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Testing turbines to save energy

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Research associate Michael Barringer setting air pressure and checking parameters in order to supply the appropriate amount of compressed energy flow to the turbines. Credit: Patrick Mansell

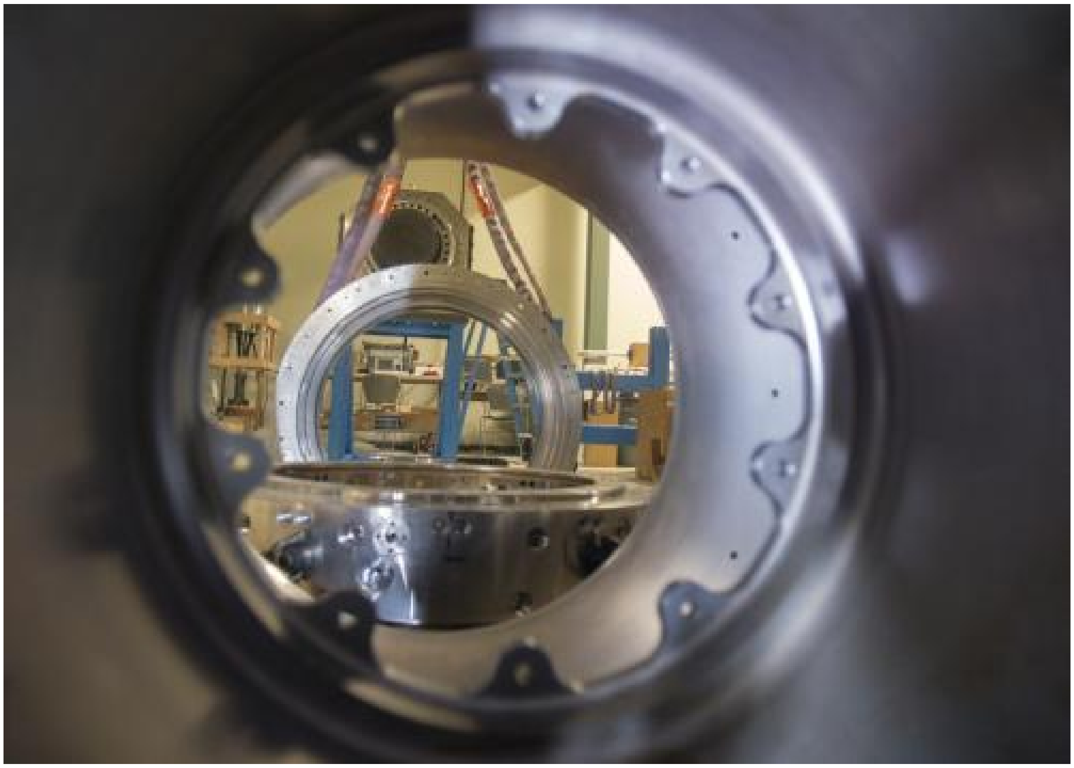
They say a little knowledge is a dangerous thing. But a little knowledge can also be comforting. For anyone who has sat on a jet airplane at takeoff, tense and sweaty-palmed, wondering how in the world this gigantic assemblage will manage to climb into the sky and stay up, here is a little knowledge: That plane is propelled by a gas turbine engine, which is ideal for jet aircraft because of its excellent power-to-weight ratio—it's a relatively small turbine engine that produces a lot of power for its light weight.

Gas turbine engines, lesser known than their steam, water, and wind counterparts, are found primarily in jet aircraft and in electric power plants. They are well suited for these uses because they operate best under a long-term, consistent load, rather than a fluctuating load, like that experienced by an automobile engine. Because gas turbines spin at high speeds and at temperatures well over 2,000 degrees Fahrenheit, they generate large amounts of power. In fact, gas turbines produce 15 percent of all energy used in the U.S. for air transportation and electricity generation.

That process requires burning up a lot of jet fuel. To find ways to increase gas turbine engine efficiency and thus reduce fuel burn, researchers in Penn State's College of Engineering have teamed with aerospace manufacturer Pratt & Whitney and the Department of Energy's National Energy Technology Laboratory, performing experiments on a full-scale test turbine at the Steady Thermal Aero Research Turbine (START) facility near University Park. "The United States uses 1.4 million barrels of jet fuel each day, and our goal is to reduce that number by 5 percent," says Karen Thole, professor and head of Penn State's Department of Mechanical and Nuclear Engineering.

One important step toward greater engine efficiency is improved air system seals. Gas turbines have both rotating and stationary components—blades and vanes, respectively—that contain gaps at their interfaces, creating airflow leakages, Thole explains. She and her research team will experiment with various types of seals to see which ones best reduce leakage, and the data they generate will help Pratt & Whitney improve its engine design tools.

After completing the experiments on turbine seals, the team will shift its focus to cooling technologies—how to better cool the vanes and blades that drive a gas turbine. A gas turbine engine consists of a compressor that takes in and pressurizes air; a combustor that burns fuel (propane, natural gas, kerosene, or jet fuel) and produces high-pressure, high-velocity gas; and a turbine that extracts energy from the gas.



Turbine components are lined up in the Steady Thermal Aero Research Turbine (START) lab prior to assembly. Credit: Patrick Mansell

"The hot combustion gas is on the order of 2,000 to 3,000 degrees Fahrenheit," Thole says. "So the turbine's vanes and blades need to withstand extremely high temperatures, and the better we can cool them, the more durable and long-lasting the airfoils will be."

The Department of Energy (DOE), a partner in the gas turbine research, has a particular interest in advanced cooling designs. "We're interested in applying improved cooling technology to the larger, stationary gas turbines in power plants," says Richard Dennis, turbine technology manager of DOE's Office of Fossil Energy. "Our goal in this project is greater energy efficiency, and cooling is a key component. The better cooling we can do, the higher temperatures we can use, the more efficient the machines. That greater efficiency means less fuel needed, less air pollution, and lower electricity costs."

One of a kind

The START facility boasts two qualities that make it unique in the nation. First, it operates under full-scale engine conditions. That's important for accurate research results. "Because this gas turbine will run at realistic engine scales and speeds, it will give us relevant data that we need to make military and commercial jet engines more fuel efficient," says John Wiedemer, chief engineer for Pratt & Whitney's hot section.

The second standout feature of the START lab is that it's a steady-state, long-duration facility, meaning that it can run continuously. "Other gas turbine labs are blowdown facilities," explains research associate Mike Barringer. "That means they'll blow air for a second or even a few milliseconds, and that short-term flow doesn't have the chance to establish itself as it would in an operating engine. Here, we can keep the air blowing—several hours of testing will be no problem. And that will let us generate more realistic, fully developed flow conditions."

As well as the research on sealing and cooling, experiments with additive manufacturing (3D printing) are advancing gas turbine design and development at the START facility. In current industrial practice, Thole explains, gas turbine vanes are first cast and then shipped to a turbine manufacturer, where engineers use lasers to drill cooling holes into them.

"But the engineers are limited in where they can drill the holes because they need a line of sight for the laser," she says. "We thought, What if you could skip those processes and instead grow the vane using additive manufacturing? So we start with a very thin layer of powdered metal, melt it with a laser, and grow the part, one layer at a time. This technique allows us to incorporate the cooling holes in the initial design, eliminating the need for drilling. And this is an important role for our facility—we're becoming a test bed for a variety of research projects. This lab has many uses."

Yet another test-bed role for the START lab is to facilitate research on sensors. Thole's team recently won a $500,000 Defense University Research Instrumentation Program (DURIP) award through the Office of Naval Research to incorporate sensor instrumentation into the gas turbine.

"All turbines need sensors that monitor temperature and pressure," she says. "Often, a professor will develop a sensor in a nice, clean lab, take it to a gas turbine company, and say, 'I've created this new sensor. Why don't you put it on your engine?' But the reality is that a simple lab test won't translate into a real-world situation. Our lab is the intermediate step that will allow instrumentation such as sensors to be developed and tested in a realistic engine environment."

Provided by Pennsylvania State University

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