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Jet-Powered Flight

Many scientists today are frequent fliers. But as they stride on to the planes they give little thought to the mechanical details that make possible rapid and relatively safe flight. The original inventions of jet engines and their subsequent improvements have involved a high level of creativity and skill in the application of basic scientific principles.

More than 200 years ago it was recognized that Newton's third law could be applied in a jet engine; that is, air could be compressed at the front of an engine and directed into a combustion chamber. The hot products would be expelled at the rear, driving a turbine and furnishing a thrust on the engine. But with the technology available in 1906 the overall efficiency in conversion of heat to work was an unattractive 3%. In contrast, reciprocating internal combustion engines at that time had efficiencies as high as 30%.

During the 1930s Sir Frank Whittle, then of the United Kingdom, and Hans J.P. von Ohain, then of Germany, independently invented jet engines with improved features. Each man also carried his invention through to demonstrations of the practicality of flying jet-powered planes. Their independent achievements were only slowly exploited by their respective governments. Large-scale production of jet-powered military aircraft occurred only toward the end of World War II. The planes had speeds greater than propeller-driven aircraft and, consequently, much greater effectiveness in combat. Had they been produced in quantity earlier they might have had a substantial effect on the course of the war. Faced with the necessity of attempting to protect their production facilities from bombing, the Germans developed the fastest jet fighter. It flew at about 525 miles per hour.

Thus, German combat planes had a speed comparable to modern jet transports. However, there the comparison stops. Flight lifetimes of the German World War II jet engines were as little as 25 hours. Lifetimes of modern jet engines are 10,000 to 20,000 hours. The thrust of today's engine is as much as 80,000 pounds. That of the early engines was 1000 to 2000 pounds. Modern air compressors create pressures in the combustion chamber that are as much as 35 times those of outside air, in contrast to earlier values of 3 and 4. An important criterion of quality in an aircraft engine is the ratio of thrust to weight. In the World War II engines, the ratio was about 1.5; now it is 5. Temperatures in combustion chambers were about 1500°F (815°C) in the first jet engines. Now they are about 2900°F. Correspondingly, Carnot cycle efficiency is enhanced. Fuel efficiency has increased by about a factor of 3, and is comparable to that of piston engines.

In the early days, the engines often failed because of the development of localized hot spots in the combustion chamber. The walls of present-day chambers are cooled. Especially useful is air cooling of the turbine blades. Their temperature is maintained 1000°F below that of the hot combustion gases. Air is introduced into an inner hollow in the blades and leaked through small holes to the outside surface of the blades. The tips of the blades move at supersonic velocities. Special care must be taken to minimize harmonic vibrations in the blades. To optimize strength and minimize corrosion the blades are drawn from a melt as single crystals. The fact that these blades can endure for 10,000 or more hours at 2900°F in a reactive chemical environment is testimony to human ingenuity.

Another factor in the efficiency of modern jet engines is the use of turbofans. That is, only a small fraction of the incoming air is used in combustion. About eight times as much is bypassed and used to provide thrust at the rear of the engine.

The jet engine has made long-distance travel fast and efficient. Development of reliable, powerful engines was the key to formation of a global aircraft industry dominated by U.S. firms. In 1990, the U.S. aerospace sector produced an estimated $28-billion trade surplus. The jet engine is an example where foreign technology was adopted and improved by U.S. manufacturers. General Electric and Pratt and Whitney had key roles. Nevertheless, we should also remember two men who independently had the creative genius and drive to invent and develop the first practical jet engines. The award to them by the National Academy of Engineering of the biennial Charles Stark Draper Prize (*Science*, 11 October, p. 193) was well deserved. It is also fitting that great engineering achievements be recognized by prizes, for they often involve levels of creativity comparable to or greater than those recognized by the Nobel Prize.—Philip H. Abelson