The Development History of Planes Engine

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Abstract. The development of jet engines represents one of the greatest achievements in modern engineering, reflecting humanity's constant pursuit of speed, efficiency, and innovation. From the early piston engines that first lifted aircraft into the sky to today's advanced turbofan and combined-cycle propulsion systems, the evolution of aircraft engines has continuously reshaped transportation, economics, and defense. Piston engines, though mechanically simple and reliable, were limited in speed and altitude, paving the way for turbojets in the 1940s, which enabled supersonic flight. As aviation demand grew, turbofan engines emerged, offering a balance between power, fuel efficiency, and noise reduction, while turboprop engines became essential for regional and short-haul aircraft due to their superior economy. In recent years, combined-cycle engines have opened new frontiers in hypersonic and reusable aerospace propulsion. At the same time, computational tools such as Computational Fluid Dynamics (CFD) and thermodynamic modeling have revolutionized engine design and optimization, accelerating innovation. Looking forward, with continuous breakthroughs in materials, digitalization, and intelligent control, jet engines will become even cleaner, safer, and more efficient, continuing to drive the progress of human civilization.

Keywords: Jet Engine, Piston Engine, Turbofan, Turboprop.

1. Introduction

Jet engines have made an important development to our civilization. Since it appeared in 1950s, it has developed the territory of us in transportation and military capacity. Jet engines have refined the limitation of speed and range by their unique structure, so it changed the transportation network, economic exchange and defense strategies. The rise of jet engines has experienced a long time. In 1900s, France engineer proposed the theory of ramjet engine. However, the material science then is not developed enough for building jet engines. In 1940s, Nazi Germany become the first to construct planes with jet engines [1]. Me262 was the first jet fighter. After World War 2, different nations in the world became to develop their own jet engine and jet planes, so different kinds of jet planes appeared. In 1949, the de Havilland Comet became the world's first commercial jetliner [2]. At the same time, large groups like pratt & Whitney and GE began to develop low-bypass turbofan engines like JT3D. In 1960s, high-bypass engines appear, increasing the turbine inlet temperature over 1700K and improving the thermal efficiency a lot. Nowadays, jet engines are still developing efficiency and security. This paper will focus on the major breakthroughs and recent research to produce an overlook of jet engine's evolution, analyzing the technical obstacles existed and the trend of its development in the future.GE Aerospace from US remains at the forefront of both commercial and military jet engine innovation. Its flagship GE9X engine, designed for the Boeing 777X, is currently the biggest and most powerful commercial turbofan engine in the world, offering higher fuel efficiency and lower emissions. At the same time, CFM International—invested by both GE and Safran from France—produces the LEAP engine family, which powers new-generation narrow-body aircraft such as the Airbus A320neo and Boeing 737 MAX series. On the military side, GE's XA100 and XA102 adaptive-cycle engines are being developed for next-generation fighter aircraft, marking a shift toward intelligent propulsion management. Pratt & Whitney, a subsidiary of RTX, has established a distinctive advantage with its Geared Turbofan (GTF) technology. The GTF family (such as the PW1100G-JM) uses a planetary gearbox that allows the fan and turbine core to operate at different speeds, significantly improving fuel efficiency while reducing noise and emissions at the same time. This engine powers the Airbus A320neo series and has received FAA certification for use on the long-range A321XLR. The first part of the introduction provides the information of development of piston engine, which is the first engine human civilization developed and pushed us to the air-age. After that, I will explain the first jet engine-turbojet engine. This engine gave people the ability to propulse their plane over sound speed but be replaced by other kinds of jet engines in some domain. Turbofan engine is the engine that appeared after turbojet engine, its efficiency was improved through adding a fan in front of the core. Next is the turboprop engine. Different from turbofan engine, this engine's main thrust is from its fan rather than the thrust ejected by the main duct. Besides traditional engines, I will also introduce combined circle engines and some methods to design and examine engines.

2. The Piston Engine

The piston engine, also known as the reciprocating internal combustion engine was first appeared at the late 19 century and be widely used in 20 centuries. They were widely used in cars, boats and planes. Although the usage on planes has been already displaced on planes, they are still be using on cars nowadays due to its popular price, long life period and low fuel consumption. The operation principle of it is transforming the heat produced by the burning of fuel in cylinder into the kinetic energy of reciprocating moving of pistons. Then the kinetic energy of pistons can be transformed to rotary output via a connecting rod and crankshaft assembly.

The piston engine consists of several key components: cylinders, pistons, connecting rods, a crankshaft, valves, fuel injection or carburetion systems, and ignition mechanisms. In the widely used four-stroke cycle, the piston executes four distinct phases—intake, compression, combustion, and exhaust—coordinated by the valve train and ignition system. The crankshaft transforms the reciprocating moving of piston into the circular motion. The picture is a typical 6-sylinder piston engine, with high fuel efficiency and reliability.

Figure 1. 6-cylinder horizontally opposed aviation piston engine [1]

The structure leads to two obvious traits. The first is piston engines have relative more simple structure, and the technology to construct it is mature, this makes it has a low producing cost and wide usage. Also, standardization of parts and decades of production experience created robust repair networks, making piston engines suitable for widespread use in both civilian and military contexts. However, piston engines also have trait of low power-height ratio. Piston engines include structures like reciprocating mass (pistons and connecting rods) and several cylinders which are heavy, making the pistons engines always heavy. When same power is required, piston engines always heavier than jet engines appeared later, so this makes it not the best choice for aircraft which is very sensitive with mass.

Piston engines were widely used in early centuries on planes, played as the major kind of engines. All kinds of fighter, bomber and transport planes used piston engines as the source of power.

Nowadays, although jet engines have replaced piston engines in most situations on planes, they still exist as a low-cost kind of engine. For example, apart from cars and boats, there are still some planes are using this kind of engine. Especially in some small kinds of general-purpose airplanes, piston engines serve the training planes, short distance transport planes and aerobatic planes for its low cost and maintainability. What's more, piston engines remain attractive in contexts requiring frequent start-stop cycles, low-speed torque, and lower upfront costs compared with turbines.

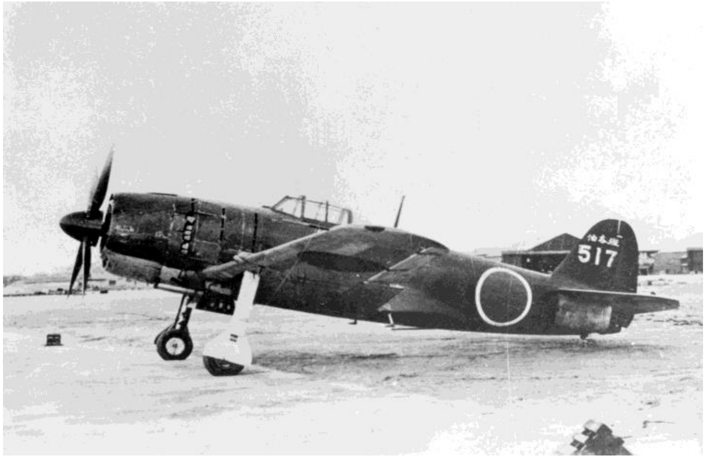

Figure 2. N1K2-J "Shiden-Kai" fighter, which is a improved version of N1K [2]

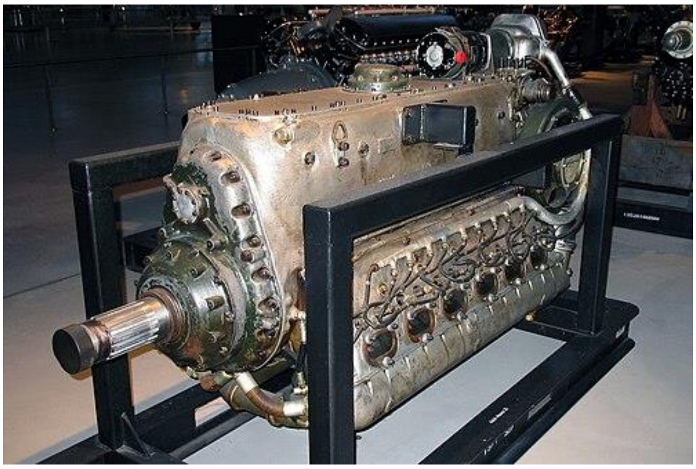

Figure 3. Daimler-Benz DB601engine [3]

However, despite from these advantages, piston engines are facing some serious issues. The biggest limitation is it has low efficiency in high-speed working condition because the mechanical stress and thermal management issues became increasingly severe at higher speeds and power levels. Besides, the reciprocating unit like pistons and connecting rods can shake, requiring more balancing and shock reducing measures that are very complex, making the engines have higher complexity and weight. What's more, environmental and emissions challenges, including nitrogen oxides (NOx), unburned hydrocarbons, and particulate matter—became increasingly important in the late 20th century. Without costly aftertreatment systems, piston engines often struggled to meet modern regulatory standards. Bf 109 with Maimler-Benz DB601 and N1K" Shiden" (FIG. 2) are two fighters during WW2 with piston engines. Bf 109's DB601 engine is liquid-cooled, inverted V-12 piston configuration with direct fuel injection, generating about 1,100 horsepower at 2,400 rpm, flight at 1940 to 1945. The direct fuel injection technology allows it to keep thrust at diving. However, there are designing problem with its piston, causing the problem of heat dissipation. N1K with Ha-2 engine which is air-cooled, twin-row 18-cylinder radial configuration, delivering up to 1,990 horsepower. This engine has a great power, making N1K able to fight with US's fighters like F6F or F4U. However, too complex structure makes it hard to manufacturing, leading Imperil Japanese only produced about 600 of it.

3. Turbojet Engine

The invention and maturation of turbojet engine was a great turning point of the development of human aircraft propulsion. Turbojets convert the chemical energy of fuel into high-speed exhaust jet thrust by compressing incoming air, burning fuel in a combustor, and expanding the hot gases through a turbine and nozzle as shown in FIG. 4. Compared to piston engines, the turbojet engine has higher thrust-to-weight ratio and high efficiency in high-speed working condition. It can provide a great propulsion force and make it possible for planes to have great velocity. So, it is widely be used in high-speed fighter and first generation of commercial jet. However, compared to turbofan engines, their performance in subsonic speed is not perfect, showing in low propulsive efficiency.

An example of turbojet engine is the CJ610(originated from military J85). The CJ610 is a compact, single-shaft axial-flow turbojet that powered many early business jets (e.g., Learjet 23) and logged millions of operational hours; its design exemplifies the turbojet tradeoffs of high specific thrust at the cost of higher specific fuel consumption for subsonic cruise. The picture below is a CJ106 Turbojet engine.

Figure 4. CJ106 turbojet engine [4]

4. Turbofan Engine

Another kind of engine is turbofan engine. A fan was added to the front of the core of turbojet engine which make some air bypass the core directly and enhance propulsion efficiency. So, the turbofan engine has higher propulsion efficiency while the maximum propulsion force is limited.

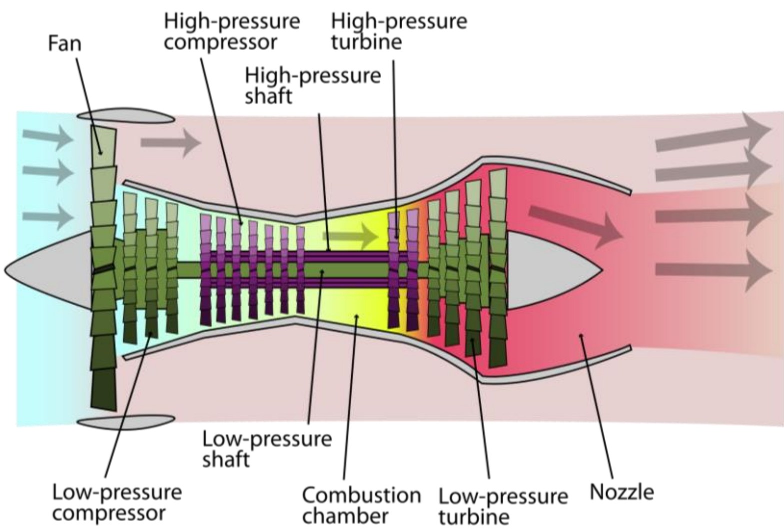

Figure 5. CJ610 Turbojet engine [5]

An example of turbofan engine is CF700 from General Electric (GE), which evolved from turbojet engine CJ610 (FIG. 5) by adding an aft-mounted fan driven by the low-pressure turbine. The CF700 demonstrated how modest bypass and careful matching could substantially improve cruise efficiency without a complete redesign of the core. The picture shows the structure of turbofan engine.

Major advances continued toward high-bypass and geared turbofan architectures. The Pratt & Whitney PW1000G (GTF) family introduced a reduction gearbox between fan and low-pressure turbine, allowing the fan to rotate slower (for higher propulsive efficiency) while the turbine spins faster (for thermodynamic efficiency) because the driven of fan required lots of energy. The pictures below show CF700 (FIG .6) turbofan engine and PW1000G (FIG .7) engine which is super big.

Figure 6. CF700 engine on A Dassault Falcon 20 [6]

The comparison between turbojet engine and turbofan engine. The turbojet engine has higher specific thrust, meaning it can drive the plane with higher speed; while the turbofan engine has relatively lower specific thrust but has high propulsion efficiency by accelerating a larger mass of air to a lower velocity (bypass flow). The turbofan engine’s fuel consumption can be reduced from turbojet engines for even more than 15%. Also, profit from its structure with a bypass flow and lower exhaust velocity, turbojet engine has smaller noise compared to traditional turbojet engine in subsonic speed. What’s more, Studies and experimental measurements show turbofan installations with acoustic liners and low-velocity fan flow achieve significantly lower perceived noise levels than turbojets. Advanced nacelle and fan-treatment technologies further reduce community noise.

Nowadays, the turbojet engine is always be used in military because it has high thrust-weight ratio, providing a great speed performance for fighters. Oppositely, the planes more concentrate in economical like airliners that does not require extreme high velocity have widely used turbojet engine not only for its high fuel economy but also for the quiet and comfortable atmosphere it can provide for passengers.

Figure 7. The testing of Pratt & Whitney PW1000G on Boeing 717sp platform [7]

5. Turboprop engine

The turboprop engine (FIG. 8) is a combination of turbine engine and propeller system. where the turbine's mechanical output drives a reduction gearbox and propeller rather than producing thrust solely through high-speed exhaust. Their most distinctive feature is even higher propulsive efficiency at low to medium subsonic speeds (typically below Mach 0.6–0.7) which is lower than turbofan engines. This engine also has the ability to produce large propulsion force with its small weight. Compared with turbojets and turbofan, turboprops offer excellent fuel economy, short takeoff capability, and the ability to operate on shorter runways. The picture below shows the structure of turboprop engine.

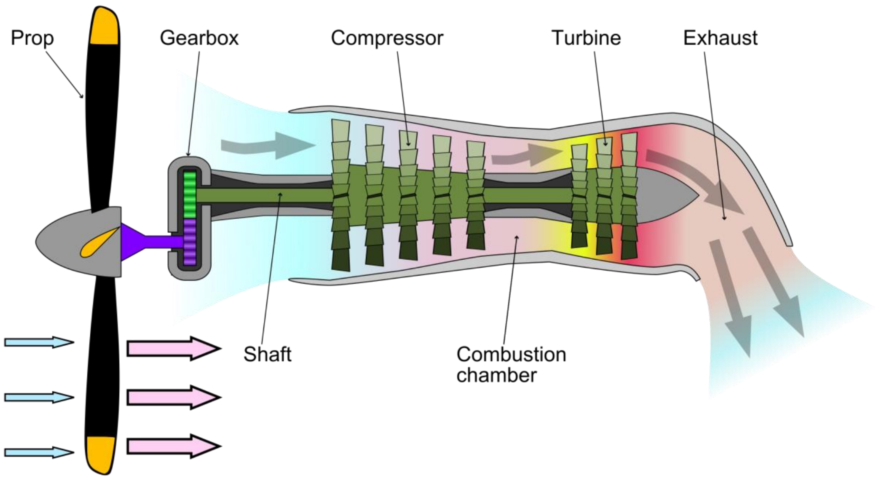

Figure 8. Turboprop engine [8]

The limitation of this kind of engine is the planes with them cannot fly with a high speed. The efficiency of propeller system's aerodynamic losses rise sharply with Mach number. As a result, the appliance of turboprop engine is always low-altitude surveillance, and cargo operations where fuel economy and payload are prioritized over top speed.

Applications are widespread in regional aviation (e.g., ATR 72, Bombardier Dash 8) and military transports (e.g., C-130 Hercules, shown in FIG. 9).

Figure 9. Lockheed Martin C130J super Hercules [9]

6. Combined cycle Engines

Combined cycle (**FIG. 10**) propulsion refers to the integration of two or more engine types into a single system, enabling operation across a much broader flight regime than any single engine cycle could cover. The central idea is to leverage the high efficiency of traditional engines at lower Mach numbers and the high thrust of rockets at very high Mach numbers or in vacuum. Combined cycle engines use a turbojet engine in a low speed just like traditional planes. However, the power will be changed into Ramjet which operates efficiently at Mach 3–7.

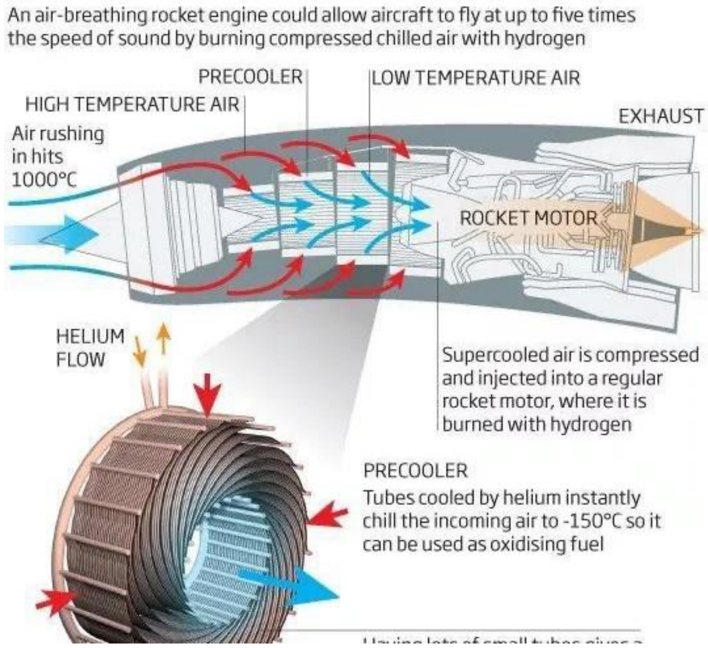

Figure 10. SABRE Turbojet rocket variable cycle engine [10]

The biggest advantage of combined cycle engines is they have extreme great speed, allowing the aircraft with this kind of engine have ability to deliver passages from a place to another place in a short time. As a result, people expect it to be power source of Hypersonic cruise aircraft that capable of global travel in under three hours. Others even expect it to be on the spaceplanes or military attacker due to its high speed and recycle utilization.

However, this kind of engine are facing some serious problems, making it cannot become reality. At Mach 5+, inlet air temperatures exceed 1200 K, demanding advanced heat exchangers, precoolers, or actively cooled structures. Also, switching between turbine, ramjet/scramjet, and rocket modes requires precise control of airflow, fuel scheduling, and variable-geometry inlets. All of these technical questions are waiting for a solution in the future. The picture below shows the principle of Turbojet rocket variable cycle engine.

7. Simulation and Design

Computational Fluid Dynamics (CFD) is one of the most critical simulation tools in modern jet engine design. By numerically solving the Navier–Stokes equations, CFD enables researchers to model gas flow, temperature distribution, pressure variations, and combustion processes inside the engine. Engineers can optimize compressors, combustors, and turbines virtually before physical prototypes are built, thereby improving thrust efficiency and reducing fuel consumption and noise. The major advantage of CFD is its ability to visualize aerodynamic and help designers to find problems easily; however, it is extremely expensive because it requires high-performance computing resources.

Beyond local flow and combustion simulations, overall engine performance assessment is often conducted through thermodynamic cycle modeling. This method applies thermodynamics and energy conservation principles to represent the major components of the engine—compressor, combustor, turbine, and nozzle—within a system-level mathematical framework. Widely used platforms include NASA’s NPSS (Numerical Propulsion System Simulation) and GasTurb. Such tools can quickly estimate thrust, specific fuel consumption, efficiency, and thrust-to-weight ratio, supporting concept evaluation and parameter optimization. Their advantage lies in fast and intuitive overall performance prediction, while their limitation is the relatively lack of representation of detailed flow physics and combustion chemistry. FIG. 11 shows an application of CFD while simulating the flow passing through a turbofan engine.

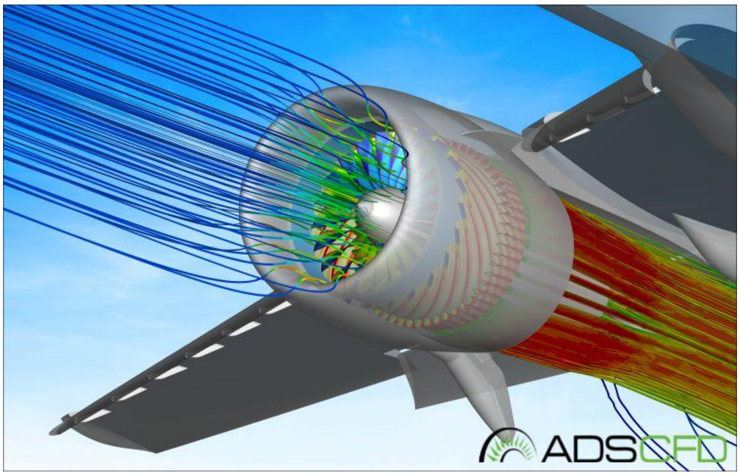

Figure 11. The CFD image in simulating the airflow passing through a turbofan engine [11]

8. Conclusion

The development of aircraft engines reflects one of the most remarkable technological journeys in human history. From the birth of the piston engine at the end of the 19th century to the emergence of advanced combined-cycle propulsion systems in the 21st century, the continuous evolution of engine technology has profoundly shaped aviation, global transportation, and human civilization itself. Each generation of propulsion technology represents a balance between scientific exploration, engineering innovation, and practical demand.

The piston engine marked the beginning of powered flight and symbolized the transition of humanity from ground transportation to aerial mobility. Its simple structure, mature manufacturing technology, and reliability made it the dominant power source for aircraft throughout the early 20th century. Although limited by a low power-to-weight ratio and mechanical vibration, the piston engine laid the essential foundation for the study of thermodynamics, internal combustion, and fuel-air mixture control, all of which became key theoretical bases for later propulsion systems.

With the advent of the turbojet engine in the 1940s, aviation entered a new era of high-speed flight. By using continuous combustion and gas expansion through turbines, the turbojet achieved far higher thrust and efficiency at high speeds than any piston engine could provide. This innovation enabled supersonic military aircraft and the first generation of commercial jets, breaking the boundaries of distance and time in global transportation. However, the high fuel consumption and limited efficiency of turbojets at subsonic speeds encouraged further improvements.

The turbofan engine, which evolved from the turbojet, became the dominant propulsion system for modern civil aviation. By introducing a large bypass ratio fan that accelerates a greater mass of air at lower velocity, turbofan engines dramatically improved propulsive efficiency and reduced noise. The high-bypass turbofan remains the standard configuration for today’s airliners, balancing performance, fuel economy, and environmental sustainability. Meanwhile, the turboprop engine—though operating at lower speeds—offered exceptional fuel efficiency and short takeoff capabilities, making it ideal for regional and cargo aircraft.

Beyond these established designs, the exploration of combined-cycle propulsion has opened new frontiers for aerospace applications. Engines such as the SABRE and other turbine-based combined-cycle (TBCC) systems aim to integrate turbine, ramjet, and rocket technologies within a single platform, offering efficient propulsion from takeoff to hypersonic or even orbital flight. Although these concepts remain experimental, they represent the next major step toward achieving global hypersonic travel and reusable space access vehicles.

Modern advancements in simulation technology have also transformed engine research and development. Computational Fluid Dynamics (CFD) allows engineers to simulate complex flow fields, combustion reactions, and thermal stresses inside engines with unprecedented accuracy. Together with thermodynamic cycle modeling tools like NASA's NPSS and GasTurb, these computational approaches significantly reduce development costs, optimize performance parameters, and accelerate innovation. They enable engineers to refine compressor design, enhance turbine cooling systems, and improve combustion efficiency even before a physical prototype is built.

Looking forward, the future of jet engine development will continue to be driven by three key trends: efficiency, sustainability, and intelligent design. Efforts to reduce carbon emissions, adopt sustainable aviation fuels (SAF), and develop hybrid-electric propulsion are already reshaping the aerospace industry. Meanwhile, the integration of artificial intelligence (AI) and machine learning in engine control and maintenance promises smarter, safer, and more predictive systems. Adaptive-cycle engines like GE's XA100 further illustrate how variable geometry and real-time optimization can redefine performance across different flight conditions.

In conclusion, the evolution of aircraft engines—from reciprocating piston engines to advanced combined-cycle propulsion—demonstrates the continuous human pursuit of efficiency, performance, and environmental harmony. Each technological milestone not only enhanced the capability of flight but also reflected broader advancements in materials science, thermodynamics, and computational engineering. As innovations continue to emerge, future engines will become cleaner, lighter, and more intelligent, enabling faster and more sustainable air travel. Ultimately, the development of jet engines embodies the enduring spirit of human progress, driving aviation toward a future that is more efficient, more connected, and more capable than ever before.

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