

# Adaptive Engi

**A**irpower is nothing without propulsion, and this summer, USAF made a \$213.6 million down payment on its future by launching a new Adaptive Engine Technology Development (AETD) research program. With the adaptive engine program, USAF is laying the foundation for a new class of engines that go beyond the limits of today's fixed cycle engines. The goal is clear: Demonstrate a variable cycle propulsion system enabling a 25 percent or greater specific fuel consumption reduction.

Senior officials say that success in adaptive engine technologies can deliver better range, persistence, performance, and energy savings for multiple types of combat aircraft.

"AETD technologies are expected to improve fuel efficiency, durability, and thrust performance for a wide range of

air vehicles and applications," Steven H. Walker, then deputy assistant secretary of the Air Force for science, technology, and engineering, testified in February.

## Exciting Advances

"This effort really does leverage off of some fairly exciting technological advances" and opens the door to "all of industry that may want to participate," testified Gen. Janet C. Wolfenbarger in May.

"This engine could be used in a whole host of platforms should it ever reach the point of being a development program," said Wolfenbarger, who was then USAF's three-star military deputy for acquisition. "Right now, it's just a question of ensuring that we are ready to go, should we as an Air Force decide that we want to embrace this opportunity to really reduce the fuel consumption in future generations of ...

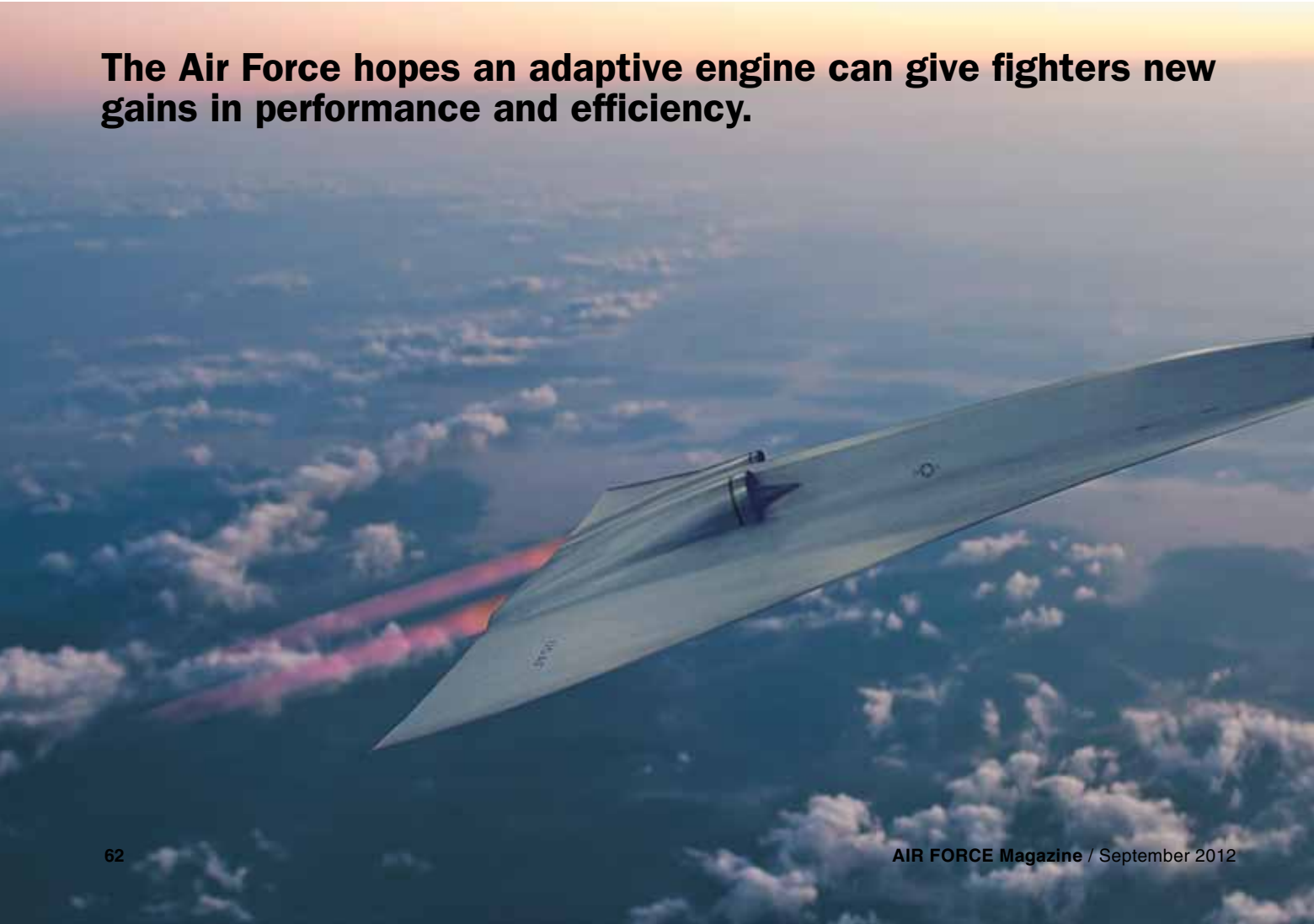
strike aircraft, bomber aircraft, tactical aircraft."

The potential for an adaptive, variable cycle engine is enormous. As Walker said, fuel efficiency buys range in combat. As a result, a new engine family "will also increase the unrefueled range for several platforms engaged in [anti-access, area-denial missions]," he said.

Take the case of a future long-range bomber powered by a new adaptive engine. Adaptive technology opens up the possibility for fuel savings that could be utilized in many ways: lighter vehicle weight, supercruise dash while preserving fuel efficiency, and of course, a longer combat radius.

Flying a segment at higher speed—without a big fuel penalty—could help bomber aircrews get from a theater base to the target area for faster response time. Then they could use the variable

**The Air Force hopes an adaptive engine can give fighters new gains in performance and efficiency.**



By Rebecca Grant

cycle engine to add bursts of speed for a tactical dash through enemy SAMs and fighters to get to the target and out safely.

In short, the investment in adaptive engine technology has the makings of a game changer.

The funding commitment comes as overall spending on RDT&E accounts is heading for a 10 percent decline from Fiscal 2012 through 2016, according to the DOD comptroller's budget tables. In recent years, rapid acquisition for immediate war needs took top priority.

During this time, USAF kept alive a five-year engine research program run by the Air Force Research Laboratory.

Two decades have passed since the Air Force introduced the current family of high-performance combat engines, which dates back to the early 1990s, when the Pratt & Whitney F119 engine



USAF photo by TSgt. Justin D. Pyle

**An F-22 in afterburner. Today's high-performance combat engines date to the 1990s, when the F119 engine was selected for the Raptor.**

was selected for the F-22 fighter. The production F119 later became the basis for the F135 engine for the F-35 strike fighter.

However, the technologies leading to the F119 took root in research that began in the late 1960s and 1970s. The backstory sheds light on why investing in long-term research on propulsion is so important.

Decades ago, aircraft programs drove engine development. Radical designs such as the SR-71's Pratt & Whitney J58 engine and the General Electric J93 designed for the supersonic XB-70 Valkyrie bomber—both capable of Mach 3 flight—highlighted this period.

With a steady flow of aircraft programs under way, engine development was robust. "The 1960s were glory days of aircraft engine development," found authors William S. Hong and Paul D. Collopy in a case study of jet engine development published in the fall 2005 issue of the *Journal of Propulsion and Power*. An average of one new engine per year was introduced in the 1960s.

Engines were developed as complete products with research advances taking place inside the scope of the engine work. "Every program provided opportunities to develop new components, explore new material temperature capabilities, and work in new aerodynamic regimes," they wrote. When a new engine debuted, it was usually produced in quantity and often modified over time. This allowed engine innovation to piggyback on aircraft development programs, benefit

from long production runs, and carry over to commercial applications.

A good example was the GEF101. This 30,000-pound-thrust engine was designed in 1970 for the original B-1 bomber program. When the Air Force restarted the B-1 program in 1981, GE tweaked the engine to become the F101-GE-102 and the Air Force ultimately bought 469 of them for the bomber.

## From B-1 to U-2

A nonafterburning version of the engine became the F118 for the B-2 bomber, which first flew in 1989. Then it morphed into another derivative to power the upgraded U-2R as the F118-GE-101 in a 1990s program.

The F101 fed a big commercial success, too. In 1974, after much political wrangling, GE set up a 50-50 joint venture company with the French firm Snecma to produce the CFM56 family of engines. The CFM56 was based directly on the F101 core. Part of the deal was a royalty payment to the US to compensate for the F101 technology flow. By 2011, the joint venture had delivered more than 22,208 CFM56 family engines to worldwide customers.

Even in the midst of plenty, USAF propulsion managers noticed the innovation curve was leveling. Already it was taking longer to develop new engine technology than to design airplanes.

The Air Force stepped in with a series of long-term research and development programs to maintain continuous effort on breakthrough propulsion technologies.



Artist's conception by Erik Simonsen

*An adaptive, variable cycle engine could be used on a host of airplanes. Shown here: an artist's illustration of a hypersonic aircraft.*



**The F135 engine—shown here in a test—powers the F-35. It is a derivative of the F119 that powers the F-22, so it, too, has its origins in the 1990s.**

The first of these began in the 1960s. It was called the Advanced Turbine Engine Gas Generator (ATEGG) project, which took a different path by focusing not on a specific engine but on component technologies: materials, fan, compressor, modeling of the engine environment, and so on.

Seeding funds to industry advanced propulsion teams was essential to the strategy. The USAF propulsion directorate in Air Force Systems Command funded research study and work at all the major engine makers of the day.

A sample of the kind of work done under ATEGG was a 1969 report on diffusion titanium bonding and other material topics by Frederick G. Groh of Pratt & Whitney. The work was funded by USAF's Aero Propulsion Lab's longtime chief of the Turbine Engine Division, Ernest C. Simpson. Having key individuals like Simpson in place for long periods of time assured continuity of effort.

The Air Force was not the only market, either. In the mid-1970s, USAF and the Navy formalized cooperation under a Joint Technology Demonstrator Engine program; it broadened research to all engine components.

Ongoing development work led directly to today's best engines. For example, a 1976 Pratt & Whitney study outlined the potential for supercruise. The concept was picked up by the Air Force Scientific Advisory Board, then written into secret early requirements for the Advanced Tactical Fighter, which became the F-22. The engine was demonstrated in the 1990-1991 ATF competition and powered the F-22's first flight in 1997.

Next came the Integrated High Performance Turbine Engine Technology initiative. Like other programs before it, IHPTET deliberately reached for new technology breakthroughs. Program managers set an ambitious goal of doubling engine thrust-to-weight ratio. The initiative was active from 1987 through 2005. The Joint Advanced Strike Technology (JAST) program, which begat the F-35, carried out engine work within IHPTET. Money came from both industry and government.

### On Their Own

The ... commitment to IHPTET was a major step for both the government and the engine companies with respect to programs and funding stability," observed Hong and Collopy.

The Air Force was fortunate to have made that investment via IHPTET. After the early 1990s, aircraft buys plummeted and the market for military engines shrank with it.

That all but guaranteed future advanced propulsion work would have to be led by USAF efforts that were not tied to any particular program.

In the past, military engine sales were robust enough to create a substantial share of the overall engine market. For example, on the commercial side, Pratt & Whitney has an installed base of 16,000 large commercial engines, with roughly 11,000 military engines in service with 29 armed forces around the world.

The military engine numbers reflect past sales and inventories that won't be seen again. The count includes much older engines such as the TF33 on the E-3 AWACS. In other cases, for example,

the F117 engine for the C-17, the buy is largely complete.

Even the buy of the F135 for the single-engine F-35 variants is unlikely to top more than 3,000 engines over two decades. The military engine market has collapsed into a prestigious but tiny niche.

Since market forces alone won't drive the kind of research needed for combat applications, what are the incentives to continue advanced propulsion development? The Air Force answer has two parts.

One is continuing to take the lead for the basic work toward the revolutionary performance enhancements that are now within reach.

The second is finding common areas of interest between commercial and combat designs, such as fuel efficiency.

The Air Force has maintained its leadership role in engine research and development through the 2000s. Final research under IHPTET showed that engineers were on the cusp of advances in efficiency and refinements pointing toward adaptive engine technology. The Air Force Research Laboratory planted more seeds of innovation with a batch of no-fuss engine research projects under yet another acronym: VAATE, or Versatile Affordable Advanced Turbine Engines.

"After the success of IHPTET, we faced an uphill battle bringing VAATE on board," the first VAATE program manager, Larry Burns, told *Flight Global* in 2007. According to Burns, "People believed turbine technology had peaked and asked why we needed another multi-year program. It was a fierce battle to convince military planners to put research and development money into technology for next generation turbine engines."

AFRL won the battle. One helpful factor was broadening the VAATE research slate. Work included everything from Mach 4 missile motors to improving helicopter engines. For the Air Force, the most enticing item on the VAATE research menu was a program called ADVENT.

The clue was in the name: Adaptive Versatile Engine Technology. In simplified terms, the idea of an adaptive engine is to vary the airflow and pressure ratios in the engine. Aircrews can then toggle between fuel-efficient cruise modes and thrust for high-speed and even supersonic flight. That, however, required a string of refinements and outright inventions.

GE and Rolls Royce North American Technologies, Inc., won 2007 contracts for ADVENT work, while Pratt & Whitney was deeply engaged in the F119 and F135 engines and other advanced engine research.

ADVENT set out to demonstrate specific improvements. One was auxiliary or third-stream technology. Different engines are optimized either for long-range cruise or for speed bursts in combat. Airliner engines and high-speed military airlifters employ high bypass ratios. A high bypass ratio produces better efficiency with less fuel burn because it allows in more air around the engine and flows less through the core. A low bypass ratio does the opposite. Low bypass ratios squeeze more air through the core to produce greater thrust, as with fighter jet engines.

ADVENT research explored the possibility of toggling between cycles. For example, ducts running to the engine could be opened to raise the bypass ratio and improve efficiency of fuel burn. Or the duct could be closed to push more air into the core and gain additional thrust.

ADVENT already has logged several demonstrations to prove the technology is within reach, and they will culminate in 2013 with test stand demonstrations.

The Air Force is keeping up the pace: The start of AETD overlaps with the end of the ADVENT program and takes the work further. The goal is for AETD to fully mature adaptive component and common core technologies aligned with multiple future Air Force combat aircraft ready for a notional engineering and manufacturing development start in three years. Call it sixth generation propulsion. Key beneficiaries are likely to be strike aircraft—future bombers and fighters.

The Air Force accepted a new set of competitive proposals for the adaptive engine program this summer, and two teams will push ahead with work beginning in the fall. That's just in time to support future aircraft programs for the 2020s.

The AETD program is adding technologies not covered by ADVENT such as thrust augmentors and exhaust systems. Taken together, the flow of research from 2007 through 2016 will prepare for a smooth, low-risk engine solution not tied to any one platform.

The bar is high. The program is aiming to demonstrate a 25 percent reduction in fuel consumption. Beyond this, AETD will clear the way for an engine that has real benefits in anti-access and area-denial scenarios.

USAF is funding the program at \$213.6 million for the first year. It's a classic mix of 6.2, 6.3, and 6.4 money—funds for applied research, advanced technological development, and demonstration and validation—to nurture and prove



**A B-1 runs up to full takeoff power. With the collapse of the military engine market, USAF must find creative ways to advance propulsion development.**

technologies. Industry teams are expected to kick in their own internal research and development funding, too.

Over a three-year period, that should take the technology demonstration to Technology Readiness Level 6, the desired threshold where a formal development program should begin. At TRL 6, a near final version of the technology is tested in real-life conditions. Flight test occurs at TRL 8.

Hence, the adaptive engine program is on an aggressive path. Tests of the compressor rig will occur in 2014, with separate fan and core tests to follow in 2015. On that schedule, a full engine run on a ground test stand could take place in 2016.

#### **Not for the F-35**

In reality, AETD is not delivering an engine. The deliverables for the three-year schedule are component rig tests, modeling and simulation, an engine ground demonstration, and an adaptive engine preliminary design.

Still, the program raised eyebrows and questions from Congress when the funding first appeared in the Fiscal 2013 budget.

"We just have gone through a multiyear battle here in Congress about whether we would build one or two engines for the Joint Strike Fighter," said Sen. Joseph I. Lieberman (I-Conn.), who questioned whether the Adaptive Engine Technology Development program was actually an alternative engine for the F-35. "I wanted to ask you flat out," he said to Wolfenbarger.

"No, sir, it is not," she replied. "It is a technology maturation program that takes the advances that we have seen under the ADVENT program and takes them to the

next maturity level."

Wolfenbarger also clarified that the target 25 percent fuel efficiency gains can't be reached by modifying any current engines.

Advanced engine work is important to the industrial base, too. Most of the work is under export control. Primes therefore use almost exclusively a slate of highly specialized US suppliers for tasks from precision castings to manufacture of blisks, airfoils, fuel pumps, and even fasteners. Dollars spent on advanced propulsion help fuel cutting-edge US manufacturing. "The investment will also help maintain a competitive industrial base in turbine engine technology, an area critical to our future military capability," Walker said.

National security competitors in Russia and China are sticking with their efforts to develop high-performance engines, too. Russia's Saturn engines have been highly successful. China has purchased Russian engines, the CFM56 core family through its Boeing 737s, and has a co-production deal for an older Rolls Royce engine.

"The China Gas Turbine Establishment (GTE) apparently is also leading the development of the fifth gen turbofan that will power the Chengdu J-20 fifth gen fighters," noted Richard Fisher Jr., an expert on China's military and technology.

As others move forward, in the US an adaptive engine could advance technologies and lower risks. With any luck, it will put USAF within striking distance of a new adaptive engine family ready for flight in the 2020s. As Walker noted, "We haven't developed anything new since the F119 in the F-22." ■

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