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Boeing 787 from the Ground Up

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THE 787 DREAMLINER TAKES ADVANTAGE OF NEW TECHNOLOGIES TO INCREASE RELIABILITY AND IMPROVE MAINTAINABILITY.

Boeing 787 from the Ground Up

by Justin Hale,
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With the 787 Dreamliner, Boeing is using a new approach to design which takes into greater account the cost to maintain airplane structure and systems over their lifetimes. As a result of this approach, the basic 787-8 airplane will have 30 percent lower airframe maintenance costs than any comparable product and will be available for revenue service more often than any other commercial airplane.

The Boeing 787 program has consciously designed in new, state-of-the-art features and performance that reduce cost and increase airplane availability. These features will lead to additional savings and greater revenue for Boeing customers. The 787 reflects a new life-cycle design philosophy that has dictated some significant changes in the way the airplane will be built. These changes include extensive use of composites in the airframe and primary structure, an electric systems architecture, a reliable and maintainable design, and an improved maintenance program. Taken together, these changes will offer customers a guaranteed reduction in maintenance costs.

LIFE-CYCLE COST DESIGN PHILOSOPHY

The life-cycle cost approach to design looks at the total cost picture for design options by examining all of the factors that affect an airplane over its lifetime. Traditionally, the value of a given design solution has been measured using factors such as:

- Drag
- Weight
- Noise (cabin and community)
- Schedule reliability
- Development cost
- Build cost

Using these measures to compare design options helps determine the optimum choice.

With the 787, Boeing has expanded the life-cycle design approach by adding two unique performance measures: maintenance cost and airplane availability. Clearly, looking at the cost to maintain systems over their lifetimes becomes a significant factor when attempting to understand the total effect of a design decision on an operator's cost structure. Airplane availability includes not only schedule reliability but also other factors such as the length of time an airplane must be out-of-service when maintenance is required. Obviously, taking an airplane out of service for two days has a much bigger effect on operator revenue than taking it out of service for two hours.

COMPOSITES IN THE AIRFRAME AND PRIMARY STRUCTURE

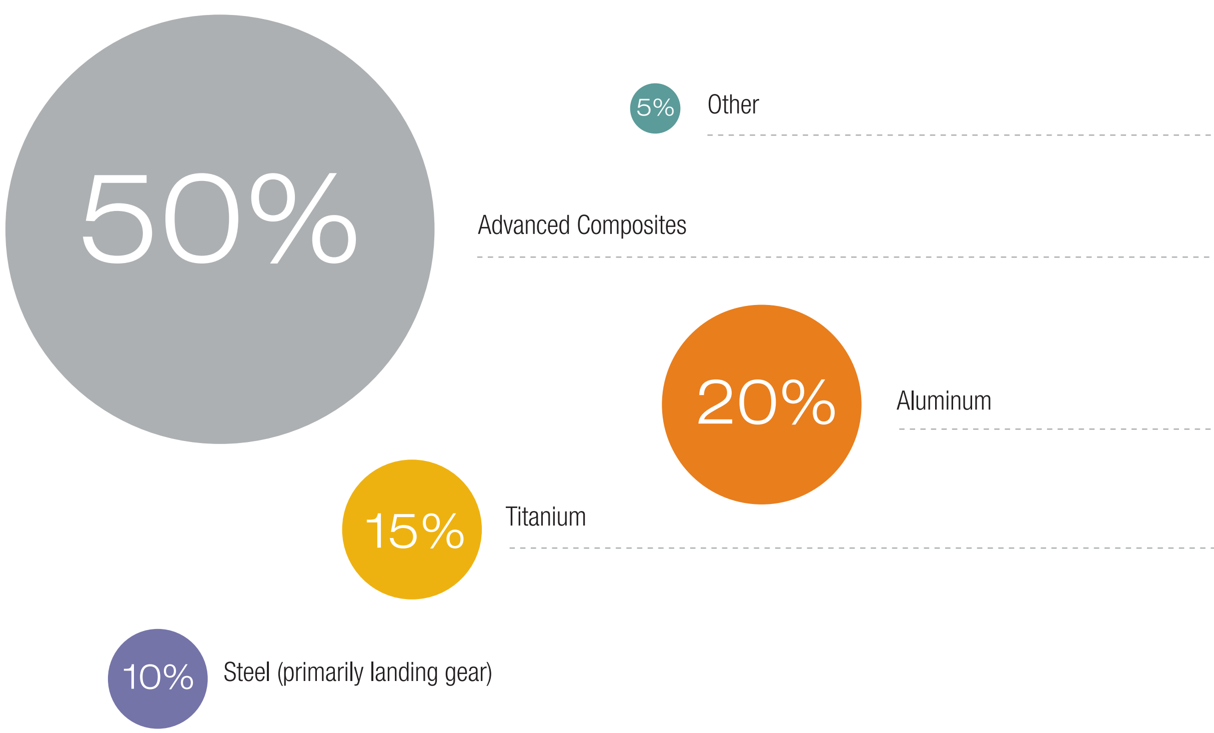
The Boeing 787 makes greater use of composite materials in its airframe and primary structure than any previous Boeing commercial airplane. Undertaking the design process without preconceived ideas enabled Boeing engineers to specify the optimum material for specific applications throughout the airframe.

The result is an airframe comprising nearly half carbon fiber reinforced plastic and other composites. This approach offers weight savings on average of 20 percent compared to more conventional aluminum designs.

Selecting the optimum material for a specific application meant analyzing every area of the airframe to determine the best material, given the operating environment and loads that a component experiences over the life of the airframe. For example, aluminum is sensitive to tension loads but handles compression very well. On the other hand, composites are not as efficient in dealing with compression loads but are excellent at handling tension. The expanded use of composites, especially in the highly tension-loaded environment of the fuselage, greatly reduces maintenance due to fatigue when compared with an aluminum structure. This type of analysis has resulted in an increased use of titanium as well. Where loading indicates metal is a preferred material system but environmental considerations indicate aluminum is a poor choice, titanium is an excellent low-maintenance design solution. Titanium can withstand comparable loads better than aluminum, has minimal fatigue concerns, and is highly resistant to corrosion. Titanium use has been expanded on the 787 to roughly 14 percent of the total airframe. Every structural element of the 787 has undergone this type of life-cycle analysis and material types are based on a thorough and disciplined selection process.

In addition to using a robust structural design in damage-prone areas, the 787 has been designed with the capability to be repaired in exactly the same manner that airlines would repair an airplane today – with bolted repairs. These can be just as permanent and damage tolerant as they are on a metal structure.

HOW COMPOSITE SOLUTIONS ARE APPLIED THROUGHOUT THE 787



In addition to lowering the overall airplane weight, moving to a composite primary structure promises to reduce both the scheduled and nonroutine maintenance burden on the airlines.

Reduced scheduled maintenance. Experience with the Boeing 777 proves that composite structures require less scheduled maintenance than noncomposite structures. For example, the 777 composite tail is 25 percent larger than the 767's aluminum tail, yet requires 35 percent fewer scheduled maintenance labor hours. This labor hour reduction is due to the result of a reduced risk of corrosion and fatigue of composites compared with metal.

Reduced nonroutine maintenance. A composite structure also results in less nonroutine maintenance. The 777 floor structure is all composite and highlights the advantages of this material when applied in a harsh environment. Airline operators are aware of the fatigue cracking and corrosion difficulties experienced with traditional aluminum floor beams. The 777 model has been flying for more than 10 years with more than 565 airplanes in the fleet and to date has not replaced a single composite floor beam.

Boeing has also implemented a rigorous process for evaluating the use of aluminum that combines likelihood of corrosion with consequence of corrosion. This scoring system provides a definitive measure for establishing acceptable application of aluminum in the design with full understanding of the maintenance implications.

Corrosion and fatigue in a structure add significantly to the nonroutine maintenance burden on an operator. Nonroutine maintenance frequently doubles or even triples the total labor hours expended during a maintenance check. With the expanded use of composites and titanium combined with greater discipline in usage of aluminum, Boeing expects the 787 to have much lower nonroutine labor costs than a more conventional metallic airframe.

In addition to using a robust structural design in damage-prone areas, such as passenger and cargo doors, the 787 has been designed from the start with the capability to be repaired in exactly the same manner that airlines would repair an airplane today — with bolted repairs. The ability to perform bolted repairs in composite structure is service-proven on the 777 and offers comparable repair times and skills as employed on metallic airplanes. (By design, bolted repairs in composite structure can be permanent and damage tolerant, just as they can be on a metal structure.)

In addition, airlines have the option to perform bonded composite repairs, which offer improved aerodynamic and aesthetic finish. These repairs are permanent, damage tolerant, and do not require an autoclave. While a typical bonded repair may require 24 or more hours of airplane downtime, Boeing has taken advantage of the properties of composites to develop a new line of maintenance repair capability that requires less

The right material for the right application. Without preconceived ideas, Boeing engineers were able to specify the optimum material for specific applications throughout the airframe.

NO BLEED / MORE ELECTRIC ARCHITECTURE

UNAFFECTED SYSTEMS:	PNEUMATIC COMPONENTS REMOVED FROM THE ENGINE AND APU:
Engine anti-ice system	Precooler Pneumatic starter Valves Ducts APU load compressor

The transition from bleed-air power to an electric architecture reduces the mechanical complexity of the 787.

than an hour to apply. This rapid composite repair technique offers temporary repair capability to get an airplane flying again quickly, despite minor damage that might ground an aluminum airplane.

In total, the reduced risk of corrosion and fatigue associated with composites combined with the composite repair techniques described will lower overall maintenance costs and maximize airline revenue by keeping airplanes flying as much as possible.

One innovative application is the move from hydraulically actuated brakes to electric. Electric brakes significantly reduce the mechanical complexity of the braking system and eliminate the potential for delays associated with leaking brake hydraulic fluid, leaking valves, and other hydraulic failures.

NO-BLEED, MORE ELECTRIC SYSTEMS ARCHITECTURE

The Boeing 787 reflects a completely new approach to onboard systems. Virtually everything that has traditionally been powered by bleed-air from the engines has been transitioned to an electric architecture. The affected systems include:

- Engine start
- Auxiliary power unit (APU) start
- Wing ice protection
- Cabin pressurization
- Hydraulic pumps

The only remaining bleed system on the 787 is the anti-ice system for the engine inlets.

While much can be said regarding the efficiency gains achieved by changing the means of extracting power for airplane systems from the engines, the 787's no-bleed architecture brings with it some significant maintenance cost and reliability advantages as well. By eliminating the pneumatic systems from the airplane, the 787 will realize a notable reduction in the mechanical complexity of airplane systems. The list below highlights just a few of the components eliminated as a result of this systems change:

- Pneumatic engine and APU start motors
- APU load compressor
- Precoolers
- Various ducts, valves, and air control systems
- Leak and overheat detection systems

Auxiliary power unit. The APU provides an excellent illustration of the benefits of the more-electric architecture. One of the primary functions of a conventional APU is driving a large pneumatic load compressor. Replacing the pneumatic load compressor with starter generators results in significantly improved start reliability and power availability. The use of starter generators reduces maintenance requirements and increases reliability due to the simpler design and lower parts count. In terms of inflight start reliability, the 787 APU is expected to be approximately four times more reliable than conventional APUs with a pneumatic load compressor.

Electrical power generation. Another fundamental architectural change on the 787 is the use of variable frequency electrical power and the integration of the engine generator and starter functions into a single unit. This change enables elimination of the constant speed drive (also known as the integrated drive generator, IDG), greatly reducing the complexity of the generator. In addition, by using the engine generator as the starter motor (an approach used with great success on the Next-Generation 737 APU), the 787 has been able to eliminate the pneumatic starter from the engine.

PNEUMATIC COMPONENTS REMOVED FROM THE AIRFRAME:

Ducts
Valves
Heat shields
Overheat monitoring systems
Duct burst protection systems

AFFECTED SYSTEMS:

APU start
Brakes
Cabin pressurization
Engine start
Hydraulic pumps
Wing ice protection

When compared to the more complex 767 IDG, the 787 starter generator is predicted to have a mean time between faults (MTBF) of 30,000 flight hours — a 300 percent reliability improvement compared to its in-service counterpart.

Brakes. One innovative application of the more-electric systems architecture on the 787 is the move from hydraulically actuated brakes to electric. Electric brakes significantly reduce the mechanical complexity of the braking system and eliminate the potential for delays associated with leaking brake hydraulic fluid, leaking valves, and other hydraulic failures. Because its electric brake systems are modular (four independent brake actuators per wheel), the 787 will be able to dispatch with one electric brake actuator (EBA) inoperative per wheel and will have significantly reduced performance penalties compared with dispatch of a hydraulic brake system with a failure present. The EBA is line-replaceable enabling in-situ maintenance of the brakes.

In general, electric systems are much easier to monitor for health and system status than hydraulic or pneumatic systems; the brakes take full advantage of this. Continuous onboard monitoring of the brakes provides airlines with a number of advantages, such as:

- Fault detection and isolation
- Electrical monitoring of brake wear
- Ability to eliminate scheduled visual brake wear inspections
- Extended parking times

Because the 787 brakes can monitor the braking force applied even while parked, the electric brakes enable extended parking brake times by monitoring and automatically adjusting its parking brakes as the brakes cool.

At an airplane level, the reduction in systems parts by moving to a primarily electric architecture is significant. Overall, the 787 will reduce mechanical systems complexity by more than 50 percent compared to a 767; elimination of pneumatic systems is a major contributor. As a consequence of this reduction in complexity, airlines will experience reduced airplane-level maintenance costs and improved airplane-level dispatch reliability.

In fact, the move to electric systems is expected to cut about a third of the schedule interrupts compared to a 767 for the systems affected by the no-bleed/more-electric architecture. Other benefits include improved health monitoring, greater fault tolerance, and better potential for future technology improvements.

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RELIABLE AND MAINTAINABLE BY DESIGN

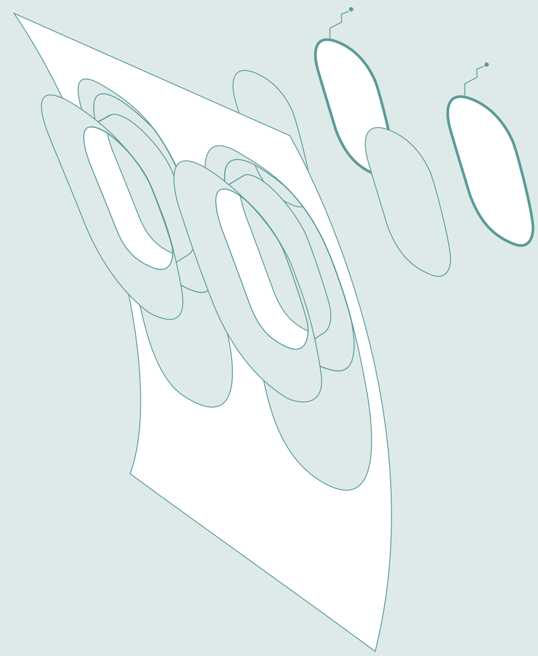
In addition to major changes such as use of composites and the elimination of pneumatic systems, the 787 takes advantage of new technologies to increase reliability and improve maintainability. Boeing has looked for opportunities large and small to reduce maintenance costs while making the 787 highly available for revenue service.

Here are some wide-ranging examples that illustrate the extent of these improvements.

Advanced maintainability analysis. A new generation of digital analysis tools is enabling Boeing to better understand future maintenance issues during the design process. Through

ELECTRO-CHROMATIC DIMMABLE WINDOWS:

Eliminated mechanical window shades
High reliability – 70,000 cycles / 20 years
Operational temperature range -40C – +60C
Installed between the dust cover and outside window
Easily replaced by removing window reveal



animated simulations, designers ensure mechanics can perform various procedures effectively and efficiently, resulting in a more maintainable airplane and higher quality maintenance procedures. Boeing has already identified about 4,000 areas of maintenance on the airplane and will both digitally and physically validate 100 percent of 787 maintenance procedures prior to entry into service (EIS).

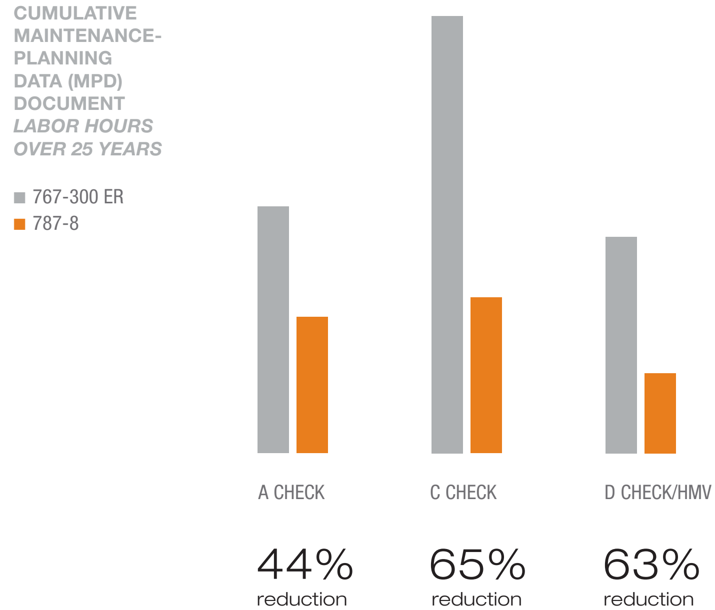
Advanced maintenance computing systems. The 787 features greatly expanded and improved systems monitoring capability coupled with an advanced onboard maintenance computing system. This capability combined with e-enabling technologies, which make real-time ground-based monitoring possible, will significantly aid in rapid, accurate troubleshooting of the 787. Airplane systems information used in conjunction with fully integrated support products will help maintenance and engineering organizations quickly isolate failed components and reduce return-to-service times. Boeing expects the 787 to show a reduction in no-fault-found (NFF) removals of 58 percent compared to the 767, reducing yet another major cost driver for 787 operators.

Selective paint stripping. Boeing is pioneering a new paint stripping technique that makes it possible to chemically strip the paint on the airplane's composite airframe. A three-hour chemical strip removes decorative paint. This eliminates the hand-sanding requirement for paint removal on composite structure and puts the 787 on par with a metal airplane in terms of repaint times.

Electro-chromatic dimmable windows. The 787 replaces mechanical window shades with highly reliable electro-chromatic dimmable windows with a projected life of more than 20 years. In addition to eliminating the maintenance associated with light-leaking or inoperable window shades, electro-chromatic dimmable windows give cabin crews the ability to dim or brighten an entire cabin at the press of a single button.

Propulsion structure and airplane interface. The 787 marks the first time Boeing has made the engine type interchangeable at the wings. That allows a 787 owner to quickly and easily convert an airplane to a different engine brand in order to place it into a fleet. The 787 engine cowlings have a quick composite repair capability, enabling small damages to be repaired in one hour at the gate, maximizing the airplane's availability.

High-intensity discharge (HID) and light emitting diode (LED) lighting. The 787 has replaced virtually all cabin, flight deck and exterior lighting with HID and LED lighting technologies. Because these light types have no filament, the operational life of the lights is dramatically longer than that of an incandescent bulb. For example, HID landing lights will last an order of



Improved and expanded monitoring, advanced onboard maintenance systems, and e-enabling technologies make real-time ground-based monitoring possible. This will aid in troubleshooting the 787. Airplane systems information and fully integrated support products will help maintenance and engineering organizations quickly isolate failed components and reduce return-to-service times. Boeing expects the 787 to show a reduction in NFF removals of 58 percent compared to the 767, reducing yet another major cost driver for 787 operators.

magnitude longer than the lights in service today. LED cabin lights will last 50,000 operational hours and LED aircraft position lights 20,000 operational hours. Overall, 787 lights will last ten to twenty times longer than their in-service counterparts.

Improved dispatch reliability. In the 787, Boeing is demonstrating that generational improvements in systems technology result in airplane-wide reliability improvements. At an airplane level, component reliability is improved by more than 15 percent when compared to the 767. That translates into improved schedule reliability. The 787 program is targeting a mature schedule reliability of more than 99 percent.

MAINTENANCE PROGRAM DEVELOPMENT

By working closely with airlines, major partners and suppliers, and regulatory agencies, Boeing plans to deliver a scheduled maintenance program approved by the U.S. Federal Aviation Administration and European Aviation Safety Agency before taking the 787 into flight testing. The 787 program has set target intervals for EIS that exceed those of any other commercial airplane. These target intervals include a first external visual inspection of the structure at 6 years and the first internal visual inspection of the structure (heavy check) at 12 years. The 787 maintenance program is on track to deliver the target intervals at EIS.

In addition to longer intervals between scheduled maintenance checks, the 787 program projects labor hours content will be reduced by 20 percent on a per-check basis and total scheduled labor hours will be reduced by 60 percent over the life of the airplane.

This reduction in required scheduled maintenance is another significant contributor to the overall 30 percent airframe and systems maintenance cost reduction guaranteed by the 787.

SUMMARY

By designing the 787 with features and performance that reduce cost and increase airplane availability, Boeing is developing an airplane that promises to offer Boeing customers significant savings and greater revenue. For more information, contact Justin Hale at justin.e.hale@boeing.com.