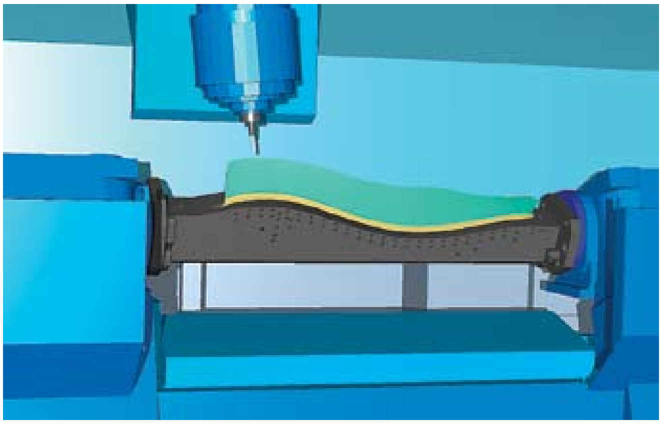
software does not have any information about the remaining material when generating 5-axis motions, which creates the potential for collisions. After using Vericut, GE found that most potential collisions occurred with the toolholder. To mill the required deep pocket, GE modified its shrink-fit toolholder to fit into the space between the two walls. For example, the cavity is close to 7" deep in some areas but the tool is never more than 4.5" out of the holder.

Courtemanche used Vericut to detect the toolholder and predict tool collisions inside the V shape. Some of the toolholders come as close as 0.010" to the part wall. When a collision was detected, Courtemanche reprogrammed the 5-axis motion



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Vericut was used to both prove out GE Aviation's milling process and create the specifications for a future machine order. After altering the virtual machine's dimensions in Vericut, the virtual models were sent to StarragHeckert to custom-build the new machine to GE's requirements.

to create a new virtual surface in the CAM system, enabling a smooth, high-speed milling toolpath. The new toolpath, which includes a lead angle and a tilt angle, allowed GE Aviation to "swing" the holder in many directions to follow the part geometry. This process was repeated hundreds of times.

"Vericut has been running 16 hours a day for the past 2½ years to work out the details of this process," said Courtemanche. "It would have been impossible to test new processes on an actual machine. We can now try every idea, no matter how crazy it may seem at the time."

Once the machining process was proven in a virtual environment, it was taken to the machine. The first leading edge—cut from a solid-titanium billet—took over 110 hours to complete. By using a titanium forging instead of a billet and refining the process—again designed and modeled in Vericut—machining time was reduced to 46 hours. The forging has a large tab at the base of the V where the part is held in a long vise. Once the part is completed on the machine, it only has two small tabs at the bottom; the operator grabs the part and breaks the tab off by hand, much like separating the plastic parts of a model airplane.

The part is then inspected to confirm it is within tolerance. GE Aviation uses what it calls "free-state" inspection, meaning

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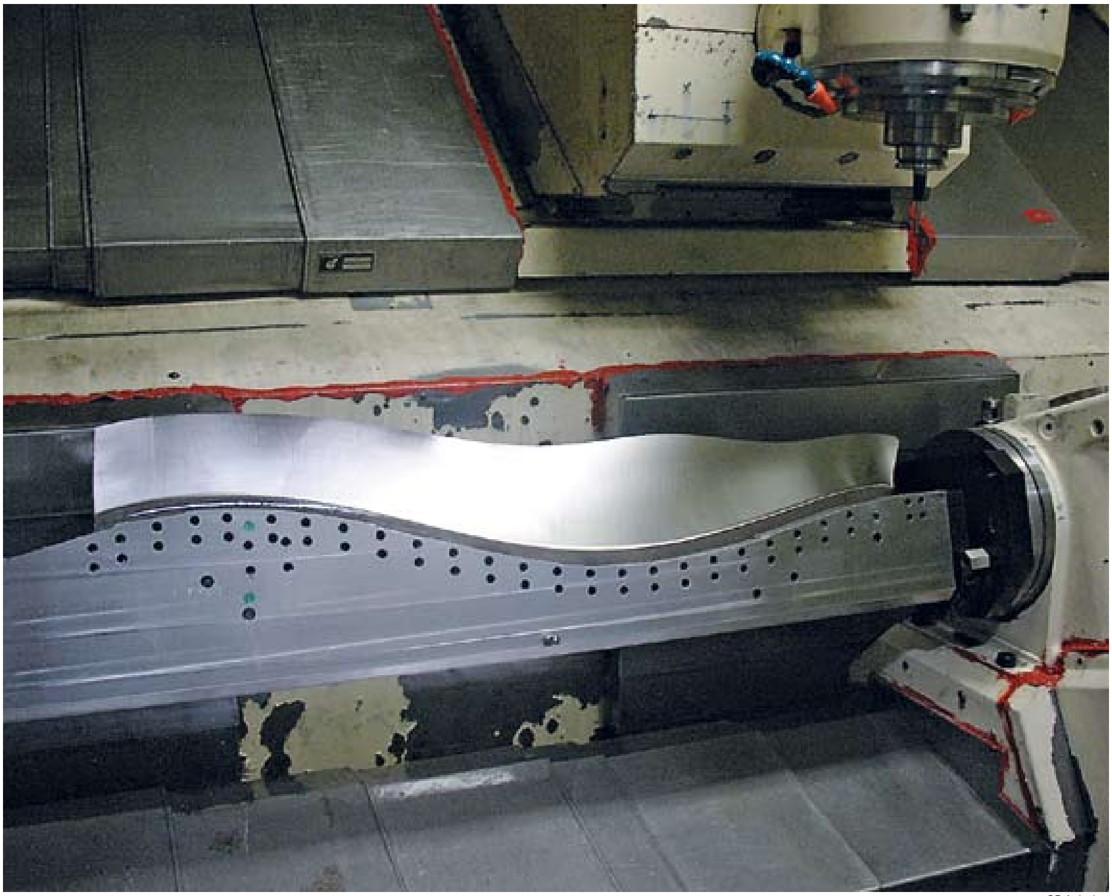
that the part is not constrained during inspection. Normally, a thin-wall part like the leading edge is constrained against a nominal shape and only the thickness and the external surfaces are checked. In free-state inspection, all of the internal and external surfaces are scanned with a Zeiss CMM, which detects any deviation.

The new machining process has worked so well for GE Aviation that it is buying two additional machine tools so it can increase production. The new machine technologies, use of Vericut's OptiPath module and the application of new tooling, coolant and roughing strategies should allow GE Aviation to reduce total machining time for each leading edge to less than 24 hours.

Creating a Virtual Machine

In fall 2008, GE Aviation will begin producing leading edges in one operation on a new, custom-made StarragHeckert machine. GE Aviation used Vericut in the machine tool acqui-



GE Aviation

A 5-axis StarragHeckert machine was used to machine the first titanium leading edge. When the part is completed, it has two small tabs at the bottom; the operator simply grabs the part and breaks the tab off by hand, much like separating the plastic parts of a model airplane.

sition process. For example, to develop specifications for its new machine, Courtemanche examined Vericut models of an existing StarragHeckert machine that most closely matched his requirements. He then used Vericut to alter the machine's dimensions to match his specifications. Once his process was again proven virtually, the models were sent to StarragHeckert to custom-build the new machine.

"Vericut allows us to test the latest machine technology without having the actual machine in place," said Courtemanche. "If we did not have Vericut, we would have been forced to buy the identical machine that we proved the process on—not the machine that best suited our process."

GE Aviation has produced 60 leading edges so far, and the machining process has changed many times. Even with those changes, there has not been a single machine collision and scrapped material has been reduced to a minimum.

With the success of the leading edge project, GE Aviation's R&D team is now taking a fresh look at other existing projects. Said Courtemanche, "Before Vericut, proving a new process might take 1 week; now it can be done in less than 1 day, which allows us to take a fresh look at how we do things." CTE

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