By the time World War II ended, it was clear that the future of military aircraft lay with jet engines.

The Jet Age in Review

By Peter Grier

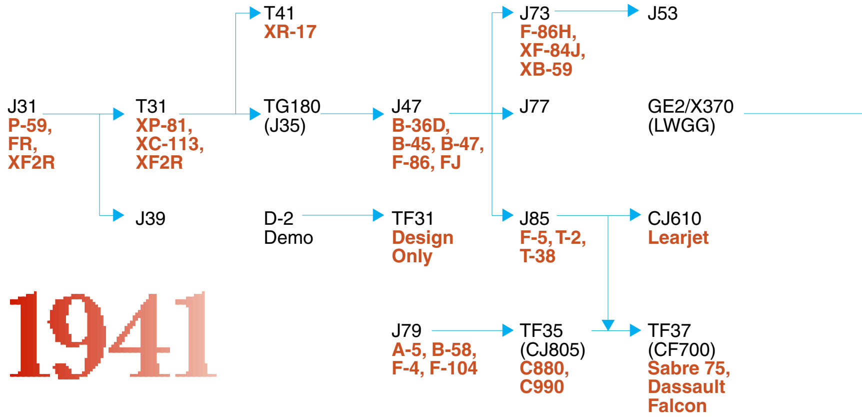
Cliff Simpson thought that the prevailing wisdom about aircraft engine design was wrong. It was the early 1950s, a time of great ferment in aircraft development in general and jet propulsion systems in particular. Engineers around the world were tinkering with the technology of the turbofan—a new type of efficient jet that pumped a stream of cold "bypass" air around the engine's core turbine and combustion chamber.

At the time, most propulsion scientists believed that the size of this bypass flow had to remain quite modest. They thought that building so-called "high-bypass" engines—where the amount of diverted cold air was 12 or even 15 times greater than the hot central exhaust—would be too hard to do. Inlet fans would be dauntingly large, for one thing. Airplanes capable of carrying the weight of such an engine might have to be huge.

One who was not convinced, however, was Ernest C. "Cliff" Simpson, a key member of the US Air Force's gas-turbine research and development team. He thought that the high-bypass engine was not only possible

General Electric Turbine Engine Family Tree

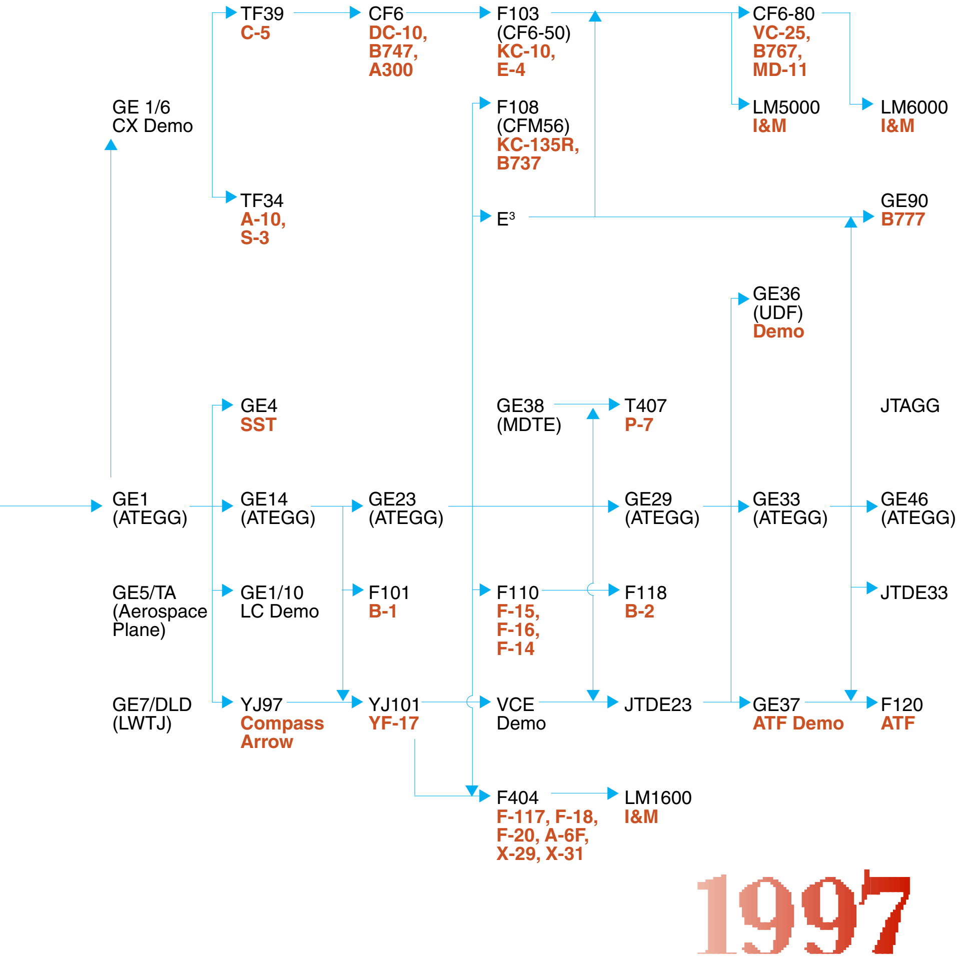
KEY	
ATEGG	Advanced Turbine Engine Gas Generator
CX	Cargo Experimental
Demo	Demonstrator
I&M	Industrial and Marine
JTAGG	Joint Turbine Advanced Gas Generator
JTDE	Joint Technology Demonstrator Engine
LC	Lift Cruise
LWGG	Lightweight Gas Generator
LWTJ	Lightweight Turbojet
MTDE	Modern Technology Demonstrator Engine



Civil and military engines. Does not include all engines.

The first US jet powerplant—the P-59's J31-GE-5 turbojet—owed much to the research efforts of British propulsion pioneer Frank Whittle.

USAF engine experts and private-sector engine-makers have been focusing on new alloys, thrust-reversing, and fan-blade shapes in an effort to increase performance and reliability while holding the line on cost.



but also practical and probably essential. The engine's increased fuel efficiency, he maintained, might be needed for a coming generation of bigger aircraft.

Mr. Simpson, then a senior staffer in Wright Air Development Center's Power Plant Lab at Wright-Patterson AFB, Ohio, began pushing paper studies of the problem, despite widespread skepticism. Eventually, he conducted a small-scale test that proved a 12 to one high-bypass-ratio engine would indeed work as he predicted. The result: By the early 1960s, Air Force officials had demonstrated that they could build an efficient high-bypass engine that would make their big new C-5 airlifter feasible.

In the end, the engine technology pioneered by Simpson and the labs at Wright-Patterson helped to make possible a whole new type of civilian aircraft: the globe-circling jumbo jet transport.

On the Cutting Edge

This example is just one part of a larger story. From the beginning of the jet age in the years following World War II to today's race for twenty-first-century turbine performance, the Air Force R&D community has been at the cutting edge of turbojet propulsion. In concert with engine contractors, such as Pratt & Whitney and General Electric, to name only the most prominent, USAF efforts have produced an impressive line of better turbines, improved fan blades, more efficient bearings, and similar advances in materials, components, and technology.

As Simpson noted in 1980 when he retired as chief of the Aero Propulsion Lab Turbine Engine Division, engine research consists of both big leaps—such as high-bypass technology—and inch-by-inch progress. "Turbine engines go in cycles," he said. "We'll get a whole flock of new engines, and then everyone starts to feel the pain. New engines usually have problems. So you work and work and finally get to the bottom of the problem, and someone says, 'We need a new engine.' So it's new engine, old engine, new engine, old engine."

Simpson himself was involved in the development of every major US jet engine of his time, including the C-5's GE TF39 and the F-15's and F-16's Pratt & Whitney F100. At his retirement ceremony, he accurately predicted the direction engine research would take after his departure, through such efforts as today's Integrated High-Performance Turbine Engine Technology initiative.

"It will be in the area of producing a lower-parts-count, lower-cost, reduced-weight engine," he noted. "New engines like that could be operational by the 1990s."

Development of the first practical jet engines began in pre–World War II Europe. In 1928, Englishman Frank A. Whittle published a thesis outlining his proposal for the use of gas turbines in aircraft. In its outline, the basic turbojet idea was a simple one, building on well-known physical principles. First, air would be scooped into a tube-shaped engine. Then it would be compressed by a spinning, fan-like compressor. The pressurized air, passing into a combustion chamber, would be mixed with a spray of fuel and then ignited. The resulting hot air would exit the chamber and pass over the blades of a turbine, which in turn would power the first-stage compressor via a central drive shaft. Exiting the back of the engine, the exhaust would still have enough energy to produce tremendous thrust.

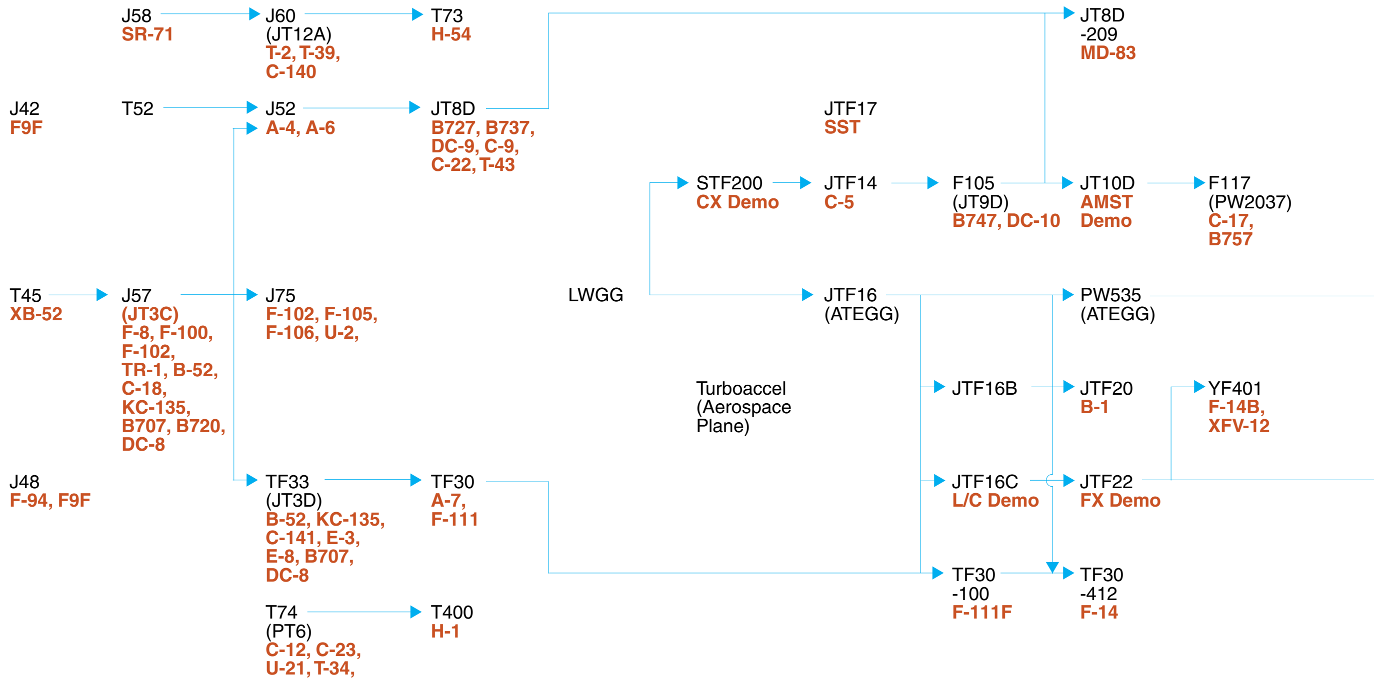
Mr. Whittle took out jet-engine patents in 1930. Meanwhile, a young German engineer named Hans P. von Ohain was proceeding along similar lines. The first flight of a jet-powered aircraft took place in Nazi-ruled Germany, at Rostock, on August 27, 1939. Mr. Von Ohain's He S.3b turbojet performed perfectly, although the landing gear of the Heinkel He 178 aircraft which carried it failed to retract.

Coming to America

Whittle's first engine, the W-1, flew in a Gloster E.28/39 Pioneer at Cranwell, UK, on May 15, 1941. A prototype W-1 was flown to the US in June 1941 and copied by General Electric. Bell Aircraft hurried through an experimental airframe to carry the engine, and on October 1, 1942, a Bell XP-59A made the first jet flight in the US from Muroc Dry Lake, Calif.

The German high command, however, was more interested in rocketry than

Pratt & Whitney Turbine Engine Family Tree



1947

in jet engines, even though jet-powered Messerschmitt Me-262 fighters were produced in quantity and appeared in combat near the end of World War II. Britain's Gloster Meteor twin-jet was rolling off factory lines by 1945 but never saw actual combat. A few US jet fighters deployed to Europe for a demonstration, but World War II ended before the aircraft could be employed in combat.

Still, by 1945 it was clear that turbojets would power the next generation of military aircraft. Frank Whittle, appearing as an honored guest at a Wright-Patterson AFB symposium in 1978, recalled the enthusiasm of a top British Air Ministry official after he witnessed a W-1 engine demonstration. "I had a curious experience as I took him back to the station in my car. He was telling me all the advantages of the engine—free of vibrations, run on almost any fuel, this, that, and the other. . . . He was a VIP, so I just said, 'Yes sir, yes sir.' I was really thinking, 'You're telling me?' "

When the war ended, Allied intelligence officers were scouring Germany for scientists whose work had possible military implications. Many were brought to the US and became key players in defense-related American industries. One was Hans von Ohain himself. By the mid-1970s, the co-inventor of the jet engine was the Aero Propulsion Lab's chief scientist. Appearing with Whittle at the 1978 symposium, von Ohain said that, without the pressure and the money stemming from defense needs, progress in jet technology—which by then had revolutionized air travel—would have been greatly slowed.

"Not necessarily the war, but definitely the military" was the force behind the development of the most important aviation technology of the last 50 years, said von Ohain.

One of the first tasks for Air Force and contractor scientists as they planned the initial generation of operational US jet engines was to do all they could to improve fuel consumption and component life span. The demonstration engines produced by Whittle and von Ohain lasted only a few hours, after all. The greatest technical difficulty, at first, was burned-out combustors. Later, the jet-age pioneers were plagued by high-frequency component fatigue and failures of impellers and turbine blades.

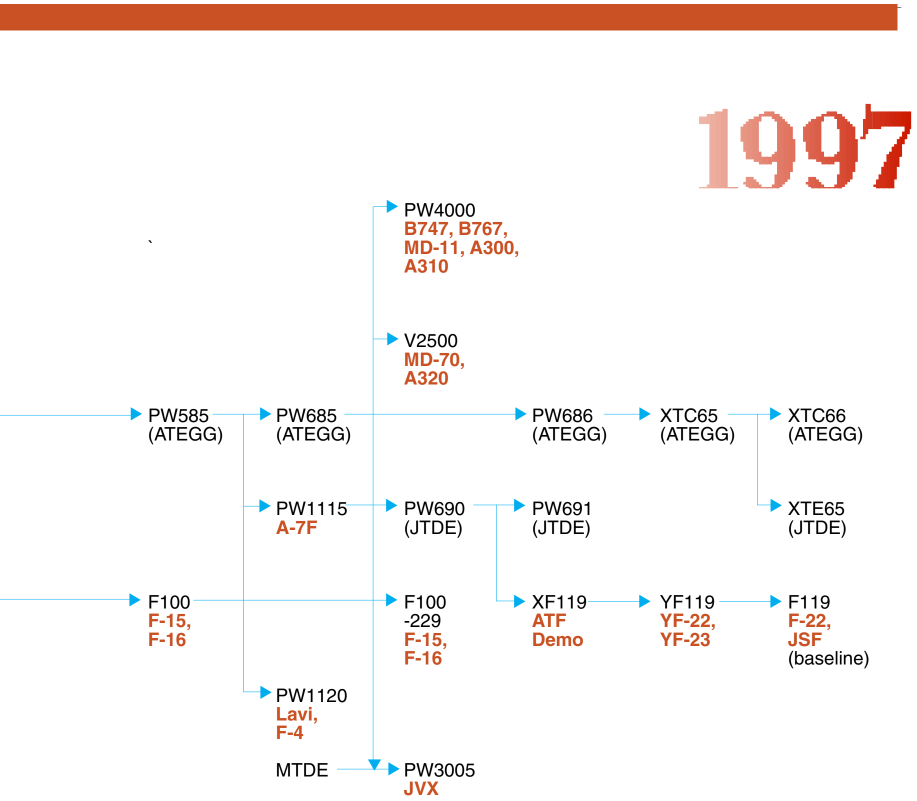
Family Resemblances

Even so, within only a few years, the life span of some turbojets had reached 1,000 hours. The improvement was the result of patient advances in design, materials, and many other technologies. It was a pattern of gradualism that propulsion engineers follow to this day, resulting in "family trees" of engines that can trace their ancestors back through years, if not decades, of models.

"Once you get a compressor proven, then maybe you put on a better combustor," explained Fred Oliver, chief of the Technology Management Division at the Aero Propulsion and Power Directorate of Wright Laboratory. "By the time you've got that down, maybe you improve the turbine. It's like that old story about the 200-year-old hammer whose head has been replaced five times and its handle three times."

The first turbojet engine to be produced in quantity in the US was the GE J31. Derived from Whittle's designs, it powered the pioneering P-59 fighter. Like all early jet engines, it featured a single-stage centrifugal compressor, in which the incoming air was swirled around and thrown out at the compressor blade tips. Centrifugal compressors were rugged and simple, but to obtain the compression necessary for jet propulsion they needed to be fairly large in diameter, which created unwanted drag.

So GE decided to take the J31 and insert an axial-flow compressor, in which air is compressed and pushed straight back, as it is in an electric fan. Axial-flow compressors are more sophisticated and complicated to build than their centrifugal counterparts, but GE engineers knew that the payoff in reduced drag through a narrower profile would be considerable. The result was a milestone in aerospace development: the J35, the first US axial-flow turbojet. Co-produced by Allison, it powered the X-5 series of research aircraft and the F-84 Thunderjet series of fighters.



In the late 1940s, the J35 was refined into the J47, which remains the most-produced US jet engine of all time. More than 30,000 were built before the assembly line shut down in 1956. Aircraft outfitted with J47s ranged from the F-86 to the B-47. A J47 variant was the first axial-flow engine approved for commercial use in the US.

Pratt & Whitney jumped into jet-engine production a few years later than GE. Unlike its competitor, Pratt & Whitney had been busy producing piston-powered aircraft production engines during the war. Furthermore, GE had much more World War II experience with turbosuperchargers. Superchargers are not as complicated as turbojets, but they feature many of the same basic components, such as compressors and turbine assemblies.

At first, P&W built British turbojet designs licensed from Rolls-Royce. Then, in the early 1950s, the firm developed the J57—the first jet engine in the world to produce 10,000 pounds of thrust.

Two Spools

Dual-spool technology was one of the keys to the wasp-waisted J57's power. Other powerplants of the day, in cross section, looked something like a spool of thread, with the fan of the compressor on the front of the combustion chamber and the fan of the turbine mounted on the back. The J57, however, had two compressors, which rotated independently. The first fan in this "dual spool" compressed air sweeping into the inlet; the second compressed it even further, producing higher performance.

The J57 powered the F-8 and F-100 fighters, the KC-135 tanker, and early models of the B-52 bomber, among other American aircraft. Pratt & Whitney was awarded the 1952 Collier Trophy, the nation's highest aviation award, for the engine's design. Eventually, the J57 pointed the way to a whole new class of engine—the turbofan.

The transition went like this: Pratt & Whitney took the first, low-pressure compressor in their two-spool engine (the first stage that air hits) and made its blades much bigger. That let some of the compressor's airstream bypass the engine's central combustion chamber altogether. "All that bypass stream does is produce thrust. That way you can get more thrust without burning more fuel," said Oliver of Wright Laboratory.

Engine designers had long thought that this type of turbofan engine design would show markedly better fuel consumption figures than pure turbojets. Critics had countered that drag from the larger nacelles necessary to house turbofans would offset any fuel gains.

Pratt & Whitney's modification of the J57 into the TF33 turbofan proved the engine designers right. Retrofitted into B-52s, it reduced specific fuel consumption by 19 percent. Gains in commercial applications were even larger.

The next step was determining the optimum size of the bypass stream. Initial studies showed that the amount of air flowing past the combustion chamber should be about 1.5 times the amount of air flowing through it.

But the Aero Propulsion Lab—pushed by Cliff Simpson—thought this bypass ratio should be much, much higher. Their small-scale test proved their case. High-bypass engines would have to burn hundreds of degrees hotter than low-bypass ones, however, so Wright technicians developed advanced cooling techniques that allowed engines, such as the C-5's TF39 turbofan, to operate at temperatures 600° above the point at which its turbines ordinarily would melt.

Both GE and Pratt & Whitney transformed the military high-bypass engine designs into civilian versions for a new generation of wide-body airliners. "Simply put, Air Force technology made these airplanes possible by reducing fuel consumption up to 30 percent, compared to low-bypass engines," concludes an Air Force turbine-engine history.

Secret Weapon

Technology demonstration programs have long been one of the Air Force's secret weapons in the gas-turbine development effort. One of the most successful of these was the Lightweight Gas Generator (LWGG) program, which began in the late 1950s. Focusing on the engine's core turbine and combustion parts—its "gas generator"—this Aero Propulsion Lab–directed effort worked on such evolutionary improvements as new fan-blade shapes. Within three years, the LWGG program showed it was possible to build engine cores with thrust-to-weight ratios of 10 to one, more than double the performance of most large engines of the time.

"LWGG provided a proven [technical] base to help upgrade existing engines," says Fred Oliver.

LWGG advances contributed to the design of an afterburning, low-bypass turbofan with 25,000 pounds of thrust, an engine intended for use in a vertical-takeoff-and-landing fighter. Though the VTOL aircraft itself was never built, some of its engine technology lives on in the powerplants of the F-15 fighter and B-1 bomber.

Eventually, the LWGG program metamorphosed into Wright Lab's long-running Advanced Turbine Engine Gas Generator (ATEGG) program. Over the years, ATEGG has contributed something to just about every US military engine currently in the air, according to the Air Force. The family tree of the F-22's Pratt & Whitney F119 engine reaches back to ATEGG, for instance, via a USAF-Navy Joint Technology Demonstrator Engine program that used ATEGG cores. Among the Aero Propulsion and Power Directorate–developed items in the F119 are turbine disks of advanced nickel alloy, abrasive turbine-blade-tip coatings, and a rectangular thrust-vectoring nozzle.

Today's Integrated High-Performance Turbine Engine Technology program now aims for yet another doubling of powerplant performance. Short, squat, compressor blades with unusual shapes hold out the promise of increasing aerodynamic efficiency, for instance. New materials will likely further reduce engine weight.

"People keep saying, 'What's going to replace the turbine engine?' " says Fred Oliver. "That's being achieved by evolutionary means." ■

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