Open rotor research revs up

Researchers in the U.S. and Europe are reviving an old concept and reshaping it into advanced technology for a new generation of open rotor aircraft engines. When first proposed in the 1980s, the idea met with low acceptance from the public, who viewed propellers as noisy and outmoded. Today, however, the promise of greater fuel savings and lesser environmental effects will likely give the updated technology a better reception.

by Philip Butterworth-Hayes
Contributing writer

It is increasingly possible that the next generation of Airbus and Boeing single-aisle aircraft, due to enter service around 2019/2020, will fly with open rotor engines.

Open rotor engines use a gas-turbine core to drive a large-diameter fan which propels large amounts of cool air around the outer part of the engine—creating very high "by-pass" ratios and thereby considerably increasing the efficiency of the engine over conventional turbofans.

Rolls-Royce and General Electric (GE) have made sufficient progress in their competing open rotor technology demonstration programs that both companies believe the engines will be able to deliver the necessary step-changes in economics while meeting stringent new performance and noise targets. The concept has been proven, both say—now the hard work starts on defining the details of the engine architecture that will provide the vital 1-2% competitive advantage.

Reviving an old idea

For GE, the past two years of open rotor research has involved revisiting the unducted fan (UDF) technology of the past. GE and the Fundamental Aeronautics Program of NASA's Aeronautics Research Mission Directorate in Washington are jointly funding a research program into open rotor research, while GE's partner in the CFM International consortium Snecma is concentrating on fan blade designs. The three organizations are essentially recreating the GE36 research team of the mid-1980s.

LEAP-X is the CFM International technology program focusing on future advances for next-generation CFM-56 engines. Ted Ingling, the program's manager of engineering, leads the company's open rotor work.

"The early generation of engines were built at a time when fuel was at a very high price, and it was thought it would stay like that forever," according to Ingling. "We demonstrated in ground and flight tests the theory and practice of open rotors. Fundamentally it was a sound technology to put fuel performance first and then work on delivering Stage III noise performance in the production version."

The acoustic challenge will have to be met by any open rotor design going forward.

Two basic challenges

Ingling believes that, apart from meeting stringent new reliability certification and operating standards, there are two fundamental design challenges to be met in the next generation of open rotor engines: acoustics, and the reliability of the pitch-change mechanism.

"Today requirements are different," he says. "Regulations are more stringent, and the challenge is to reduce the source of noise dramatically. This means looking at the source noise of the props and how they integrate with the airframe. We will have to make substantial changes to blade designs, and it's still not clear exactly what the optimal acoustic performance will look like.

"All propellers lose efficiency at high speed, as the tips of the propeller approach the speed of sound. This creates increasing 'wave drag,' which can be obviated by increasing the number of blades and developing 'swept' or 'scimitar' designs. In these designs the blade is progressively more swept toward the outside, to counter the increasing speed.

"The second enabling technology to bring the engine up to today's standard of reliability is the design of the pitch change mechanism, which will allow us to change the fan-blade orientation depending on the Mach number and throttle setting. That mechanism is a piece of equipment that will be embedded in machinery, so reliability and weight are key

Increased wave drag can be obviated by increasing the number of blades and developing swept or scimitar designs.

Snecma is heading up SAGE work on the direct-drive open rotor concept engine.

enablers of the technology," Ingling says.

For the past two years GE has been reviewing the data from the 1980s, talking to the technicians and engineers involved in earlier UDF studies and seeing what improvements could be made with current testing technology. "We have focused on how much more acoustic benefit we could get using modern tools—especially in areas such as predicting outcomes of new aerodynamic designs," says Ingling. "In the 1980s there was a lot of trial and error. We've taken some of the data from the old rigs, run new aerodynamic designs, and launched additional analysis in areas such as aerodynamic testing, aeroperformance, and acoustics. The new advanced codes tell us that for the same acoustic signature, we could recover overall engine performance."

With the first-generation UDF, according to Ingling, GE engineers had to sacrifice some of the engine's overall performance capabilities to meet the Stage III noise requirements.

Wind tunnel testing

In the next stage of research, GE Aviation and NASA have been working together on a wind tunnel test program to evaluate counterrotating fan-blade systems. The research phase began in 2009 and is continuing into 2010. The team has built a one-fifth subscale model comprising two rows of counterrotating fan blades, with 12 blades in the front row and 10 in the back. They are being tested in simulated flight conditions in NASA Glenn's low-speed wind tunnel to simulate low-altitude aircraft speeds for acoustic evaluation, and in Glenn's high-speed wind tunnel to simulate high-altitude cruise conditions.

Building on the past

General Electric developed its GE36 unducted fan (UDF) featuring an aft-mounted, open rotor fan system with two rows of counterrotating composite fan blades during the mid-1980s. It was a joint development with NASA and Snecma, GE's French partner in the Snecma consortium that had a 35% stake in the program.

The core was based on a GE F404 military turbofan. Exhaust gases were discharged through a seven-stage low-pressure (LP) turbine; each stator ring was designed to move freely in the opposite direction to that of the rotors. One set of fan blades was connected to the LP turbine rotor system and the other set to the contra-rotating LP turbine stators—effectively creating a 14-stage LP turbine system.

The GE36 flew on the Boeing 727 and MD-80 aircraft and enabled speeds of around Mach 0.75. Although specific fuel consumption improvements of around 30% better than contemporary jet aircraft were measured, there were extensive noise and vibration issues—though the engine met Stage III noise limits, according to company officials.

An alternative UDF test program in the mid-1980s was pioneered by Allison and Pratt & Whitney. The 578-DX propfan featured a more conventional reduction gearbox between the LP turbine and the propfan blades and was also flight tested on an MD-80.

The team is currently designing and testing a classic airfoil design to a certain level of performance and will then be "looking at an enhanced design to see how the goal of a Stage III tradeoff with performance can be made," says Ingling.

"The speed at which the aircraft cruises will have major implications for the design," he says. "As a company we are putting a great deal of investment into the program, but we have to be selective about where that investment goes.

"I am extremely encouraged on the acoustic side that we will get to where we need to be—but at some stage we will have to look at how we are going to trade overall engine efficiency against acoustics. Will the noise issue be more important than greenhouse gas emissions, for example? Should we customize performance or trade it against environmental improvements? Many of these issues will depend on what certification standards are employed. At the moment it's too early to determine how much we should look at trading noise improvements with fuel burn performance," Ingling says.

Other efforts toward the goal

The goal is to have a certified engine in production, providing double-digit performance enhancements over contemporary turbofans, by the end of the next decade.

GE and Snecma will feed new technologies into the open rotor research from the Leap X research program as they become available. GE is redesigning the CFM-56 core to provide around 7% of the targeted 16% fuel consumption improvement for the new engine; Snecma's work on the CFM Leap X program is focused on developing new 1.8-m-diam blades manufactured through a 3D resin transfer molding process.

Snecma's understanding of open rotor fan-blade design will be enhanced through its work on the €40-million DREAM (validation of radical engine architecture systems) program, a three-year research project led by Rolls-Royce and funded half by European industry and half by the European Commission. During the past year one-fifth-scale and one-seventh-scale blade testing has taken place at Russia's Central Aerohydrodynamic Institute, on electrically powered rigs at speeds of up to Mach 0.85.

The DREAM work is also part of a wider European research initiative into next-generation engines called the Sustainable and Green Engine Integrated Technology Demonstrator

(SAGE ITD), a component of the €1.6-billion Clean Sky Joint Technology Initiative research program. SAGE researchers will develop two types of open rotor demonstrator engines.

Rolls-Royce is heading up work on a geared open rotor demonstrator, in a €111-million program involving Rolls-Royce ITP, Deutschland, Volvo Aero, Airbus, and Alenia. The research will focus on the propeller pitch mechanism, the donor core gas turbine, the transmission system that transfers energy from the free power turbine to the contrarotating assemblies, and the contrarotating propellers themselves.

Snecma is heading up SAGE work on the direct-drive open rotor concept engine. This €135-million program involves Hispano-Suiza, Techspace Aero, Aircelle, AVIO, Volvo Aero, Airbus, and Alenia Macchi, with work focused on the propeller pitch change mechanism, the contrarotating propellers, the contrarotating turbine directly linked to the propellers, and the gas generator.

Rolls-Royce, meanwhile, has already undertaken high- and low-speed tests of various configurations of its own propriety technology research program and has dedicated a new testing regime, which it calls "Rig 145," to detailed open rotor concept validation.

"We have now moved open rotor work from the theoretical physics to the engineering stage," says Robert Nuttall, vice president for strategic marketing at Rolls-Royce. Early wind tunnel tests have shown its design would comfortably meet current Stage IV noise regulations. Tests were finished earlier this year at the DNW wind tunnel in the Netherlands, using a one-sixth-scale electrically driven rotor to simulate low-speed operations, including takeoffs and landings. "We ran different configurations and different numbers of blades at different blade speeds—we finally discovered the optimal configuration for low-noise open rotor operations," says Nuttall.

The model is now undergoing high-speed tests at the Bedford (U.K.) Aircraft Research Association transonic wind tunnel. "We first ran these tests at the end of 2008 and spent the first quarter of 2009 understanding the results," says Nuttall. "We're still being very cautious with our claims but we think that, in terms of economic performance, our open rotor engine will perform 25% to 30% better than current turbofans."

Rolls-Royce has yet to firm up on a core design. "We have a number of options in this area," says Nuttall, "and we now have an internal competition between our two-shaft center of excellence in Dahlewitz [Germany] and our three-core center of excellence in Derby, U.K."

Nuttall believes there are five key technology risks that must be addressed—the gearbox, pitch change mechanism, blades,

Competitive market and technology challenges

Developers of open rotor technologies face a number of challenging hurdles, not all of them technical:

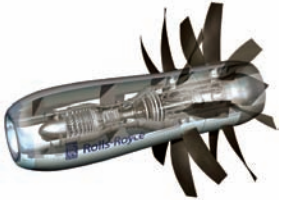
*•**Competing technologies.** The efficiency of current technology engines is improving at an average of 1% a year—which means traditional turbofan engines available in 2020 are likely to be at least 11% more efficient than today's production models, without any major technology risk. Meanwhile, the Pratt & Whitney PW1000G geared turbofan could provide a 22-23% fuelefficiency gain by 2017, according to the company, while the CFM International non-open rotor LEAP-X design could provide 16% lower fuel consumption than the CFM56-7 by 2018. Some manufacturers are skeptical about open rotor technology, worried that installation effects, additional weight, complexity and interference drag could obviate any improvements in fuel savings.*

*•**Slower aircraft operating speeds.** An open rotor powered aircraft is likely to have a cruising speed 5-10% slower than a turbofan powered aircraft. "The average route length for a single-aisle short/medium-range airliner is around 500 n.mi.," according to Rolls-Royce's Nuttall, "and at that range, speed is not crucially important."*

*•**Regulatory issues.** Engine and airframe manufacturers have already approached regulators such as the European Aviation Safety Agency and the FAA to determine whether there might be any airworthiness certification concerns around issues such as engine layout and blade containment. Manufacturers would need to know as early as possible if regulators did have major concerns, to eliminate areas of potentially wasteful research.*

*•**Airframe integration.** The integration of the engine within the airframe will be a critical issue, especially if the prop diameter is close to the 170 in. under review by Rolls-Royce. With this size blade a "pusher" arrangement would be more elegant, as the engines would be placed behind the rear pressure bulkhead in the fuselage, minimizing noise. It also would allow for an aerodynamically "clean" wing. A "puller" arrangement would dictate a high wing design, with the large rotating assembly next to the fuselage.*

*•**Public perception.** In the 1980s manufacturers were concerned that passengers viewed propeller-driven aircraft as outmoded, noisy and slow. Open rotor engine manufacturers have started some early research into this area. But it is likely that the environmental concerns of the 20th-century traveling public would make the open rotor concept an easier "sell" than the UDF concepts of the 1980s.*



Rolls-Royce is targeting 2014 for a flight demonstration of its open rotor engine but its design has not yet been locked in.

noise/vibration, and airframe integration. In one of its preferred current configurations, Rolls-Royce is working on an engine with 170-in.-diam contrarotating blades—roughly the diameter of regional jet fuselage. This will demand a 16,000 shp gearbox to drive the contrarotating blades, a sophisticated pitch-change mechanism and highly aerodynamic blade design made of composite materials.

"In the work so far we have proved we can deliver what we thought we could at a macro level. Now the work is to zoom down to specific work areas such as blades and the gearbox. In this we are now looking for partners—a pitch-change mechanism is not something we are expert in, for example."

Airframe integration is a sensitive issue, as much of this work will have to be pioneered by airframe manufacturers themselves. Rolls-Royce, Boeing, Ruag Aerospace, and Deharde Maschinenbau began a research program in May 2009 to test a model concept airframe this year at Ruag's low-speed wind tunnel in Emmen, Switzerland. Airbus is working with engine manufacturers on new engine integration issues within the Clean Sky program, which should deliver the first results around 2014.

Both GE and Rolls-Royce are working to a similar timescale. Rolls-Royce has targeted its flight demonstration with an open rotor engine—based on the core of a current production engine—for 2014, and a final go/no-go decision shortly after that, with a service date of 2020.

Market uncertainties

While both GE and Rolls-Royce have proven that the core concept of the open rotor is viable—that 25% fuel improvements over current engines are possible within current and planned noise regulations—there are still a great many market uncertainties to overcome.

For Airbus or Boeing to consider an open rotor for their A320 or B737 replacement families, they would have to embrace some radical new design concepts and be sure about the key operating cost and environmental drivers that will prevail over the next 40 years. "One of the fundamental remaining questions is whether you trade noise for carbon dioxide emissions," according to Nuttall. "It will depend on what the industry wants."

The problem for engine and airframe manufacturers is that no one can be quite sure what the industry will really want in 2030.