787 No-Bleed Systems: Saving Fuel and Enhancing Operational Efficiencies

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The Boeing 787 Dreamliner features a unique systems architecture that offers numerous advantages to operators. The new airplane's use of electrical systems reduces fuel usage and increases operational efficiency.

The primary differentiating factor in the systems architecture of the 787 is its emphasis on electrical systems, which replace most of the pneumatic systems found on traditional commercial airplanes.

One of the advantages of the no-bleed electrical systems architecture is the greater efficiency gained in terms of reduced fuel burn — the 787 systems architecture accounts for predicted fuel savings of about 3 percent. The 787 also offers operators operational efficiencies due to the advantages of electrical systems compared to pneumatic systems in terms of weight and reduced lifecycle costs.

This article explores the 787's no-bleed systems architecture and explains how the airplane's efficiencies are realized.

REASONS BEHIND THE MOVE TO A MORE ELECTRIC AIRPLANE

Recent advances in technology have allowed Boeing to incorporate a new no-bleed systems architecture in the 787 that eliminates the traditional pneumatic system and bleed manifold and converts the power source of most functions formerly powered by bleed air to electric power (for example, the air-conditioning packs and wing anti-ice systems). The no-bleed systems architecture offers operators a number of benefits, including:

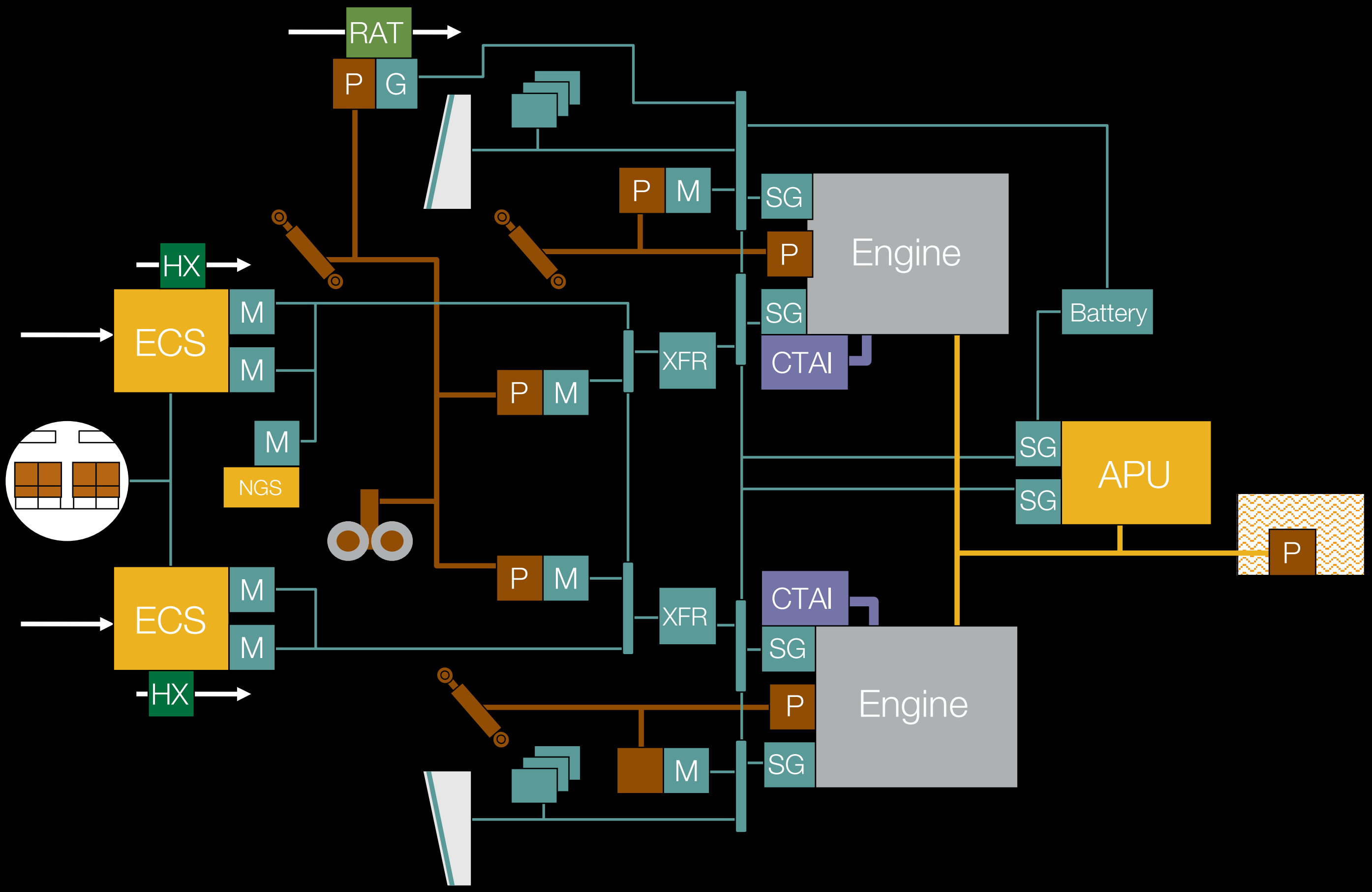
- Improved fuel consumption, due to a more efficient secondary power extraction, transfer, and usage.
- Reduced maintenance costs, due to elimination of the maintenance-intensive bleed system.
- Improved reliability due to the use of modern power electronics and fewer components in the engine installation.
- Expanded range and reduced fuel consumption due to lower overall weight.
- Reduced maintenance costs and improved reliability because the architecture uses fewer parts than previous systems.

The 787's no-bleed systems architecture will allow the airplane's engines to produce thrust more efficiently — all of the high-speed air produced by the engines goes to thrust. Pneumatic systems that divert high-speed air from the engines rob conventional airplanes of some thrust and increase the engine's fuel consumption.

Boeing believes that using electrical power is more efficient than engine-generated pneumatic power, and expects the new architecture to extract as much as 35 percent less power from the engines. Conventional pneumatic systems generally develop more power than is needed in most conditions, causing excess energy to be dumped overboard.

787 NO-BLEED SYSTEMS ARCHITECTURE
Figure 1

The 787's no-bleed systems architecture replaces the traditional pneumatic system and the bleed manifold with a high-power electrical system that, in addition to the traditional electrical system functions, supports a majority of the airplane functions that were traditionally performed via bleed air.

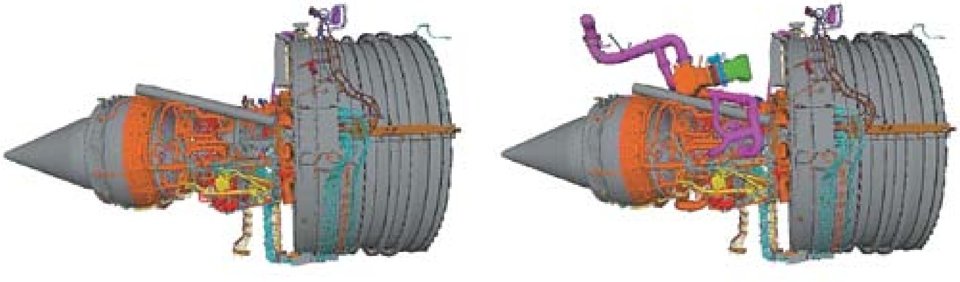


ELECTRICAL POWER IS MORE EFFICIENT THAN ENGINE-GENERATED PNEUMATIC POWER.

COMPARISON OF BLEED AND NO–BLEED ENGINE BUILDUP

Figure 2

A comparison of typical engine buildups of a no-bleed engine (left) and the traditional bleed engine.



The ducting used to pass the pressurized air around the airplane employs check valves and pre-coolers, and is itself made of titanium, which adds hundreds of pounds of weight to the airplane.

The electric system is also inherently easier to monitor and control, and produces only enough power as needed. The power, which comes off the generators at variable frequencies, is conditioned in the electronics bay before being distributed to the appropriate systems.

787 NO-BLEED SYSTEMS ARCHITECTURE

The 787 no-bleed systems architecture is shown schematically in figure 1. On the 787, bleed air is only used for engine cowl ice protection and pressurization of hydraulic reservoirs. The electrified functions are wing deicing protection, engine starting, driving the high-capacity hydraulic pumps, and powering the cabin environmental control system.

In this architecture, the power sources for the electrical system are engine-driven and auxiliary-power-unit (APU)-driven generators, while the power sources for the hydraulic system are engine-driven and electric-motor-driven hydraulic pumps. The engine-driven hydraulic power sources in the no-bleed architecture are similar to those in the traditional architecture.

In the no-bleed architecture, electrically driven compressors provide the cabin pressurization function, with fresh air brought onboard via dedicated cabin air inlets. This approach is significantly more efficient than the traditional bleed system because it avoids excessive energy extraction from engines with the associated energy waste by pre-coolers and modulating valves. There is no need to regulate down the supplied compressed air. Instead, the compressed air is produced by adjustable speed motor compressors at the required pressure without significant energy waste. That results in significant improvements in engine fuel consumption.

ENGINES

In the traditional architecture, the engines provide the majority of secondary airplane systems power needs in pneumatic form; in the no-bleed architecture, the engines provide the majority of airplane systems power needs in electrical form via shaft-driven generators. The traditional airplane pneumatic bleed system architecture results in less than optimum engine efficiency. Eliminating the pneumatic bleed results in a more efficient engine operation due to reduced overall airplane level power requirements — the airplane does not draw as much horsepower off the engine in cruise, so it doesn't burn as much fuel. The corresponding predicted improvement in fuel consumption, at cruise conditions, is in the range of 1 to 2 percent.

Moreover, the no-bleed architecture allows significant simplification in engine buildup due to the elimination of the pneumatic system and associated pre-coolers, control valves, and required pneumatic ducting. Figure 2 compares typical engine buildups of no-bleed engine and the traditional bleed engine.

HYDRAULIC SYSTEM

The hydraulic system in the 787 no-bleed architecture is similar to the one in the traditional architecture. There are three independent systems — left, center, and right — that collectively support primary flight control actuators, landing gear actuation, nose gear steering, thrust reversers, and leading/trailing edge flaps.

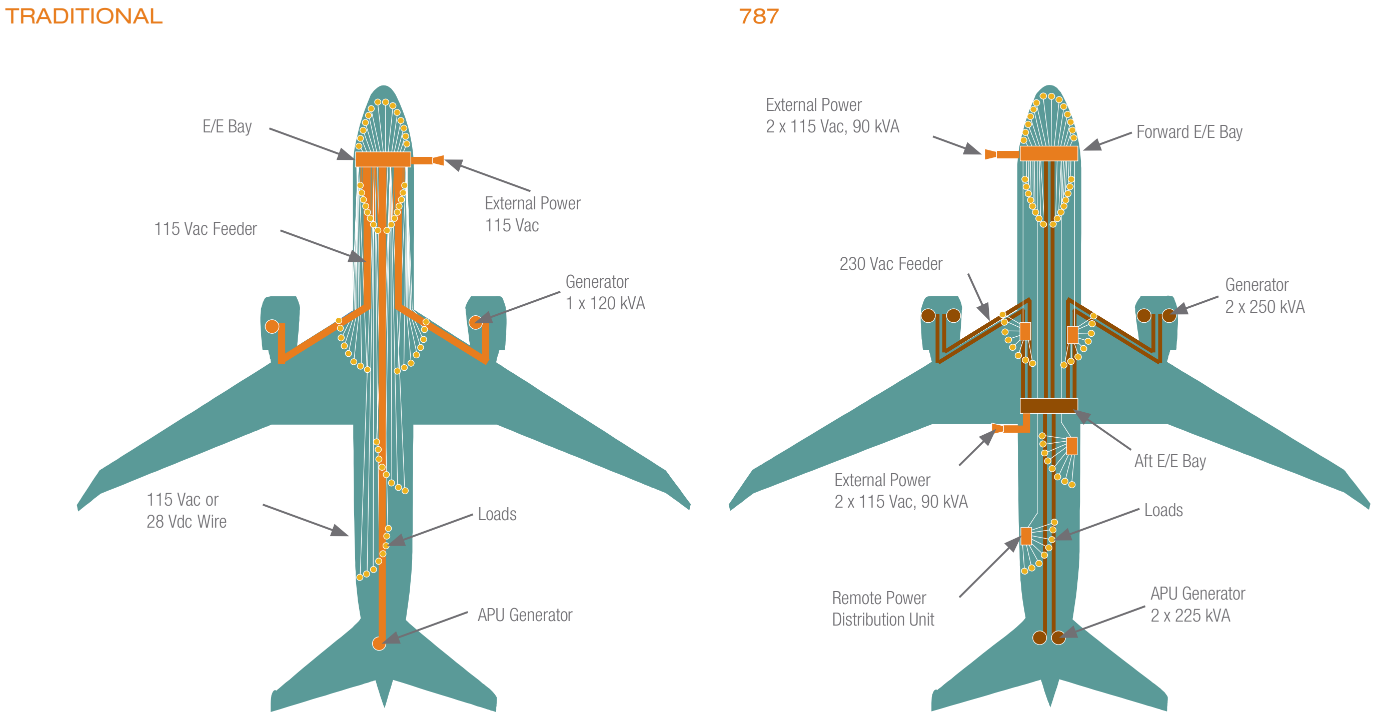
The primary power source for the left and right systems are engine-driven pumps mounted on the engine gearbox. In addition, the left and right systems are each powered by an electric-motor-driven hydraulic pump for peak demands and for ground operations.

The key difference between the traditional and 787 hydraulic system is the power source for the center system. In the traditional architecture, the center system is powered by two large air-turbine-driven hydraulic pumps, which operate at approximately 50 gallons per minute (gpm) at 3,000 pounds per square inch (psi) to meet peak hydraulic demands for landing gear actuation, high lift actuation and primary flight control during takeoff and landing. During the remainder of the flight, two small (approximately 6 gpm) electric-driven hydraulic pumps power the center system.

In the 787 no-bleed architecture, the center hydraulic system is powered by two large (approximately 30 gpm at 5,000 psi) electric-motor-driven hydraulic pumps. One of the pumps runs throughout the entire flight and the other pump runs only during takeoff and landing. The higher pressure of the 787's hydraulic system enables the airplane to use smaller hydraulic components, saving both space and weight.

Figure 3

The 787's electrical system uses a remote distribution system that saves weight and is expected to reduce maintenance costs.



Centralized Distribution:
Circuit Breakers, Relays,
and Contactors

Remote Distribution:
Solid-State Power Controllers
and Contactors

ELECTRICAL SYSTEM

The 787 uses an electrical system that is a hybrid voltage system consisting of the following voltage types: 235 volts alternating current (VAC), 115 VAC, 28 volts direct current (VDC), and ±270 VDC. The 115 VAC and 28 VDC voltage types are traditional, while the 235 VAC and the ±270 VDC voltage types are the consequence of the no-bleed electrical architecture that results in a greatly expanded electrical system generating twice as much electricity as previous Boeing airplane models. The system includes six generators — two per engine and two per APU — operating at 235 VAC for reduced generator feeder weight. The system also includes ground power receptacles for airplane servicing on the ground without the use of the APU.

The generators are directly connected to the engine gearboxes and therefore operate at a variable frequency (360 to 800 hertz) proportional to the engine speed. This type of generator is the simplest and the most efficient generation method because it does not include the complex constant speed drive, which is the key component of an integrated drive generator (IDG). As a result, the generators are expected to be more reliable, require less maintenance, and have lower spare costs than the traditional IDGs.

The electrical system features two electrical/electronics (E/E) bays, one forward and one aft, as well as a number of remote power distribution units (RPDU) for supporting airplane electrical equipment. The system saves weight by reducing the size of power feeders. A limited number of 235 VAC electrical equipment is supplied from the aft E/E bay, while the majority of airplane electrical equipment, being either 115 VAC or 28 VDC, are supported by the forward E/E bay and RPDUs as shown schematically in figure 3. The RPDUs are largely based on solid-state power controllers (SSPC) instead of the traditional thermal circuit breakers and relays. The ±270 VDC system is supplied by four auto-transformer-rectifier units that convert 235 VAC power to ±270 VDC. The ±270 VDC system supports a handful of large-rated adjustable speed motors required for the no-bleed architecture. These include cabin pressurization compressor motors, ram air fan motors, the nitrogen-generation-system compressor used for fuel-tank inerting, and large hydraulic pump motors.

The system, as shown in figure 3, features two forward 115 VAC external power receptacles to service the airplane on the ground without the APU and two aft 115 VAC external power receptacles for maintenance activities that require running the large-rated adjustable speed motors.

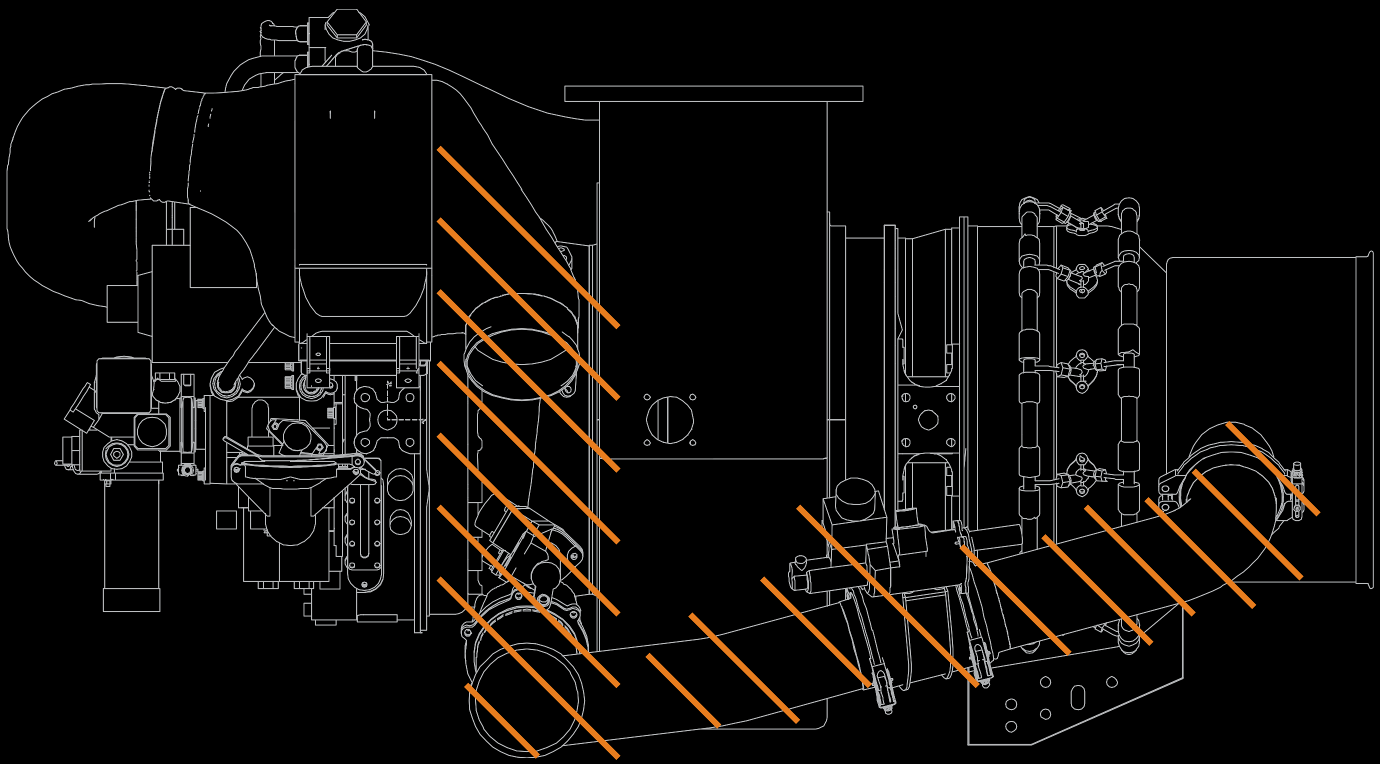
ENGINE AND APU START

The 787's engine-start and APU-start functions are performed by extensions of the method that has been successfully used for the APU in the

APU SYSTEMS ELIMINATED IN THE NO-BLEED ARCHITECTURE

Figure 4

This diagram of an APU for a 767-400 airplane shows the pneumatic portions that will be eliminated in a no-bleed architecture.



> The 787 utilizes an electro-thermal ice protection scheme, in which several heating blankets are bonded to the interior of the protected slat leading edges.

Next-Generation 737 airplane family. In this method, the generators are run as synchronous starting motors with the starting process being controlled by start converters. The start converters provide conditioned electrical power (adjustable voltage and adjustable frequency) to the generators during the start for optimum start performance.

Unlike the air turbine engine starters in the traditional architecture that are not used while the respective engines are not running, the start converters will be used after the respective engine is started. The engine- and APU-start converters will function as the motor controller for cabin pressurization compressor motors.

Normally, both generators on the APU and both generators on the engine are used for optimum start performance. However, in case of a generator failure, the remaining generator may be used for engine starting but at a slower pace. For APU starting, only one generator is required.

The power source for APU starting may be the airplane battery, a ground power source, or an engine-driven generator. The power source for engine starting may be the APU generators, engine-driven generators on the opposite side engine, or two forward 115 VAC ground power sources. The aft external power receptacles may be used for a faster start, if desired.

ENVIRONMENTAL CONTROL SYSTEM

In the 787 electrical architecture, the output of the cabin pressurization compressors flows through low-pressure air-conditioning packs for improved efficiency. The adjustable speed feature of electrical motors will allow further optimization of airplane energy usage by not requiring excessive energy from the supplied compressed air and later regulating it down through modulating valves resulting in energy loss.

Avoiding the energy waste associated with down regulation results in improvements in engine fuel consumption, and the environmental-control-system air inflow can be adjusted in accordance with the number of airplane occupants to achieve the lowest energy waste while meeting the air-flow requirements.

WING ICE PROTECTION

In the traditional architecture, hot bleed air is extracted from the airplane bleed system and distributed through the areas of the wing leading edge that need ice protection. For each wing, one valve controls the flow of the bleed air to the wing leading edge, while a “piccolo” duct distributes the heat evenly along the protected area of the wing leading edge. In addition, should ice protection on the leading edge slats be required, a telescoping duct supplies bleed air to the slats in the extended position. The spent bleed air is exhausted through holes in the lower surface of the wing or slat.

The 787 utilizes an electro-thermal ice protection scheme, in which several heating blankets are bonded to the interior of the protected slat leading edges. The heating blankets may then be energized simultaneously for anti-icing protection or sequentially for deicing protection to heat the wing leading edge. This method is significantly more efficient than the traditional system because no excess energy is exhausted. As a result, the required ice protection power usage is approximately half that of pneumatic systems. Moreover, because there are no-bleed air exhaust holes, airplane drag and community noise are improved relative to the traditional pneumatic ice protection system.

APU

As in a traditional architecture, the APU in the no-bleed electrical architecture is mounted in the airplane tail cone, but it provides only electrical power. Consequently, it is much simpler than the APU for the traditional architecture because all of the components associated with the pneumatic power delivery are eliminated. This should result in a significant improvement in APU reliability and required maintenance.

Figure 4 shows the APU for a 767-400 airplane, identifying the pneumatic portions that will be eliminated in a no-bleed electrical architecture. Moreover, taking advantage of the variable frequency feature of the 787 electrical system, the APU operates at a variable speed for improved performance. The operating speed is based on the ambient temperature and will be within a 15 percent range of the nominal speed.

SUMMARY

A key benefit expected from the Boeing 787’s no-bleed architecture is improved fuel consumption as a result of more efficient engine cycle and more efficient secondary power extraction, power transfer, and energy usage.

Eliminating the maintenance-intensive bleed system is also expected to reduce airplane maintenance needs and improve airplane reliability because there are fewer components on the engine installation; there are no IDGs, pneumatic ducts, pre-coolers, valves, duct burst protection, and over-temperature protection; and there is no compressed air from the APU, resulting in a simplified and more reliable APU.

The 787 no-bleed architecture also features modern power electronics and motors that will provide increased overall reliability, decreased costs, and improved performance. Finally, the architecture means reduced airplane weight, reduced part count, and simpler systems installation. For more information, please contact Lori Gunter at loretta.m.gunter@boeing.com