Flight Plan

▶ BY BILL KENNEDY, CONTRIBUTING EDITOR

Seven-axis machining allows one propeller manufacturer to eliminate variability and trim production time.

Since the early days of flight, aeronautical engineers have known that changing the shape of a propeller blade airfoil directly affects flight performance. They've also known that airfoil shapes that improve performance in one way often negatively affect performance in another. For example, a propeller designed to facilitate a fast takeoff might also produce more noise.

Designing propellers that can overcome performance trade-offs is a challenge. And transforming a design into the desired manufactured shape is a larger challenge still.

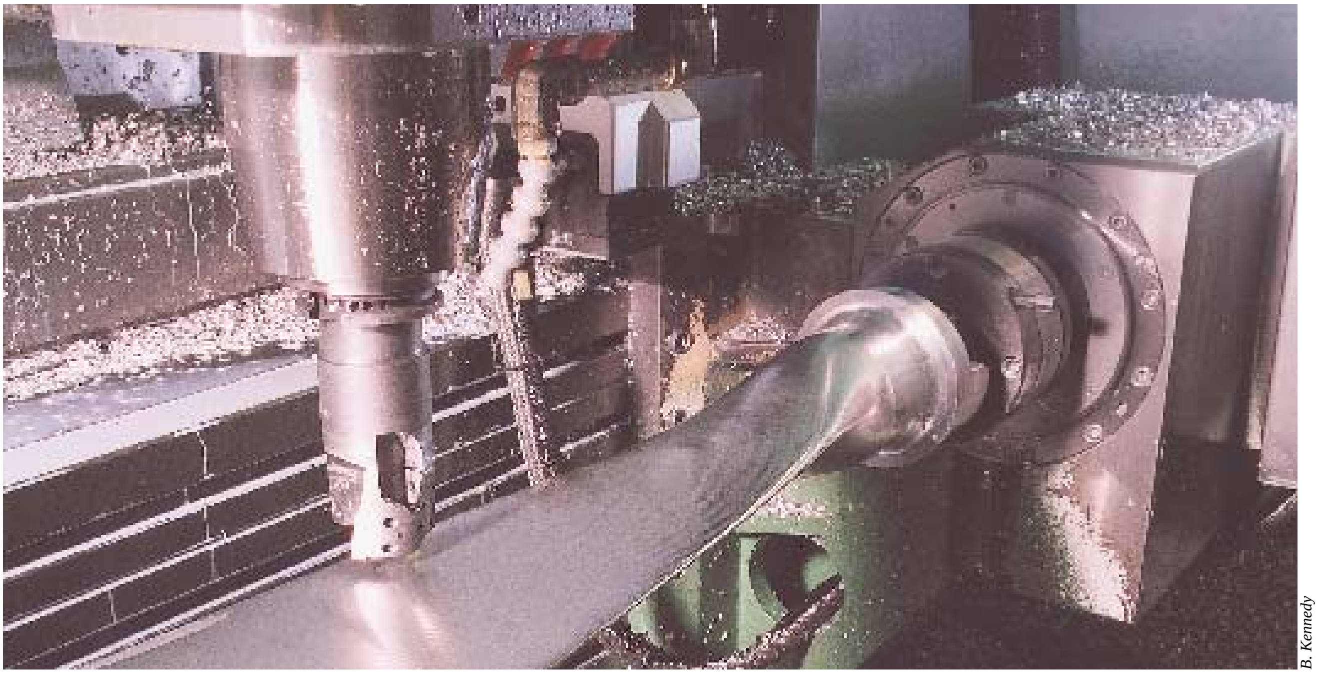
Today, however, software and machining systems have evolved to the point where propeller manufacturers can vary the airfoil profile across a blade and minimize the compromises. In these "blended" propeller designs, a blade's midsection, for instance, can be engineered to maximize low-speed thrust while its tips are contoured to minimize noise.

Hartzell Propeller Inc., Piqua, Ohio, has combined advanced software and metalcutting systems to develop a blade manufacturing process that enables propeller performance to be tailored to a specific customer's needs.

Hartzell also encourages individual employees to think about ways to simplify and speed their specific duties. The combination of technology and teamwork helps the company maintain market leadership in a highly competitive niche of the aerospace industry.

Learning to Fly

In the mid-1980s, Hartzell introduced what was then a sophisticated blade pro-



B. Kennedy

Seven-axis blade-milling at Hartzell Propeller.

B. Kennedy

CNC programmer Mike Rowe demonstrates the CAD system used to design a propeller hub.

duction process. It began with a rather large and heavy (55"×12", 60 lbs.), high-strength, corrosion-resistant aluminum forging.

Bob Allenbaugh, Hartzell's manager of manufacturing services, said the forging's awkward shape and size, in combination with the machine tool and workholding technology of the day, dictated that his firm machine the propellers' round blade shanks on a horizontal mill. Each shank design required custom-made, carbide form tools. That was troublesome, said Bruce Ford, manufacturing service support representative, because it could take anywhere from 2 weeks to 2 months for outside suppliers to deliver the tools.

Today, advanced turning tool technology and fixturing capabilities enable Hartzell to turn the blade shanks on a lathe, employing standard toolholders and uncoated carbide inserts. Cycle times are more than two-thirds faster than before. But more importantly, the use of readily available standard tooling has reduced the lead time needed to design and machine a new shank from weeks to hours.

In addition, the turning operation produces accuracy within 0.0001". That is important because the shank is used to locate the forging for machining the airfoil in a way that's more advanced than the original method.

With the old process, Hartzell milled the blades' airfoil shape on a 3-axis machining center. The forgings were clamped on work supports, and a milling cutter led by a roller machined one side of the blade. When the first side was completed, the workpiece was taken out of the machine, turned over and clamped on a set of templates shaped to hold the profile of the first side. Then the second side of the blade was milled.

Achieving precision and consistency wasn't easy. The problem was workpiece "movement," resulting from the nature of the aluminum forging. The impact and pressure of forging raises the yield point of the surface of the material, but not of its inner layers. When the forging is milled, Joe Brown, copresident of manufacturing, said, "the more you cut, the more elastic the remaining material is. It's like a lobster. After you've taken the shell off, you get into the softer, more pliant layers."

After machining, he added, the workpiece "kind of 'settles' in."

In anticipation of part movement, Hartzell programmers wrote tool paths that left about 0.015" material above the high blueprint tolerance. Final contours of each blade were ground by hand, but, often, irregularities in the blade were too great to grind. In response, programmers had to rewrite their programs to minimize the high or low areas resulting from workpiece movement during the cutting operation. It was also necessary to make new workholding templates to grip the new blade profiles.

It took a lot of time and affected quality. Brown outlined the frustrations: A half-million-dollar profiling mill was being used as, basically, a test bed for new tool-path programs, which then had to be doctored to get an acceptable result. Every time a program was revised, new workholders had to be made. Finally, hand grinding was necessary to bring the blade to the desired level of precision. "Our grinders are highly trained and skilled, but we still had only an 85 percent first-time-

B. Kennedy

Next to the machining center Don Anthony runs is an inspection bench he created to help speed and optimize the inspection of parts produced at his workstation.

through quality rate," Brown said. In other words, 15 percent of blade output had to go through the grind shop a second time to achieve final tolerances.

Adding up time needed for reprogramming and developing multiple sets of templates, it took at least 2 weeks to produce a new blade. And, for production runs, hand grinding often resulted in blade-to-blade variances in weight.

Cruising Speed

Hartzell's staff knew they needed to increase the blade-making operation's speed, efficiency and quality. And they could have made some incremental progress had they simply decided to update their machinery.

To their credit, they flat out sought a different way, knowing that the accumulation of advancements in machine technology could support it.

"It wasn't a better version of what we did before," Brown said in comparing today's system to the previous technique. "It was an entirely different approach."

Hartzell's engineers reasoned that machining both sides of the blade nearly simultaneously, before it had a chance to settle, might solve the problem. They secured the forging with indexing chucks, which permitted machining all sides of it without unclamping and reclamping it. A 5-axis machining head held the cutting tool normal (perpendicular) to the rotating workpiece during the cut.

The new process combines a 5-axis head with two independently programmable indexers, for a total of seven axes. The workpiece is fixtured between the indexers, which can turn the workpiece as fast as 133 rpm. An endmill fitted with indexable, uncoated carbide inserts is used for roughing, and an uncoated solid-carbide endmill carries out finishing. The cutter proceeds down the length of the workpiece as it turns like a barber pole.

The 3-axis mill used previously was limited to 2,000 rpm and a feed rate of 250 ipm; the new head is capable of 20,000 rpm and a feed rate up to 900 ipm. Allenbaugh said milling time is cut in half.

Because both sides of the blade are milled at effectively the same time, the problems resulting from the forging's uneven response to machining are eliminated. This enables Hartzell to machine "to print." Grinding is now necessary only to remove feed marks. And blade-to-blade weight is consistent.

Eliminating the processes of rewriting CAM programs, making multiple sets of custom fixturing and hand grinding blades to final form has cut the lead time to produce a new blade from weeks to hours. Specifications for a new blade can be on a designer's computer in the morning, shanks can be machined by noon and blades can be milled by the end of the day.

CAD/CAM Power

With its spinning chucks and swinging 5-axis head, the blade-milling process, on a massive mechanical scale, compares to patting your head and rubbing your stomach simultaneously. (If you had five heads and two stomachs!) Making it happen takes a lot of coordinated computing power.

Hartzell developed a design process that enables it to tailor propeller performance to specific customer needs.

What goes down must come up

Manufacturing activity in the aerospace industry rides the jet streams of the global economy. Aerospace structural component maker Excel Manufacturing Inc., Wichita, Kan., accepts cyclicality as part of its business. In fact, Excel anticipates downturns and uses them as opportunities to prepare for future growth.

The company's vice president and general manager, Marwan Hammouri, said, "When operations are running at a fast pace, it is difficult to grow and expand." During slowdowns in 1991, 1995 and 2002, Excel made significant investments in facilities and equipment. The most recent upgrades included $4 million in equipment and $1 million for a plant addition that added 50 percent to the company's manufacturing floor space.

Hammouri stresses a positive approach. "A lot of shops only try to improve on jobs that are losers. They don't look at the winners and make bigger winners out of them."

Hammouri believes the downfall of some shops is that they try again and again to improve inefficient operations but never really change their output. Concentrating just on inefficient operations, he said, "keeps you focused on the wrong things."

On the other hand, he said when an operation is making money, "no one looks at it, and it continues to run as it has for 20 years." Excel, he said, doesn't consider whether a process is a loser or a winner. "It's just pure process-oriented analysis."

Excel's investments mirror its manufacturing philosophy. Part of the latest plan was an automated palletized machining system designed to reduce setup times and improve product quality on short-lead-time jobs. The system consists of two Makino A88E high-speed, 4-axis horizontal machining centers, 20 individual pallets and an automatic guided vehicle for transferring work. The system's control can store up to 250 part programs.

Hammouri said that the stored programs eliminate overruns and verifying the first piece. "We only run what's necessary for the customer."

Setup-time savings, he said, are in the range of 20 to 25 percent.

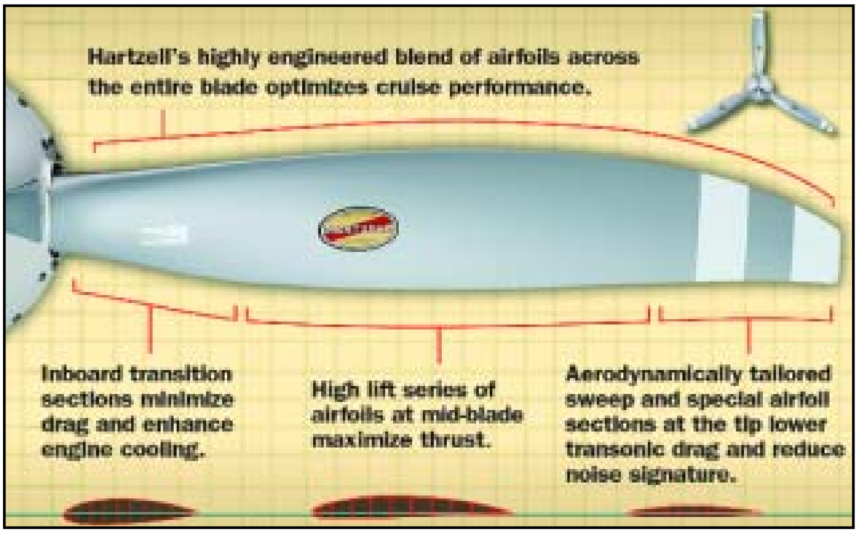
A concurrent benefit is consistent product quality. "Setting up and resetting up, you have a possibility for mistakes," Hammouri said.

"We do a lot of short-lead-time work, and maybe 80 percent of the jobs that are set up on that system are for just-in-time delivery. We try to put as many of that type of job as possible on the system to reduce our inventory."

These strategies help Excel prosper while it endures the ups and downs of aerospace manufacturing.

—B. Kennedy

For additional information about Excel Mfg., call (316) 942-0432 or visit www.excelmfginc.com.



Hartzell Propeller

The company integrated it with a proprietary CAM system.

Brown said, "An engineer can develop an aerodynamic code and put it out into a form that our CAD system can read. We can solid-model it, drive CAM code over it and get it out to the floor quickly, without any additional expense for hard tooling.

"Our prototyping and low-volume program support business is tremendously strengthened," Brown added. "The system can accommodate both those requirements, as well as 50 years' worth of product designs that are still active. So we use the same system for daily production and rapid development."

Mike Disbrow, Hartzell's senior vice president of marketing, applications and customer support, said the new system is suited to his company's philosophy of winning new blade programs (contracts), based on performance and turnaround time. "The new design methods produce propellers with enhanced performance, and the new blade-processing equipment enables us to rapidly and accurately produce the new designs."

Continuous Input, Improvement

Hartzell has been making propellers nearly as long as there have been airplanes. Early supporters included a certain western Ohio neighbor named Orville Wright.

It produces all of the hundred-plus components that comprise the constant-speed (variable-pitch) propellers it makes, including hubs, blade-pitch-change mechanisms and blades. In addition to aluminum blades, which represent the bulk of its output, Hartzell also makes blades of composite materials, including Kevlar and graphite.

Hartzell's main customers are general aviation leaders such as Beechcraft, Piper, EADS Socata, Cirrus and Lancair. Typical lot sizes are six blades, which are manufactured to just-in-time delivery schedules. The company also enters competitions to supply blades for new aircraft, and that can require rapid custom design and the production of just a few units.

Brown said that participating in such competitions previously consisted of picking an existing blade that approximated performance requirements and doing a flight test. Today, custom designs are the rule. "You want to give somebody the ideal blade, if possible," he said.

Allenbaugh said a significant turning point in the company's evolution was the Brown family's 1987 acquisition of Hartzell Propeller from then-owner TRW Co. "They started promoting continuous improvement," Allenbaugh said of the new owners.

Even as the business flourished, the owners sought ongoing process improvements.

"It's easy to get complacent," said Terry Walker, tooling coordinator. "Once you think you've done a great job, you [should] go back and re-examine" your processes.

Hartzell's drive for continuous improvement is not limited to investing in

Left to right: Bruce Ford, Bob Allenbaugh and Terry Walker examine machined and unmachined spinner bulkheads, which are part of a propeller assembly. The part (inset) is milled and drilled on a 5-axis machine in a single fixturing. Previously, four machines were required to manufacture the component.

B. Kennedy

multimillion-dollar hardware and software programs. Management encourages input from all employees. Walker said: "It's unlimited what you can do if you involve the people who produce the parts. Once they realize that what they say is directly proportional to the advances we make, there's no stopping them. It's a wonderful thing to watch."

Go with the flow

It's all about agility. Pratt & Whitney's Turbine Module Center in East Hartford, Conn., employs "flow-line cells" to process nickel-alloy blades and vanes used in jet engines. Each cell incorporates an electrical discharge machine(s), multiple creep-feed grinders and a real-time coordinate measuring machine(s). As in automotive transfer lines, every machine in a cell completes its operation in the same set period of time as the others, assuring maximum machine uptime and no queuing of parts. Compared to automotive manufacturing, though, the parts machined are smaller—no mechanical workhandling equipment is required—and part volume is low. Lot sizes are tuned to customer demand.

"Our schedules change very quickly," said Greg Mascoli, business unit manager of cooled turbine blades. "We are set up to run one-piece flow through each machining operation."

Currently, lot sizes may be as large as 200 parts, but "every day our push is to get smaller lot sizes," Mascoli said. Why? "Agility," he explained. "To be responsive, we are trying to drive changeovers ever quicker."

Key to quick changeovers and even pacing of operations is Pratt & Whitney's move away from large, complex, batch-style grinders to modular 5-axis machines in the cells. Each grinder is dedicated to producing certain features on one part at a time.

Pratt & Whitney teamed with United Grinding Technologies Inc., Miamisburg, Ohio, to acquire and apply the Blohm Profimat MC grinders used in the cells. "[UGT] had engineers who understood the lean concept and the manufacturing operating system we were putting in place," Mascoli said. "They were very sharp in terms of grinding-line technology. Our process engineers and tool designers were very sharp also. It was clearly a teaming with UGT in the implementation of the project."

Production ramp-up on the flow lines started in 2000, and lead times dropped to 2 hours from 6 to 10 days. Innovative workholding, made possible by the dedicated nature of the new grinders, was a major reason. Traditional workholding techniques for the blades were complex and time consuming.

"You'd think nickel-alloy turbine blades are pretty tough, but you have to be very careful about how you fixture them," Mascoli said.

The workholding system developed for the flow lines enables operators to simply drop and load parts into the machines, without the need for shimming or checking.

"The operator steps up to his machine with the workpiece, drops it into the fixture, steps out of the way, hits a wobble switch and walks to his next machine. It's literally that quick," Mascoli said.

The goals are simplicity and consistency. "All manufacturing, whatever industry you're in, is really driving toward lean principles and understanding how to make the interface between the machine and the man as simple as possible," Mascoli said.

But, he stressed, total automation is not the answer. An operator is necessary to move the material through the line and to monitor the machine. But the operator should not have to tinker with the process.

Mascoli said, "In my experience, aerospace manufacturing has always required a lot of tinkering. We try to take that away and drive toward a very consistent, robust process."

—B. Kennedy

For additional information about Pratt & Whitney, call (860) 565-4321 or visit the company's Web site (www.prattwhitney.com).

One example is the vendor training programs offered to the entire staff.

"Last year, Kennametal Greenfield IPG did a class on drills, taps and reamers, and every employee had an opportunity to go. A better educated workforce can change things in a positive way," Walker said.

In the past year, the company instituted Integrated Product Teams, composed of representatives from engineering, manufacturing and quality, to assess new processes and products. Previously, teamwork was not as formalized. Allenbaugh said Hartzell "put in a lot of new processes" this year, "and we want to make sure we're all marching down the same path."

Hartzell currently operates six machining cells. Its aluminum-hub cell acts as a test bed for lean manufacturing methods, which are tailored to the company's needs and applied throughout the shop. Allenbaugh said lean manufacturing at Hartzell consists of many small contributions that have come together to optimize the overall process. He said key elements include single-piece flow, waste reduction, setup reduction and process optimization. He defines waste reduction primarily as the elimination of time spent waiting for materials and loading and unloading parts.

An example of employees' focus on reducing waste was the establishment of an innovative inspection station by machine operator Don Anthony. "I say it's my inspection bench," said Anthony, who works in the aluminum-hub cell, "but a lot of people call it my 'preacher's pulpit.'"

Located next to the machining center Anthony runs, the bench features a semicircular work surface topped with a thick, rigid-foam pad with nests for all of his inspection and gaging tools. A simple fixture at the center of the station holds the hub and allows it to be rotated. Anthony can take the part out of the machine, put it in the fixture and quickly complete inspection without leaving the bench or sorting through gages.

Say the magic word

There's no magic word or single strategy that makes competition disappear. Today, every manufacturer must continually improve quality, reduce lead times, perfect delivery performance and drive out costs.

In aerospace component manufacturing, these issues are joined by challenges particular to the sector, said Bob Segal, vice president and general manager of Middleton (Mass.) Aerospace Corp.

Middleton, a division of Canada's Magellan Aerospace Corp., competes with companies around the world that produce gas turbine components. Segal pointed out that these "flight quality" parts are made of tough-to-machine materials, including nickel-base superalloys and titanium. The parts often are large; Middleton has the capacity to turn, mill and grind products, such as engine cases, up to 65" in diameter and can produce shafts up to 120" long.

Tolerances are tight. Segal said, "On shafts, we're typically holding 0.0002"; on turbine and fan cases from 40" to 65" in diameter, we're holding 0.002"."

Component configurations can be unique. "We do one bimetal case, which is electron-beam-welded circumferencially, that is half Waspaloy and half Inconel 718. That throws a lot of variables into the process," Segal said.

A major part of the solution is lean manufacturing.

"It's real and it works," Segal said, adding that his company must work within lead times that are about half what they were 3 years ago. And just-in-time supply considerations have reduced inventory costs.

"The inventory we carry today is equivalent to the inventory we carried earlier at about two-thirds the sales," Segal said.

Another important factor, Segal said, is the technology manufacturers apply in their processes, such as advanced machine tools and tools for high-speed machining. For example, Middleton uses WG-300 whisker-reinforced ceramic inserts from Greenleaf Corp., Saegertown, Pa., to boost metal-removal rates when turning tough superalloy shafts and turbine cases. The tools permit volumetric removal rates six times greater than traditional carbide cutting tools when used for basic turning and 24 times greater when grooving. The higher speeds translate into lower manufacturing costs through reduced machining times.

It all adds up. Despite the slump in aerospace business since 9/11, Middleton has seen only a 5 percent drop in sales. One reason is that as much as 50 percent of its business is linked to regional jets, currently the strongest aircraft market. Another reason is smart management. Production peaks in 2001 were handled through subcontractors, and when the downturn occurred, subcontracted work came back inside. The company has come through the period with no layoffs. "I'm more proud of that than anything else," Segal said.

In October 2001, he told employees that the goal for the next 12 to 18 months was to keep everyone working, and he listed what needed to be done to accomplish the goal. "To their credit, they stepped up and met every challenge," Segal said.

These included quality improvements that produced an approximately 70 percent reduction in nonconforming materials.

"Through the deployment of Six Sigma quality practices, our efficiency, which was very high anyway, has increased anywhere from 7 to 8 percent," Segal said. Delinquent backlog fell to almost nothing.

To handle global competition, Segal said, "You have to do it all. Technology is a piece of it, Six Sigma is a big piece of it, lean manufacturing is an enormous piece of it. But then you need good people who know what they are doing. You put the whole thing together, and hopefully at the end of the day, you're a little better than the next guy."

—B. Kennedy

For additional information about Middleton Aerospace, call (978) 774-6000 or visit the Magellan Aerospace Web site (www.malaero.com/divisions/middleton/middleton.html).

"Before, I had to walk to another bench to gage the part, and all my tools were everywhere," he said. "Now I just clamp the hub, gage it and hand it to the guy at the next machine."

Hartzell's efforts to upgrade and improve its operations extend to every aspect of its business, from standardization of lathe and milling tooling to just-in-time EDI (electronic data interchange) replenishment programs with key vendors to cross-training of employees in different responsibilities. New manufacturing equipment is on order, and there are plans to restructure the company's machining cells for greater product focus.

Brown said that to succeed in the aerospace business, "you've got to develop the capabilities you need, and you also need cost reductions to enhance your competitiveness."

Heeding that advice will help any company take off, regardless of which industry it serves.

For additional information about Hartzell Propeller, call (937) 778-4200 or visit the company's Web site at www.hartzellprop.com.