

# Boeing 787 Dreamliner

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The **Boeing 787 Dreamliner** is an American long-haul, mid-size widebody, twin-engine jet airliner made by Boeing Commercial Airplanes. Its variants seat 242 to 335 passengers in typical three-class seating configurations. It is the first airliner with the use of composite materials as the primary material in the construction of its airframe. The 787 was designed to be 20% more fuel efficient than the Boeing 767, which it was intended to replace. The 787 Dreamliner's distinguishing features include mostly electrical flight systems, raked wingtips, and noise-reducing chevrons on its engine nacelles. It shares a common type rating with the larger Boeing 777 to allow qualified pilots to operate both models.

The aircraft's initial designation was the **7E7**, prior to its renaming in January 2005. The first 787 was unveiled in a roll-out ceremony on July 8, 2007 at Boeing's Everett factory. Development and production of the 787 has involved a large-scale collaboration with numerous suppliers worldwide. Final assembly takes place at the Boeing Everett Factory in Everett, Washington, and at the Boeing South Carolina factory in North Charleston, South Carolina. Originally planned to enter service in May 2008, the project experienced multiple delays. The airliner's maiden flight took place on December 15, 2009, and completed flight testing in mid-2011. Boeing has reportedly spent \$32 billion on the 787 program.

Final US Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) type certification was received in August 2011 and the first 787-8 was delivered in September 2011. It entered commercial service on October 26, 2011 with launch customer All Nippon Airways. The stretched 787-9 variant, which is 20 feet (6.1 m) longer and can fly 450 nautical miles (830 km) farther than the -8, first flew in September 2013. Deliveries of the 787-9 began in July 2014; it entered commercial service on August 7, 2014 with All Nippon Airways, with 787-9 launch customer Air New Zealand following two days later. As of August 2017, the 787 had orders for 1,278 aircraft from 67 customers, with All Nippon Airways having the largest number on order.<sup>[1]</sup>

The aircraft has suffered from several in-service problems, including fires on board related to its lithium-ion batteries. These systems were reviewed by both the FAA and the Japan Civil Aviation Bureau. The FAA issued a directive in January 2013 that grounded all 787s in the US and other civil aviation authorities followed suit. After Boeing completed tests on a revised battery design, the FAA approved the revised design and lifted the grounding in April 2013; the 787 returned to passenger service later that month.

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Boeing 787 Dreamliner



All Nippon Airways Boeing 787-8 landing at Okayama Airport

<b>Role</b>	Wide-body twin-engine jet airliner
<b>National origin</b>	United States
<b>Manufacturer</b>	Boeing Commercial Airplanes
<b>First flight</b>	December 15, 2009
<b>Introduction</b>	October 26, 2011, with All Nippon Airways
<b>Status</b>	In service
<b>Primary users</b>	All Nippon Airways Japan Airlines United Airlines Qatar Airways
<b>Produced</b>	2007–present
<b>Number built</b>	589 as of August 2017 <sup>[1]</sup>
<b>Program cost</b>	US\$32 billion (Boeing's expenditure as of 2011) <sup>[2]</sup>
<b>Unit cost</b>	787-8: US\$224.6 million (2015) <sup>[3]</sup> 787-9: US\$264.6 million (2015) <sup>[3]</sup> 787-10: US\$306.1 million (2015) <sup>[3]</sup>

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## Development

### Background

During the late 1990s, Boeing considered replacement aircraft programs as sales of the 767 and 747-400 slowed. Two new aircraft were proposed, the 747X, which would have lengthened the 747-400 and improved efficiency, and the Sonic Cruiser, which would have achieved 15% higher speeds (approximately Mach 0.98) while burning fuel at the same rate as the 767.<sup>[4]</sup> Market interest for the 747X was tepid, however several major American airlines, including Continental Airlines, showed initial enthusiasm for the Sonic Cruiser, although concerns about the operating cost were also expressed.<sup>[5]</sup> The global airline market was disrupted by the September 11, 2001 attacks and increased petroleum prices, making airlines more interested in efficiency than speed. The worst-affected airlines, those in the United States, had been considered the most likely customers of the Sonic Cruiser; thus the Sonic Cruiser was officially cancelled on December 20, 2002. On January 29, 2003 Boeing announced an alternative product, the 7E7, using Sonic Cruiser technology in a more conventional configuration.<sup>[6][7]</sup> The emphasis on a smaller midsize twinjet rather than a large 747-size aircraft represented a shift from hub-and-spoke theory towards the point-to-point theory,<sup>[8]</sup> in response to analysis of focus groups.<sup>[9]</sup>

For Boeing Commercial Airplanes VP Marketing Randy Baseler, airport congestion comes from a large numbers of regional jets and small single-aisles, flying to destinations where a 550-seat A380 would be too large; to reduce the number of departures, smaller airplanes can increase 20% in size and airline hubs can be avoided with point-to-point transit.<sup>[10]</sup>

The replacement for the Sonic Cruiser project was named "7E7"<sup>[11]</sup> (with a development code name of "Y2"). Technology from the Sonic Cruiser and 7E7 was to be used as part of Boeing's project to replace its entire airliner product line, an endeavor called the Yellowstone Project (of which the 7E7 became the first stage).<sup>[12]</sup> Early concept images of the 7E7 included rakish cockpit windows, a dropped nose and a distinctive "shark-fin" tail.<sup>[13]</sup> The "E" was said to stand for various things, such as "efficiency" or "environmentally friendly"; however, in the end, Boeing said that it merely stood for "Eight".<sup>[6]</sup> In July 2003, a public naming competition was held for the 7E7, for which out of 500,000 votes cast online the winning title was *Dreamliner*.<sup>[14]</sup> Other names included *eLiner*, *Global Cruiser*, and *Stratoclimber*.<sup>[15][16]</sup>

DREAMLINER

*Dreamliner* was announced in July 2003. This logo is painted on many 787s.



All Nippon Airways launched the 787 program with an order for 50 aircraft in 2004.

On April 26, 2004, Japanese airline All Nippon Airways (ANA) became the launch customer for the 787, announcing a firm order for 50 aircraft with deliveries to begin in late 2008.<sup>[17]</sup> The ANA order was initially specified as 30 787-3, 290–330 seat, one-class domestic aircraft, and 20 787-8, long-haul, 210–250 seat, two-class aircraft for regional international routes such as Tokyo Narita–Beijing, and could perform routes to cities not previously served, such as Denver, Moscow, and New Delhi.<sup>[18]</sup> The 787-3 and 787-8 were to be the initial variants, with the 787-9 entering service in 2010.<sup>[19]</sup>

The 787 was designed to be the first production airliner with the fuselage comprising one-piece composite barrel sections instead of the multiple aluminum sheets and some 50,000 fasteners used on existing aircraft.<sup>[20][21]</sup> Boeing selected two new engines to power the 787, the Rolls-Royce Trent 1000 and General Electric GENx.<sup>[6]</sup> Boeing stated the 787 would be approximately 20 percent more fuel-efficient than the 767,<sup>[22]</sup> with approximately 40 percent of the efficiency gain

from the engines,<sup>[23]</sup> plus gains from aerodynamic improvements,<sup>[24]</sup> increased use of lighter-weight composite materials, and advanced systems.<sup>[19]</sup> The airframe underwent extensive structural testing during its design.<sup>[25][26]</sup> The 787-8 and –9 were intended to have a certified 330 minute ETOPS capability.<sup>[27]</sup>

During the design phase, the 787 underwent extensive wind tunnel testing at Boeing's Transonic Wind Tunnel, QinetiQ's five-meter wind tunnel at Farnborough, United Kingdom, and NASA Ames Research Center's wind tunnel, as well as at the French aerodynamics research agency, ONERA. The final styling was more conservative than earlier proposals, with the fin, nose, and cockpit windows changed to a more conventional form. By 2005, customer-announced orders and commitments for the 787 reached 237 aircraft.<sup>[28]</sup> Boeing initially priced the 787-8 variant at US\$120 million, a low figure that surprised the industry. In 2007, the list price was US\$146–151.5 million for the 787-3, US\$157–167 million for the 787-8 and US\$189–200 million for the 787-9.<sup>[29]</sup>

### Manufacturing and suppliers

On December 16, 2003, Boeing announced that the 787 would be assembled in its factory in Everett, Washington.<sup>[6]</sup> Instead of conventionally building the aircraft from the ground up, final assembly employed 800 to 1,200 people to join completed subassemblies and to integrate systems.<sup>[30]</sup> Boeing assigned global subcontractors to do more assembly work, delivering completed subassemblies to Boeing for final assembly. This approach was intended to result in a leaner, simpler assembly line and lower inventory,<sup>[31]</sup> with pre-installed systems reducing final assembly time by three-quarters to three days.<sup>[32][33]</sup> Subcontractors had early difficulties procuring needed parts and finishing subassemblies on schedule, leaving remaining assembly work for Boeing to complete as "traveled work".<sup>[34][35]</sup> In 2010, Boeing considered in-house construction of the 787-9 tail; the tail of the 787-8 is made by Alenia.<sup>[36]</sup> The 787 was unprofitable for some subcontractors; Alenia's parent company, Finmeccanica had a total loss of €750 million on the project by 2013.<sup>[37]</sup>

Subcontracted assemblies included wing manufacture (Mitsubishi Heavy Industries, Japan, central wing box)<sup>[38]</sup> horizontal stabilizers (Alenia Aeronautica, Italy; Korea Aerospace Industries, South Korea);<sup>[39]</sup> fuselage sections (Global Aeronautica, Italy; Boeing, North Charleston, US; Kawasaki Heavy Industries, Japan; Spirit AeroSystems, Wichita, US; Korean Air, South Korea);<sup>[40][41][42]</sup> passenger doors (Latécoère, France); cargo doors, access doors, and crew escape door (Saab AB, Sweden); software development (HCL Enterprise India);<sup>[43]</sup> floor beams (TAL Manufacturing Solutions Limited, India);<sup>[44][45]</sup> wiring (Labinal, France);<sup>[46]</sup> wing-tips, flap support fairings, wheel well bulkhead, and longerons (Korean Air, South Korea);<sup>[47]</sup> landing gear (Messier-Bugatti-Dowty, UK/France);<sup>[48][49]</sup> and power distribution and management systems, air conditioning packs (Hamilton Sundstrand, Connecticut, US).<sup>[46][50]</sup>



Assembly of "Section 41", the nose section of the Boeing 787

To speed up deliveries, Boeing modified four used 747-400s into 747 Dreamlifters to transport 787 wings, fuselage sections, and other smaller parts. Japanese industrial participation was key on the project. Japanese companies co-designed and built 35% of the aircraft; the first time that outside firms played a key design role on Boeing airliner wings. The Japanese government supported development with an estimated US\$2 billion in loans.<sup>[51]</sup> On April 26, 2006, Japanese manufacturer Toray Industries and Boeing signed a production agreement involving US\$6 billion worth of carbon fiber, extending a 2004 contract.<sup>[6]</sup> In May 2007, final assembly on the first 787 began at Everett.<sup>[52]</sup>

Boeing worked to trim excess weight since assembly of the first airframe began; in late 2006, the first six 787s were stated to be overweight, with the first aircraft being 5,000 lb (2,300 kg) heavier than specified.<sup>[53]</sup> The seventh and subsequent aircraft would be the first optimized 787-8s expected to meet all goals.<sup>[54][55]</sup> Accordingly, some parts were redesigned to include more use of titanium.<sup>[56][57]</sup> Early built 787s were overweight and some carriers decided to take later aircraft; in early 2015, Boeing was trying to sell 10 such aircraft.<sup>[58]</sup> In July 2015, Reuters reported that Boeing was considering reducing the use of titanium to reduce construction costs.<sup>[59]</sup>



The first public appearance of the 787 on July 8, 2007

Boeing intended for a first flight by the end of August 2007 and premiered the first 787 (registered N787BA) at a rollout ceremony on July 8, 2007.<sup>[60]</sup> The 787 had 677 orders at this time, which is more orders from launch to roll-out than any previous wide-body airliner.<sup>[61]</sup> The major systems were not installed at the time; many parts were attached with temporary non-aerospace fasteners requiring replacement with flight fasteners later.<sup>[62]</sup>

In September 2007, Boeing announced a three-month delay, blaming a shortage of fasteners as well as incomplete software.<sup>[63]</sup> On October 10, 2007, a second three-month delay to the first flight and a six-month delay to first deliveries was announced due to supply chain problems, a lack of documentation from overseas suppliers, and flight guidance software delays.<sup>[64][65]</sup> Less than a week later, Mike Bair, the 787 program manager was replaced.<sup>[66]</sup> On January 16, 2008, Boeing

announced a third three-month delay to the first flight of the 787, citing insufficient progress on "traveled work".<sup>[67]</sup> On March 28, 2008, in an effort to gain more control over the supply chain, Boeing announced plans to buy Vought Aircraft Industries' interest in Global Aeronautica; a later agreement was also made to buy Vought's factory in North Charleston.<sup>[68]</sup>

On April 9, 2008, a fourth delay was announced, shifting the maiden flight to the fourth quarter of 2008, and delaying initial deliveries by around 15 months to the third quarter of 2009. The 787-9 variant was postponed to 2012 and the 787-3 variant was to follow at a later date.<sup>[69]</sup> On November 4, 2008, a fifth delay was announced due to incorrect fastener installation and the Boeing machinists strike, stating that the first test flight would not occur in the fourth quarter of 2008.<sup>[70][71]</sup> After assessing the program schedule with suppliers,<sup>[72]</sup> in December 2008, Boeing stated that the first flight was delayed until the second quarter of 2009.<sup>[73]</sup> Airlines, such as United Airlines and Air India, stated their intentions to seek compensation from Boeing for the delays.<sup>[74][75]</sup>

## Pre-flight ground testing

As Boeing worked with its suppliers towards production, the design proceeded through a series of test goals. On August 23, 2007, a crash test involving a vertical drop of a partial composite fuselage section from about 15 ft (4.6 m) onto a 1 in (25 mm)-thick steel plate occurred in Mesa, Arizona;<sup>[76][77]</sup> the results matched predictions, allowing modeling of various crash scenarios using computational analysis instead of further physical tests.<sup>[78][79]</sup> While critics had expressed concerns that a composite fuselage could shatter and burn with toxic fumes during crash landings, test data indicated no greater toxicity than conventional metal airframes.<sup>[80][81]</sup> The crash test was the third in a series of demonstrations conducted to match FAA requirements, including additional certification criteria due to the wide-scale use of composite materials.<sup>[77]</sup> The 787 meets the FAA's requirement that passengers have at least as good a chance of surviving a crash landing as they would with current metal airliners.<sup>[82]</sup>



On August 7, 2007, on-time certification of the Rolls-Royce Trent 1000 engine by European and US regulators was received.<sup>[83]</sup> The alternative GE GENx-1B engine achieved certification on March 31, 2008.<sup>[84]</sup> On June 20, 2008, the first aircraft was powered up, for testing the electrical supply and distribution systems.<sup>[85]</sup> A non-flightworthy static test airframe was built; on September 27, 2008, the fuselage was successfully tested at 14.9 psi (102.7 kPa) differential, which is 150 percent of the maximum pressure expected in commercial service.<sup>[86]</sup> In December 2008, the 787's maintenance program was passed by the FAA.<sup>[87]</sup>



The prototype Boeing 787 underwent taxi tests at Paine Field in November and December 2009.

On May 3, 2009, the first test 787 was moved to the flight line following extensive factory-testing, including landing gear swings, systems integration verification, and a total run-through of the first flight.<sup>[88]</sup> On May 4, 2009, a press report indicated a 10–15% range reduction, about 6,900 nmi (12,800 km) instead of the originally promised 7,700 to 8,200 nmi (14,800–15,700 km), for early aircraft that were about 8% overweight. Substantial redesign work was expected to correct this, which would complicate increases in production rates;<sup>[89]</sup> Boeing stated the early 787-8s would have a range of almost 8,000 nmi (15,000 km).<sup>[90]</sup> As a result, some airlines reportedly delayed deliveries of 787s in order to take later planes that may be closer to the original estimates.<sup>[91]</sup> Boeing expected to have the weight issues addressed by the 21st production model.<sup>[92]</sup>

On June 15, 2009, during the Paris Air Show, Boeing said that the 787 would make its first flight within two weeks. However, on June 23, 2009, the first flight was postponed due to structural reasons.<sup>[93][94]</sup> Boeing provided an updated 787 schedule on August 27, 2009, with the first flight planned to occur by the end of 2009 and deliveries to begin at the end of 2010.<sup>[95]</sup> The company expected to write off US\$2.5 billion because it considered the first three Dreamliners built unsellable and suitable only for flight tests.<sup>[96]</sup> On October 28, 2009, Boeing selected Charleston, SC as the site for a second 787 production line, after soliciting bids from multiple states.<sup>[97]</sup> On December 12, 2009, the first 787 completed high speed taxi tests, the last major step before flight.<sup>[98][99]</sup>

## Flight test program



The first 787 taking off on its maiden flight in December 2009.

On December 15, 2009, Boeing conducted the 787-8 maiden flight from Paine Field in Everett, Washington, at 10:27 am PST and landed three hours later at 1:33 p.m. at Seattle's Boeing Field, after reaching 180 kn (333 km/h) and 13,200 ft (4,000 m).<sup>[100]</sup> Originally scheduled for 5 ½ hours, the test flight was shortened to three hours with the pilots wanting to complete the flight under visual meteorological conditions while visibility and cloud ceiling were low.<sup>[101]</sup> The 6,800h, six-aircraft ground and flight test programme was scheduled in eight and a half months, the fastest certification campaign for a new Boeing commercial design.<sup>[102]</sup>

The flight test program comprised six aircraft, ZA001 through ZA006, four with Rolls-Royce Trent 1000 engines and two with GE GENx-1B64 engines. The second 787, ZA002 in All Nippon Airways livery, flew to Boeing Field on December 22, 2009, to join the flight test

program;<sup>[103][104]</sup> the third 787, ZA004 made its first flight on February 24, 2010, followed by ZA003 on March 14, 2010.<sup>[105]</sup> On March 24, 2010, flutter and ground effects testing was completed, clearing the aircraft to fly its entire flight envelope.<sup>[106]</sup> On March 28, 2010, the 787 completed the ultimate wing load test, which requires that the wings of a fully assembled aircraft be loaded to 150% of design limit load and held for 3 seconds. The wings were flexed approximately 25 ft (7.6 m) upward during the test.<sup>[107]</sup> Unlike past aircraft, the wings were not tested to failure.<sup>[108][109]</sup> On April 7, data showed the test had been a success.<sup>[110]</sup>

On April 23, 2010, the newest 787, ZA003, arrived at the McKinley Climatic Laboratory hangar at Eglin Air Force Base, Florida, for extreme weather testing in temperatures ranging from 115 to −45 °F (46 to −43 °C), including takeoff preparations at both temperature extremes.<sup>[111]</sup> ZA005, the fifth 787 and the first with GENx engines, began ground engine tests in May 2010,<sup>[112]</sup> and made its first flight on June 16, 2010.<sup>[113]</sup> In June 2010, gaps were discovered in the horizontal stabilizers of test aircraft due to improperly installed shims; all aircraft were inspected and repaired.<sup>[114]</sup> That same month, a 787 experienced its first in-flight lightning strike; inspections found no damage.<sup>[115]</sup> As composites can have as little as 1/1,000th the electrical conductivity of aluminum, conductive material is added to ameliorate potential risks and to meet FAA requirements.<sup>[80][116][117]</sup> The FAA also planned requirement changes to help the 787 show compliance.<sup>[118]</sup>

The 787 made its first appearance at an international air show at the Farnborough Airshow, United Kingdom, on July 18, 2010.<sup>[119]</sup>

On August 2, 2010, a Trent 1000 engine suffered a blowout at Rolls-Royce's test facility during ground testing.<sup>[120]</sup> The failure due to the timeline for installing Trent 1000 engines being reevaluated; on August 27, 2010, Boeing stated that the first delivery to launch customer ANA would be delayed until early 2011.<sup>[121][122]</sup> That same month, Boeing faced compensation claims from airlines owing to ongoing delivery delays.<sup>[123]</sup> In September 2010, it was reported that a further two 787s might join the test fleet for a total of eight flight test aircraft.<sup>[124]</sup> On September 10, 2010, a partial engine surge occurred in a Trent engine on ZA001 at Roswell.<sup>[125]</sup> On October 4, 2010, the sixth 787, ZA006 joined the test program with its first flight.<sup>[126]</sup>



The first 787 to visit Europe, ZA003 at the 2010 Farnborough Airshow

On November 9, 2010, Boeing 787, ZA002 made an emergency landing at Laredo International Airport, Texas, after smoke and flames were detected in the main cabin during a test flight.<sup>[127][128]</sup> The electrical fire caused some systems to fail before landing.<sup>[129]</sup> Following this incident, Boeing suspended flight testing on November 10, 2010, ground testing continued.<sup>[130][131]</sup> After investigation, the in-flight fire was primarily attributed to foreign object debris (FOD) that was present in the electrical bay.<sup>[132]</sup> After electrical system and software changes, the 787 resumed flight testing on December 23, 2010.<sup>[133][134]</sup>

On November 5, 2010, it was reported that some 787 deliveries would be delayed to address problems found during flight testing.<sup>[135][136]</sup> In January 2011, the first 787 delivery was rescheduled to the third quarter of 2011 due to software and electrical updates following the in-flight fire.<sup>[137][138]</sup> By February 24, 2011, the 787 had completed 80% of the test conditions for Rolls-Royce Trent 1000 engine and 60% of the conditions for the General Electric GEnx-1B engine.<sup>[139]</sup> In July 2011, ANA performed a week of operations testing using a 787 in Japan.<sup>[140]</sup> The test aircraft had flown 4,828 hours in 1,707 flights combined by August 15, 2011.<sup>[105]</sup> During testing, the 787 visited 14 countries in Asia, Europe, North America, and South America to test in extreme climates and conditions and for route testing.<sup>[141]</sup>

On August 13, 2011, certification testing of the Rolls-Royce powered 787-8 finished.<sup>[142]</sup> The FAA and European Aviation Safety Agency certified the 787 on August 26, 2011, at a ceremony in Everett, Washington.<sup>[143][144]</sup> Certification had taken 18 months, twice as long as originally planned.

The newer stretched version, 787-9, had flown 141 hours as of November 8, 2013.<sup>[145]</sup>

## Service entry and early operations

Certification cleared the way for deliveries and in 2011, Boeing prepared to increase 787 production rates from two to ten aircraft per month at assembly lines in Everett and Charleston over two years.<sup>[144]</sup> Legal difficulties clouded production at Charleston; on April 20, 2011, the National Labor Relations Board alleged that a second production line in South Carolina violated two sections of the National Labor Relations Act.<sup>[97]</sup> In December 2011, the National Labor Relations Board dropped its lawsuit after the Machinists union withdrew its complaint as part of a new contract with Boeing.<sup>[146]</sup> The first 787 assembled at South Carolina was rolled out on April 27, 2012.<sup>[147]</sup>



The 787-8 received FAA and EASA certification on August 21, 2011

The first 787 was officially delivered to All Nippon Airways (ANA) on September 25, 2011, at the Boeing factory. A ceremony to mark the occasion was also held the next day.<sup>[148][149]</sup> On September 27, it flew to Tokyo Haneda Airport.<sup>[150][151]</sup> The airline took delivery of the second 787 on October 13, 2011.<sup>[152]</sup>

On October 26, 2011, an ANA 787 flew the first commercial flight from Tokyo Narita Airport to Hong Kong International Airport.<sup>[153]</sup> The airliner was planned to enter service some three years prior. Tickets for the flight were sold in an online auction, the highest bidder had paid \$34,000 for a seat.<sup>[154]</sup> An ANA 787 flew its first long-haul flight to Europe on January 21, 2012 from Haneda to Frankfurt Airport.<sup>[155]</sup>

On December 6, 2011, test aircraft ZA006 (sixth 787), powered by General Electric GEnx engines, flew 10,710 nmi (19,830 km) non-stop from Boeing Field eastward to Shahjalal International Airport in Dhaka, Bangladesh, setting a new world distance record for aircraft in the 787's weight class, which is between 440,000 and 550,000 lb (200,000 and 250,000 kg). This flight surpassed the previous record of 9,127 nautical miles (16,903 km), set in 2002 by an Airbus A330. The Dreamliner then continued eastbound from Dhaka to return to Boeing Field, setting a world-circling speed record of 42 hours, 27 minutes.<sup>[156]</sup> In December 2011, Boeing started a six-month promotion 787 world tour, visiting various cities in China, Africa, the Middle East, Europe, United States, and others.<sup>[157]</sup> In April 2012, an ANA 787 made a delivery flight from Boeing Field to Haneda Airport partially using biofuel from cooking oil.<sup>[158]</sup>

ANA surveyed 800 passengers who flew the 787 from Tokyo to Frankfurt: expectations were surpassed for 90% of passengers; features that met or exceeded expectations included air quality and cabin pressure (90% of passengers), cabin ambiance (92% of passengers), higher cabin humidity levels (80% of passengers), headroom (40% of passengers) and the larger windows (90% of passengers). 25% said they would go out of their way to again fly on the 787.<sup>[159]</sup>

After its first six months of service, Rolls-powered ANA aircraft were burning around 21% less fuel than the replaced 767-300ER on international flights, slightly better than the 20% originally expected, and 15-20% on domestic routes, while GE-powered Japan Airlines aircraft were potentially slightly better.<sup>[160]</sup> Other 787 operators have reported similar fuel savings, ranging from 20-22% compared with the 767-300ER.<sup>[161]</sup> An analysis by consulting firm AirInsight concluded that United Airlines' 787s achieved an operating cost per seat that was 6% lower than the Airbus A330.<sup>[162]</sup>



The second and third United Airlines 787-8s at Los Angeles International Airport. United Airlines is the North American launch customer for all three 787 variants

Early operators discovered that if the APS5000 Auxiliary power unit was shut down with the inlet door closed, heat continued to build up in the tail compartment and cause the rotor shaft to bow. It could take up to 2 hours for the shaft to straighten again. This was particularly acute on short haul flights as there was insufficient time to allow the unit to cool before a restart was needed. Procedures were modified and the APU was later redesigned to address the issue.<sup>[163]</sup>

On September 15, 2012, the NTSB requested the grounding of certain 787s due to GE engine failures; GE believed the production problem had been fixed by that time.<sup>[164]</sup> In March 2014, Mitsubishi Heavy Industries informed Boeing of a new problem that was caused by a change in manufacturing processes. Employees did not fill gaps with shims to connect wing rib aluminum shear ties to the carbon composite wing panels; the tightened fasteners, without shims, cause excessive stress that creates hairline cracks in the wings, which could enlarge and cause further damage. Forty-two aircraft awaiting delivery were affected, and each one required 1–2 weeks to inspect and repair. However, Boeing did not expect this problem to affect the overall delivery schedule, even if some airplanes were delivered late.<sup>[165]</sup>

Dispatch reliability is an industry standard measure of the rate of departure from the gate with no more than 15 minutes delay due to technical issues.<sup>[166]</sup> The 787-8 started out with a ~96% operational reliability, increasing to ~98.5% in April 2015. Daily utilization increased from five hours in 2013 to twelve hours in 2014.<sup>[167]</sup> Dispatch reliability grew to 99.3% in 2017.<sup>[168]</sup>

Airlines have often assigned the 787 to routes previously flown by larger aircraft that could not return a profit. For example, Air Canada offered a Toronto to New Delhi route, first utilizing a Lockheed L1011, then a Boeing 747, then an Airbus A340, but none of these types were efficient enough to generate profit. The airline operated the route profitably with a 787-9, and credits the right number of seats and greater fuel efficiency for this success.<sup>[169]</sup>

Up to 30 June 2017, after 565 units were delivered since 2011 : 60% -8 (340) and 40% -9 (225), the airports with most 787 departures are Haneda airport with 304 weekly, Narita with 276 and Doha Airport with 265. By the end of 2017, there will be 39 airlines operating the 787 on 983 routes with an average length of 5,282 km (2,852 nmi), and it will have opened 163 new routes (17%), the longest will be Qantas' Perth-London Heathrow over 14,499 km (7,829 nmi) from 24 March 2018, overtaking United Airlines' 14,096 km (7,611 nmi) Los Angeles - Singapore.<sup>[170]</sup>



An Air Canada 787 at Toronto Pearson International Airport

## Market and production costs

The 787 Dreamliner program has reportedly cost Boeing \$32 billion.<sup>[2][171]</sup>

The cost of producing a 787 exceeded the purchase price at the end of 2013. Boeing's accounting method books sales immediately and distributes estimated production costs over ten years for the 1,300 aircraft it expects to deliver during that time. JPMorgan Chase analyst Joseph Nadol estimated the program's cash loss to be \$45 million per airplane, decreasing as the program moves forward. The actual cash flow reflects Boeing collecting most of the purchase price upon delivery; Boeing expects deferred costs to total \$25 billion before the company begins to break even on production; the comparable number for the Boeing 777, adjusted for inflation, is \$3.7 billion. Boeing plans to improve financial return by reorganizing the production line, renegotiating contracts with suppliers and labor unions, and increasing the 787 production rate, stepwise, to 12 airplanes per month by the end of 2016 and 14 airplanes per month by the end of the decade.<sup>[162]</sup>

The 787 program is expected to be profitable after 1,100 aircraft have been sold.<sup>[172]</sup> As of April 2015, the production rate is 10 per month.<sup>[173]</sup> Boeing lost \$30 million per 787 delivered in the first quarter of 2015, although Boeing plans to break even by the end of the year.<sup>[174]</sup> The accumulated losses for the 787 totaled almost \$27 billion by May 2015. The cost of producing the fuselage may increase because of a tentative deal reached with Spirit Aerosystems of Wichita, Kansas, wherein severe price cuts demanded by Boeing would be eased, in return for a comprehensive agreement that lowers the cost of fuselages for other jetliners that Spirit helps Boeing manufacture.<sup>[175]</sup>

On July 21, 2016 Boeing reported charges of \$847 million against two flight-test 787s built in 2009. Boeing had planned to refurbish and sell them, but instead wrote them off as research and development expense.<sup>[176]</sup> Boeing will build 14 787s per month (168 per year) from 2019, helping to offset the \$28 billion in deferred production costs accumulated through 2015, and will add 100 aircraft to the current accounting block of 1,300 at the end of the 2017 third quarter.<sup>[177]</sup>

## Design

### Overview

The Boeing 787 Dreamliner is a long-haul, widebody, twin-engine jetliner, which features light-weight construction. The aircraft is 80 percent composite by volume.<sup>[178]</sup> Boeing lists its materials by weight as 50 percent composite, 20 percent aluminum, 15 percent titanium, 10 percent steel, and 5 percent other.<sup>[179][180]</sup> Aluminum has been used throughout the wing and tail leading edges, titanium is predominantly present within the elements of the engines and fasteners, while various individual components are composed of steel.<sup>[180]</sup>

External features include a smooth nose contour, raked wingtips and engine nacelles with noise-reducing serrated edges (chevrons).<sup>[181]</sup> The longest-range 787 variant can fly 8,000 to 8,500 nautical miles (9,200 to 9,800 mi; 14,800 to 15,700 km), enough to cover the Los Angeles to Bangkok and New York City to Hong Kong routes. Its cruising airspeed is Mach 0.85,<sup>[182]</sup> equivalent to 561 mph (903 km/h; 487 kn) at typical cruise altitudes. The aircraft has a design life of 44,000 flight cycles.<sup>[183]</sup>



A Boeing 787-8 taking off from Boeing Field



## Flight systems

Among 787 flight systems, a key change from traditional airliners is the electrical architecture. The architecture is bleedless and replaces bleed air and hydraulic power sources with electrically powered compressors and pumps, while completely eliminating pneumatics and hydraulics from some subsystems, e.g., engine starters or brakes.<sup>[184]</sup> Boeing says this system extracts 35 percent less power from the engines, allowing increased thrust and improved fuel economy.<sup>[185]</sup> The total available on-board electrical power is 1.45 megawatts, which is five times the power available on conventional pneumatic airliners;<sup>[186]</sup> the most notable electrically powered systems include engine start, cabin pressurization, horizontal stabilizer trim, and wheel brakes.<sup>[187]</sup> Wing ice protection is another new system; it uses electro-thermal heater mats on the wing slats instead of traditional hot bleed air.<sup>[188][189]</sup> An active gust alleviation system, similar to the system used on the B-2 bomber, improves ride quality during turbulence.<sup>[190][191]</sup>



Front view of a British Airways Boeing 787-8 arriving at London's Heathrow Airport (2015)



The Boeing 787 flight deck

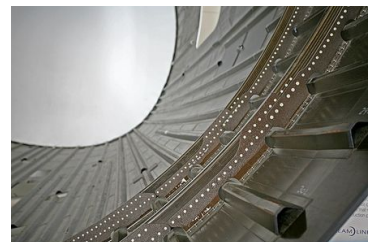
The 787 has a "fly-by-wire" control system similar in architecture to that of the Boeing 777.<sup>[192]</sup> The flight deck features LCD multi-function displays, which use an industry standard Graphical user interface widget toolkit (Cockpit Display System Interfaces to User Systems / ARINC 661).<sup>[193]</sup> The 787 flight deck includes two head-up displays (HUDs) as a standard feature.<sup>[194]</sup> The 787 shares a common type rating with the larger 777, allowing qualified pilots to operate both models.<sup>[195]</sup> Like other Boeing airliners, the 787 uses a yoke instead of a side-stick. Under consideration is future integration of forward looking infrared into the HUD for thermal sensing, allowing pilots to "see" through clouds.<sup>[6]</sup> Lockheed Martin's Orion spacecraft will use a glass cockpit derived from Honeywell International's 787 flight deck systems.<sup>[196]</sup>

Honeywell and Rockwell Collins provide flight control, guidance, and other avionics systems, including standard dual head up guidance systems,<sup>[6]</sup> Thales supplies the integrated standby flight display and power management,<sup>[6]</sup> while Meggitt/Securaplane provides the auxiliary power unit (APU) starting system, electrical power conversion system, and battery control system<sup>[197][198]</sup> with lithium cobalt oxide (LiCoO<sub>2</sub>) batteries by GS Yuasa.<sup>[199][200]</sup> One of the two batteries weighs 28.5 kg and is rated 29.6 V, 76 Ah, giving 2.2 kWh.<sup>[201]</sup> Battery charging is controlled by four independent systems to prevent overcharging following early lab testing.<sup>[202]</sup> The battery systems are the focus of regulatory investigation due to multiple lithium battery fires, which led to grounding of the 787 fleet starting in January 2013.<sup>[203]</sup>

A version of Ethernet (Avionics Full-Duplex Switched Ethernet (AFDX) / ARINC 664) transmits data between the flight deck and aircraft systems.<sup>[204]</sup> The control, navigation, and communication systems are networked with the passenger cabin's in-flight internet systems.<sup>[205]</sup> In January 2008, FAA concerns were reported regarding possible passenger access to the 787's computer networks; Boeing has stated that various protective hardware and software solutions are employed, including air gaps to physically separate the networks, and firewalls for software separation.<sup>[205][206]</sup> These measures prevent data transfer from the passenger internet system to the maintenance or navigation systems.<sup>[205]</sup>

## Composite materials

The 787 is the first major commercial airplane to have a composite fuselage, composite wings, and use composites in most other airframe components.<sup>[207]</sup> Each 787 contains approximately 77,000 pounds (35 metric tons) of carbon fiber reinforced polymer (CFRP), made with 51,000 lb (23 t) of carbon fiber.<sup>[208]</sup> Carbon fiber composites have a higher strength-to-weight ratio than conventional aircraft materials, and help make the 787 a lighter aircraft.<sup>[180]</sup> Composites are used on fuselage, wings, tail, doors, and interior. Boeing had built and tested the first commercial aircraft composite section while studying the proposed Sonic Cruiser in the early 2000s.<sup>[209][210]</sup> The first carbon/epoxy primary structure was put into service on the Boeing 737 Classic horizontal tail in 1984, and the largest use of composite structures is 60 percent in the Boeing–Sikorsky RAH-66 Comanche.<sup>[211]</sup>



Disassembled composite fuselage section of the Boeing 787

Carbon fiber, unlike metal, does not visibly show cracks and fatigue, prompting concerns about the safety risks of widespread use of the material.<sup>[80][212][213]</sup> the rival Airbus A350 XWB uses composite panels on a frame, a more conventional approach, which its contractors regarded as less risky.<sup>[81]</sup> Although fired in 2006, Boeing engineer Vince Weldon complained to management, and later to the public: the composite fuselage was unsafe compared to conventional aluminum designs, and in a crash, was more likely to "shatter too easily and burn with toxic fumes".<sup>[214]</sup>

In addition, a potential issue is the porous nature of composite materials: collected moisture expanding with altitude can cause delamination.<sup>[215]</sup> Boeing responded that composites have been used on wings and other passenger aircraft parts for many years without incident, and special defect detection procedures will be instituted for the 787 to detect any potential hidden damage.<sup>[216]</sup>

In 2006, Boeing launched the 787 GoldCare program.<sup>[217]</sup> This is an optional, comprehensive life-cycle management service, whereby aircraft in the program are routinely monitored and repaired, as needed. Although the first program of its kind from Boeing, post-sale protection programs are not new; such programs are usually offered by third party service centers. Boeing is also designing and testing

composite hardware so inspections are mainly visual. This reduces the need for ultrasonic and other non-visual inspection methods, saving time and money.<sup>[218]</sup>

## Engines



The chevron-toothed exhaust duct covers on the first 787, shown here with thrust-reversers deployed

The 787 is powered by two engines; these engines use all-electrical bleedless systems, eliminating the superheated air conduits normally used for aircraft power, de-icing, and other functions.<sup>[6]</sup> As part of its "Quiet Technology Demonstrator 2" project, Boeing adopted several engine noise-reducing technologies for the 787. These include an air inlet containing sound-absorbing materials and exhaust duct cover with a chevron-toothed pattern on the rim for a quieter mixing of exhaust and outside air.<sup>[181]</sup> Boeing expects these developments to make the 787 significantly quieter both inside and out.<sup>[219]</sup> The noise-reducing measures prevent sounds above 85 decibels from leaving airport boundaries.<sup>[180]</sup>

The two different engine models compatible with the 787 use a standard electrical interface to allow an aircraft to be fitted with either Rolls-Royce Trent 1000 or General Electric GEnx engines. This interchangeability aims to save time and cost when changing engine types;<sup>[6]</sup> while previous aircraft could exchange engines for those of a different manufacturer, the high cost and time

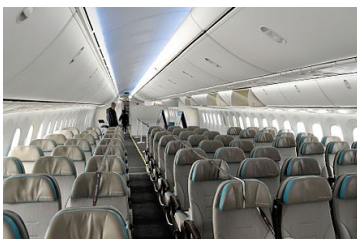
required made it rare.<sup>[220][221]</sup> In 2006, Boeing addressed reports of an extended change period by stating that the 787 engine swap was intended to take 24 hours.<sup>[221]</sup>

In 2016, Rolls Royce began flight testing its new Trent 1000 TEN engine. It has a new compressor system based on the compressor in Rolls-Royce Trent XWB engine and a new turbine design for extra thrust, up to 78,000 lbf (350 kN). Rolls Royce plans to offer the TEN on the 787-8, -9 and -10.<sup>[222]</sup>

## Interior

The 787-8 is designed to typically seat 234 passengers in a three-class setup, 240 in two-class domestic configuration, and 296 passengers in a high-density economy arrangement. Seat rows can be arranged in four to seven abreast in first or business (e.g., 1–2–1, 2–2–2, 2–3–2). Eight or nine abreast are options in economy (e.g., 3–2–3, 2–4–2, 3–3–3). Typical seat room ranges from 46 to 61 in (120 to 150 cm) pitch in first, 36 to 39 in (91 to 99 cm) in business, and 32 to 34 in (81 to 86 cm) in economy.<sup>[223][224]</sup>

Cabin interior width is approximately 18 feet (550 cm) at armrest level.<sup>[223][225]</sup> The Dreamliner's cabin width is 15 inches (38 cm) more than that of the Airbus A330 and A340,<sup>[226]</sup> 5 inches (13 cm) less than the A350,<sup>[227]</sup> and 16 in (41 cm) less than the 777.<sup>[228]</sup> The 787's economy seats can be up to 17.5 in (44.4 cm) wide for nine-abreast seating<sup>[229]</sup> and up to 19 inches (48 cm) wide for eight-abreast seating arrangements. Most airlines are selecting the nine-abreast (3–3–3) configuration.<sup>[230][231]</sup> The 787's nine-abreast seating for economy provides passengers less space, particularly across the hips and shoulders, than any other jet airliner.<sup>[232]</sup> This has led to recommendations that passengers, particularly taller or larger individuals, avoid the 787 for international service.<sup>[232][233][234]</sup>



Boeing 787-8 demonstrator aircraft cabin with economy class seating in conventional 3–3–3 layout

The 787's cabin windows are larger than any other civil air transport in-service or in development,<sup>[235]</sup> with dimensions of 10.7 by 18.4 in (27 by 47 cm),<sup>[235]</sup> and a higher eye level so passengers can maintain a view of the horizon.<sup>[236]</sup> The composite fuselage permits larger windows without the need for structural reinforcement.<sup>[237]</sup> Instead of plastic window shades, the windows use electrochromism-based smart glass (supplied by PPG Industries)<sup>[238]</sup> allowing flight attendants<sup>[239]</sup> and passengers to adjust five levels of sunlight and visibility to their liking,<sup>[240]</sup> reducing cabin glare while maintaining a view to the outside world,<sup>[236][241]</sup> but the most opaque setting still has some transparency.<sup>[239][242]</sup> The lavatory, however, has a traditional sunshade.<sup>[240]</sup>

The 787's cabin features light-emitting diodes (LEDs)<sup>[243]</sup> as standard equipment, allowing the aircraft to be entirely 'bulbless'. LED lights have previously been an option on the Boeing 777 and Airbus aircraft.<sup>[244][245]</sup> The system has three-color LEDs plus a white LED.<sup>[243]</sup> The 787 interior

was designed to better accommodate persons with mobility, sensory, and cognitive disabilities. For example, a 56 by 57 in (140 by 140 cm) convertible lavatory includes a movable center wall that allows two separate lavatories to become one large, wheelchair-accessible facility.<sup>[246]</sup>

The internal cabin pressure of the 787 is increased to the equivalent of 6,000 feet (1,800 m) altitude instead of the 8,000 feet (2,400 m) on older conventional aircraft.<sup>[247]</sup> According to Boeing, in a joint study with Oklahoma State University, this will significantly improve passenger comfort.<sup>[190][248]</sup> Cabin air pressurization is provided by electrically driven compressors, rather than traditional engine-bleed air, thereby eliminating the need to cool heated air before it enters the cabin.<sup>[249][250]</sup> The cabin's humidity is programmable based on the number of passengers carried, and allows 15 percent humidity settings instead of the 4 percent found in previous aircraft.<sup>[247]</sup> The composite fuselage avoids metal fatigue issues associated with higher cabin pressure, and eliminates the risk of corrosion from higher



ANA's first 787 Dreamliner with 2–4–2 economy class seating. The aircraft's larger windows, designed to improve passenger views, are shown.



humidity levels.<sup>[247]</sup> The cabin air-conditioning system improves air quality by removing ozone from outside air, and besides standard HEPA filters which remove airborne particles, uses a gaseous filtration system to remove odors, irritants, and gaseous contaminants as well as particulates like viruses, bacteria and allergens.<sup>[180][241]</sup> The bleedless engine cabin air system also allows the 787 air to avoid oil fumes and toxins which are dangerous to the health of passengers and crew and are found in all other aircraft bleed air systems.<sup>[251]</sup>

## Variants

The shortest 787-8 was the first variant to fly in December 2009, then the 787-9 stretch in September 2013, to be followed by the longest 787-10. They are called *B788*, *B789* and *B78X* in the List of ICAO aircraft type designators.<sup>[252]</sup> The short-range 787-3 was cancelled in 2010.

### 787-8



Thomson Airways 787-8 at Hannover Airport in June 2013

With a typical capacity of 242 passengers and a range of 7,355 nautical miles (8,464 mi; 13,621 km), the -8 is the base model of the 787 family and was the first to enter service in 2011.<sup>[253]</sup> The 787-8 is targeted to replace the Boeing 767-200ER and -300ER, as well as expand into new non-stop markets where larger planes would not be economically viable. Approximately 33% of 787 orders are for the 787-8 as of August 2017, with 342 delivered.<sup>[1]</sup>

### 787-9

Keeping the same wingspan as the 787-8, the 787-9 is a lengthened and strengthened variant with a 20 feet (6.1 m) longer fuselage and a 54,500 pounds (24,700 kg) higher maximum take-off weight (MTOW), seating 280 passengers in a typical three-class arrangement over a 7,635 nautical miles (8,786 mi; 14,140 km) range.<sup>[253]</sup> It features active boundary-layer control on the tail surfaces, reducing drag.<sup>[254]</sup> Boeing is targeting the 787-9 to replace its own 767-400ER, to compete with variants of the Airbus A330 and to allow opening new long routes like the 787-8.

In 2005, the entry into service (EIS) was planned for 2010. The firm configuration was finalized on July 1, 2010.<sup>[255]</sup> By October 2011, deliveries were scheduled to begin in 2014.<sup>[256]</sup>

The prototype 787-9 made its maiden flight from Paine Field on September 17, 2013.<sup>[257]</sup> A 787-9 was on static display at the 2014 Farnborough Air Show prior to first delivery.<sup>[258]</sup> On July 8, 2014, Launch customer Air New Zealand took its first 787-9, in a distinctive black livery in a ceremony at Paine Field.<sup>[259]</sup> Its first commercial flight was from Auckland to Sydney on August 9, 2014.<sup>[260]</sup>

The 787-9 was to begin commercial service with All Nippon Airways on August 7, 2014.<sup>[261]</sup> United Airlines was to start the longest nonstop scheduled 787 service between Los Angeles and Melbourne in October 2014.<sup>[262]</sup> Air China started a 787-9 route between Beijing and Chengdu in May 2016.<sup>[263]</sup> As of August 2017, 53% of all 787 orders are for the 787-9, with 236 deliveries.<sup>[1]</sup>

The 20-ft stretch was achieved by adding a 10-ft (five-frame) extension forward and aft. The 787-8 and 787-9 have 50% commonality: the wing, fuselage and systems of the 787-8 had required radical revision to achieve the payload-range goals of the 787-9. Following a major revamp of the original 787-8 wing, the latest configuration for the 787-9 and -10 is the fourth design evolution.<sup>[264]</sup>

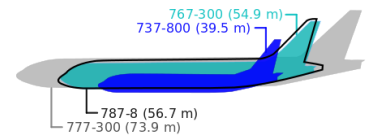
### 787-10

In December 2005, pushed by the interest of Emirates and Qantas, Boeing was studying the possibility of stretching the 787-9 further to seat 290 to 310 passengers and named 787-10. This variant would be similar to the capacity of the Airbus A350-900 and Boeing 777-200ER.<sup>[265]</sup> Customers discussions were continuing in early 2006.<sup>[266]</sup> Mike Bair, Boeing's vice president and general manager for the 787 development program at the time, said it was easier to proceed with the 787-10 development after other customers followed Emirates' request.<sup>[267]</sup>

On May 30, 2013, Singapore Airlines became the launch customer by stating it would order 30 of the 787-10, provided Boeing launches the program, to be delivered in 2018–2019.<sup>[268][269]</sup> On June 18, 2013, Boeing officially launched the 787-10 at the Paris Air Show, with orders or commitments for 102 aircraft from Air Lease Corporation (30), Singapore Airlines (30), United Airlines (20), British Airways (IAG) (12), and GE Capital Aviation Services (10).<sup>[270]</sup>



Qatar Airways 787-8 business class cabin in 1-2-1 layout



Size comparison of the Boeing 787-8 (black outline) with the Boeing 777-300 (gray), 767-300 (teal), and 737-800 (blue).



The first 787-9 in service, operated by launch customer Air New Zealand, landing at the inaugural destination, Perth Airport



787-10 rollout at Boeing South Carolina in North Charleston on February 17, 2017

The variant was envisioned as replacing 777-200, Airbus A330, and A340 aircraft.<sup>[271]</sup> The -10 is to compete against the Airbus A350-900, and offer better economics than the A350 on shorter routes, according to Boeing.<sup>[272]</sup> Steven Udvar-Hazy said "If it's identically configured, the -10 has a little bit of an edge on the -900", but smaller than Boeing's estimate of 10 percent.<sup>[273]</sup> The 787-10 is to be 224 ft (68 m) long, seat 330 passengers in a two-class cabin configuration, and have a range of 6,430 nmi (11,910 km; 7,400 mi).<sup>[274]</sup>

Boeing completed detailed design for the -10 on December 2, 2015.<sup>[275]</sup> Major assembly began in March 2016.<sup>[276]</sup> Designers targeted 90% commonality between the 787-9 and -10 and achieved 95%; the 18-ft stretch was reached by adding 10 ft forward of the wing and 8 ft aft, and by strengthening the fuselage for bending loads in the center wingbox. Because of the length and additional tail strike protection needed, a semilevered landing gear enables rotation over the aft wheels rather than at the bogie center, like the 777-300ER, and cabin air conditioning has 15% more capacity. The first and third -10s will have Rolls-Royce's new Trent 1000 TEN engines, while the second will be powered by the competing General Electric GEnx-1B engine.<sup>[264]</sup>

Major fuselage parts were received for final assembly on November 30, 2016. The 787-10's mid-body fuselage pieces are too large for transport to Everett, Washington and is built only in Charleston, South Carolina;<sup>[277]</sup> it is the first Boeing airliner assembled exclusively there.<sup>[278]</sup> The first -10 was rolled out on February 17, 2017.<sup>[279]</sup> The variant's first flight took place on March 31, 2017 and lasted 4 hours and 48 minutes.<sup>[280]</sup>

The first test aircraft is engaged in flight envelope expansion work and the second joined the program in early May 2017, while the third with a passenger cabin interior to test the uprated environmental control system and Trent fuel-burn performance should join in June. The -10 will appear at the 2017 Paris Air Show and it will be first delivered to launch customer Singapore Airlines early in 2018.<sup>[278]</sup> The second will prove the GE Aviation engines and the third made its first flight on 8 June 2017, when the flight-test programme was 30% complete.<sup>[281]</sup>

## Other proposals

Although with no set date, Boeing expects to build, possibly in the 2018-2023 timeframe, a 787 freighter version.<sup>[282][283]</sup> Boeing also reportedly considered a 787 variant as a candidate to replace the 747-based VC-25 presidential transport in 2009;<sup>[284]</sup> this was unlikely as the United States Air Force has traditionally used aircraft proven in service.<sup>[285]</sup>

## 787-3

The 787-3 would have carried 290-330 passengers in two-class over 2,500 – 3,050 nmi (4,650 – 5,650 km) range, limited by a 364,000 lb (165 t) MTOW.<sup>[286]</sup> In April 2008, to keep the -8 on track for delivery, the -9 stretch was postponed from 2010 to at least 2012 and prioritised before the 787-3 and its 43 orders to follow without a firm delivery date.<sup>[69]</sup>

It kept the -8 length but its 51.7 m wingspan would have fit in ICAO Aerodrome Reference Code D.<sup>[287]</sup> It was designed to operate on Boeing 757-300/Boeing 767-200 sized regional routes from airports with restricted gate spacing.<sup>[288]</sup> The wingspan was decreased by using blended winglets instead of raked wingtips.

By January 2010, all orders, from Japan Airlines and All Nippon Airways, had been converted to the 787-8.<sup>[289]</sup> As it was designed specifically for the Japanese market, Boeing would likely scrap it after they switched orders.<sup>[290]</sup> The -8's longer wingspan makes it more efficient on stages longer than 370 km (200 nm).<sup>[291]</sup> In December 2010, Boeing withdrew the short-haul model as it struggled to produce the 787-8 after three year delays.<sup>[292]</sup>



An artist's impression of the 787-3, which would have featured a shorter wing with winglets.

## Operators

There were 554 Boeing 787 aircraft in airline service as of July 2017, comprising 331 787-8s and 223 787-9s.<sup>[293]</sup> The largest operators were All Nippon Airways (59), Japan Airlines (33), United Airlines (32), Qatar Airways (30), Air Canada (29), American Airlines (29), British Airways (24), Air India (23), LATAM Chile (formerly LAN Airlines) (23), Norwegian (18) and other airlines operating fewer of the type.<sup>[293]</sup>

## Orders and deliveries

In September 2011, the 787 was first officially delivered to launch customer All Nippon Airways.<sup>[295]</sup> As of August 2017, the top three identified customers for the 787 are: All Nippon Airways with 83 orders (36 -8s, 44 -9s and three -10s), ILFC (an aircraft leasing company), with orders totaling 74 Boeing 787s (24 -8s and 50 -9s), and Etihad Airways with 71 orders (41 -9s and 30 -10s).<sup>[1]</sup>

Boeing 787 orders and deliveries by type

	Total orders	Total deliveries
787-8	426	345
787-9	675	244
787-10	177	–
Total	1,278	589



A 787 of LOT Polish Airlines, the first European operator<sup>[294]</sup>



Air Canada's first 787-8 touching down at Toronto Pearson International Airport during a post-delivery test flight.

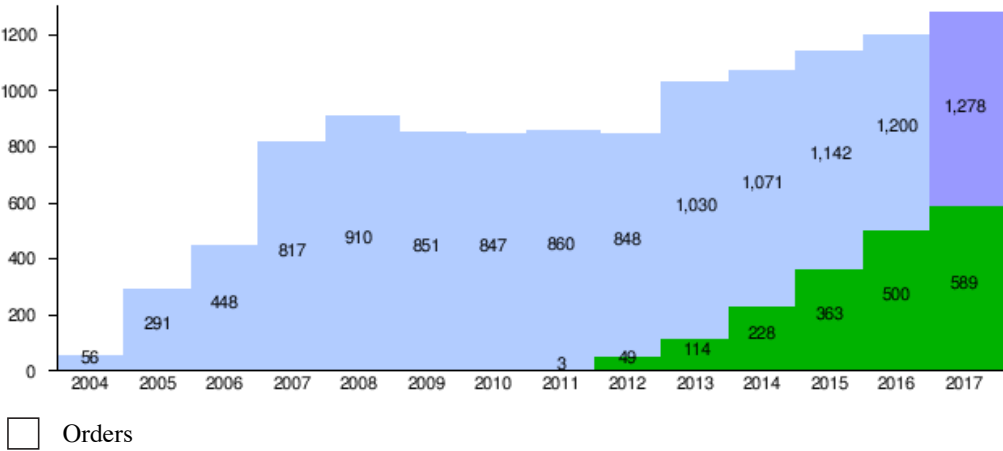


Air India 787-8 Dreamliner departs London's Heathrow Airport, 2014

Boeing 787 orders and deliveries by year

		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Orders		56	235	157	369	93	-59	-4	13	-12	182	41	71	58	78	1,278
Deliveries	787-8	–	–	–	–	–	–	–	3	46	65	104	71	35	21	345
	787-9	–	–	–	–	–	–	–	–	–	–	10	64	102	68	244
	787-10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Total	–	–	–	–	–	–	–	3	46	65	114	135	137	89	589

Boeing 787 orders and deliveries (cumulative, by year):



Orders





Orders and deliveries through August 2017<sup>[1][296][297][298][299]</sup>

## Accidents and notable incidents

The Boeing 787 has been involved in 1 aviation incident. In December 2012, Boeing CEO James McNerney stated that the problems were no greater than those experienced with the introduction of other models such as the Boeing 777.<sup>[300][301]</sup>

### Operational problems

A Japan Airlines (JAL) 787 experienced a fuel leak on January 8, 2013, and its flight from Boston was canceled.<sup>[302]</sup> On January 9, United Airlines reported a problem in one of its six 787s with the wiring near the main batteries. After these incidents, the U.S. National Transportation Safety Board subsequently opened a safety probe.<sup>[303]</sup> Later, on January 11, 2013, another aircraft was found to have a fuel leak.<sup>[304]</sup>

Also on January 11, 2013, the FAA completed a comprehensive review of the 787's critical systems, including the design, manufacture and assembly. The Department of Transportation secretary Ray LaHood stated the administration was "looking for the root causes" behind the recent issues. The head of the FAA, Michael Huerta, said that so far nothing found "suggests [the 787] is not safe".<sup>[305]</sup>

On January 13, 2013, a JAL 787 at Narita International Airport outside Tokyo was found to also have a fuel leak during an inspection, the third time a fuel leak had been reported within a week. The aircraft reportedly was the same one that had a fuel leak in Boston on January 8.<sup>[306]</sup> This leak was caused by a different valve; the causes of the leaks are unknown.<sup>[307]</sup> Japan's transport ministry has also launched an investigation.<sup>[308]</sup>

On July 12, 2013, a fire started on an empty Ethiopian Airlines 787 parked at Heathrow Airport before it was extinguished by the airport fire and rescue service. No injuries were reported.<sup>[309][310]</sup> The fire caused extensive heat damage to the aircraft.<sup>[311]</sup> The FAA and NTSB sent representatives to assist in the investigation.<sup>[312]</sup> The initial investigation found no direct link with the aircraft's main batteries.<sup>[313]</sup> Further investigations indicated that the fire was due to lithium-manganese dioxide batteries powering an emergency locator transmitter (ELT).<sup>[314][315]</sup> The UK Air Accidents Investigation Branch (AAIB) issued a special bulletin on July 18, 2013 requesting the US FAA ensure that the locator is removed or disconnected in Boeing 787s, and to review the safety of lithium battery-powered ELT systems in other aircraft types.<sup>[316]</sup> On August 19, 2015, the Associated Press reported that the fire was started by a short circuit, caused by crossed wires located under the battery. The Air Accidents Investigation Branch's investigators recommended that "the U.S. Federal Aviation Administration, together with similar bodies in Europe and Canada, should conduct a review of equipment powered by lithium metal batteries to ensure they have 'an acceptable level of circuit protection.'"<sup>[317]</sup>

On July 26, 2013, ANA said it had found wiring damage on two 787 locator beacons. United Airlines also reported that it had found a pinched wire in one 787 locator beacon.<sup>[318]</sup> On August 14, 2013, the media reported a fire extinguisher fault affecting three ANA airplanes, which caused the fire extinguishers to discharge into the opposite engine from the one requested.<sup>[319]</sup> The fault was caused by a supplier assembly error.<sup>[320]</sup>

On September 28, 2013, Norwegian Long Haul decided to take one of its two 787s in its fleet at the time out of service after the two aircraft broke down on more than six occasions in September.<sup>[321]</sup> The company will lease an Airbus A340 for its long-haul operations while the 787 is returned to Boeing for repair.<sup>[322]</sup> On December 20–22, 2013, Norwegian Long Haul experienced technical problems keeping two of its three 787 aircraft grounded at Fort Lauderdale airport and delayed six flights.<sup>[323][324]</sup>

On November 22, 2013, Boeing issued an advisory to airlines using General Electric GENx engines on 787 and 747-8 aircraft to avoid flying near high-level thunderstorms due to an increased risk of icing on the engines. The problem was caused by a buildup of ice crystals just behind the main fan, causing a brief loss of thrust on six occasions.<sup>[325]</sup>

On January 21, 2014, a Norwegian Air Shuttle 787 experienced a fuel leak which caused a 19-hour delay to a flight from Bangkok to Oslo.<sup>[326]</sup> Footage of the leak taken by passengers show fuel gushing out of the left wing of the aircraft.<sup>[327]</sup> The leak became known to pilots only after it was pointed out by concerned passengers.<sup>[328]</sup> It was found later that a faulty valve was responsible.<sup>[329]</sup> This fuel leak is one of numerous problems experienced by Norwegian Air Shuttle's 787 fleet.<sup>[326]</sup> Mike Fleming, Boeing's vice president for 787 support and services, subsequently met with executives of Norwegian Air Shuttle and expressed Boeing's commitment to improving the 787's dispatch reliability, "we're not satisfied with where the airplane is today, flying at a fleet average of 98 percent... The 777 today flies at 99.4 percent ... and that's the benchmark that the 787 needs to attain".<sup>[330][331]</sup>



Japan Airlines 787 Dreamliner at Boston Logan Airport with lithium-ion battery fire and resulting heavy smoke coming out a cargo hold



Three 787s of All Nippon Airways sit grounded at Tokyo Haneda International Airport in late January 2013.

On September 24, 2015, Indian media reported that an Air India 787 Dreamliner (VT-AND) had been grounded since January 2015 and had been scavenged for parts due to their lack of availability.<sup>[332]</sup> Air India's aircraft engineers' body advised against accepting further deliveries until Boeing resolved reliability issues. India's Minister of State for Civil Aviation Mahesh Sharma stated the reliability issues to India's Parliament.<sup>[333]</sup>

On March 4, 2016, Ethiopian Airlines 787-8 registration ET-ASH performing Flight ET-702 from Addis Ababa, Ethiopia to Rome Fiumicino, Italy, had its nose gear collapse before flight was ready to depart. A flight attendant received minor injuries and the aircraft was damaged.<sup>[334]</sup>

Later in March 2016 the FAA accelerated the release of an airworthiness directive in response to reports indicating that in certain weather conditions "erroneous low airspeed may be displayed ..." There was concern "abrupt pilot control inputs in this condition could exceed the structural capability of the airplane." Pilots were told not to apply "large, abrupt control column inputs" in the event of an "unrealistic" drop in displayed airspeed.<sup>[335][336]</sup>

On April 22, 2016, the FAA issued an airworthiness directive following a January 29 incident in which a General Electric GENx-1B PIP2 engine suffered damage and non-restartable power loss while flying at an altitude of 20,000 feet. The damage is thought to have been caused by a fan imbalance resulting from fan ice shedding.<sup>[337][338][339]</sup>

## Battery problems

On January 16, 2013, All Nippon Airways Flight NH-692, en route from Yamaguchi Ube Airport to Tokyo Haneda, had a battery problem warning followed by a burning smell while climbing from Ube about 35 nautical miles (65 km) west of Takamatsu, Japan. The aircraft diverted to Takamatsu and was evacuated via the slides; three passengers received minor injuries during the evacuation. Inspection revealed a battery fire. A similar incident in a parked Japan Airlines 787 at Boston's Logan International Airport within the same week led the Federal Aviation Administration to ground all 787s.<sup>[340]</sup> On January 16, 2013, both major Japanese airlines ANA and JAL voluntarily grounded their fleets of 787s after multiple incidents involving different 787s, including emergency landings. At the time, these two carriers operated 24 of the 50 787s delivered.<sup>[341][342]</sup> The grounding reportedly cost ANA some 9 billion yen (US\$93 million) in lost sales.<sup>[343]</sup>

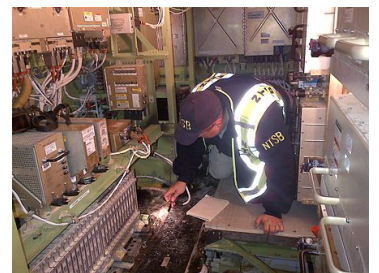
On January 16, 2013, the FAA issued an emergency airworthiness directive ordering all American-based airlines to ground their Boeing 787s until yet-to-be-determined modifications were made to the electrical system to reduce the risk of the battery overheating or catching fire.<sup>[344]</sup> This was the first time that the FAA had grounded an airliner type since 1979.<sup>[345]</sup> Industry experts disagreed on consequences of the grounding: Airbus was confident that Boeing would resolve the issue<sup>[346]</sup> and that no airlines will switch plane type,<sup>[347][348]</sup> while other experts saw the problem as "costly"<sup>[349]</sup> and "could take upwards of a year".<sup>[350]</sup>

The FAA also conducted an extensive review of the 787's critical systems. The focus of the review was on the safety of the lithium-ion batteries<sup>[345]</sup> made of lithium cobalt oxide (LiCoO<sub>2</sub>). The 787 battery contract was signed in 2005,<sup>[200]</sup> when this was the only type of lithium aerospace battery available, but since then newer and safer<sup>[351]</sup> types (such as LiFePO), which provide less reaction energy during thermal runaway, have become available.<sup>[352][353]</sup> FAA approved a 787 battery in 2007 with nine "special conditions".<sup>[354][355]</sup> A battery approved by FAA (through Mobile Power Solutions) was made by Rose Electronics using Kokam cells;<sup>[356]</sup> the batteries installed in the 787 are made by Yuasa.<sup>[197]</sup>

On January 20, the NTSB declared that overvoltage was not the cause of the Boston incident, as voltage did not exceed the battery limit of 32 V,<sup>[357]</sup> and the charging unit passed tests. The battery had signs of short circuiting and thermal runaway.<sup>[358]</sup> Despite this, by January 24, the NTSB had not yet pinpointed the cause of the Boston fire; the FAA would not allow U.S.-based 787s to fly again until the problem was found and corrected. In a press briefing that day, NTSB Chairwoman Deborah Hersman said that the NTSB had found evidence of failure of multiple safety systems designed to prevent these battery problems, and stated that fire must never happen on an airplane.<sup>[359]</sup>

The Japan Transport Safety Board (JTSB) has said on January 23 that the battery in ANA jets in Japan reached a maximum voltage of 31 V (below the 32 V limit like the Boston JAL 787), but had a sudden unexplained voltage drop<sup>[360]</sup> to near zero.<sup>[361]</sup> All cells had signs of thermal damage prior to runaway.<sup>[362]</sup> ANA and JAL had replaced several 787 batteries before the mishaps.<sup>[361]</sup> As of January 29, 2013, JTSB approved the Yuasa factory quality control<sup>[363][364]</sup> while the NTSB examined the Boston battery for defects.<sup>[365]</sup> The failure rate, with two major battery thermal runaway events in 100,000 flight hours, was much higher than the rate of one in 10 million flight hours predicted by Boeing.<sup>[340]</sup>

The only American airline that operated the Dreamliner at the time was United Airlines, which had six.<sup>[366]</sup> Chile's Directorate General of Civil Aviation (DGAC) grounded LAN Airlines' three 787s.<sup>[367]</sup> The Indian Directorate General of Civil Aviation (DGCA) directed Air India to ground its six Dreamliners. The Japanese Transport Ministry made the ANA and JAL groundings official and indefinite following the FAA announcement.<sup>[368]</sup> The European Aviation Safety Agency also followed the FAA's advice and grounded the only two European



The Aft Electronics Bay that held the JAL 787 battery that caught fire



Japan Airlines 787 battery comparison; Left: typical original battery. Right: damaged battery.

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787s operated by LOT Polish Airlines.<sup>[369]</sup> Qatar Airways grounded their five Dreamliners.<sup>[370]</sup> Ethiopian Airlines was the final operator to temporarily ground its four Dreamliners.<sup>[371]</sup> By January 17, 2013, all 50 of the aircraft delivered to date had been grounded.<sup>[371][372]</sup> On January 18, Boeing halted 787 deliveries until the battery problem was resolved.<sup>[373]</sup>

On February 7, 2013, the FAA gave approval for Boeing to conduct 787 test flights to gather additional data.<sup>[374][375]</sup> In February 2013, FAA oversight of the 787's 2007 safety approval and certification was under scrutiny.<sup>[376]</sup> On March 7, 2013, the NTSB released an interim factual report about the Boston battery fire on January 7, 2013. The investigation<sup>[377]</sup> stated that "heavy smoke and fire coming from the front of the APU battery case." Firefighters "tried fire extinguishing, but smoke and flame (flame size about 3 inches) did not stop".<sup>[378][379]</sup>

Boeing completed its final tests on a revised battery design on April 5, 2013.<sup>[380]</sup> The FAA approved Boeing's revised battery design with three additional, overlapping protection methods on April 19, 2013. The FAA published a directive on April 25 to provide instructions for retrofitting battery hardware before the 787s could return to flight.<sup>[381][382]</sup> The repairs were expected to be completed in weeks.<sup>[383]</sup> Following the FAA approval in the U.S.,<sup>[384]</sup> Japan gave permission for passenger airlines to resume Boeing 787 flights in the country effective April 26, 2013.<sup>[385]</sup> On April 27, 2013, Ethiopian Airlines took a 787 on the model's first commercial flight after battery system modifications.<sup>[382][384]</sup>

On January 14, 2014, a battery in a JAL 787 emitted smoke from the battery's protection exhaust while the aircraft was undergoing pre-flight maintenance.<sup>[386][387]</sup> The battery partially melted in the incident,<sup>[388]</sup> one of its eight lithium-ion cells had its relief port vent and fluid sprayed inside the battery's container.<sup>[389]</sup> It was later reported that the battery may have reached a temperature as high as 1,220 °F (660 °C), and that Boeing did not understand the root cause of the failure.<sup>[390]</sup>

The NTSB has criticized FAA, Boeing and the battery manufacturer for the faults,<sup>[391][392][393][394]</sup> it also criticized the flight data recorder.<sup>[395]</sup> The enclosure Boeing had to add is 185 lb (84 kg) heavier, frustratingly negating the lighter battery potential.<sup>[396]</sup>


## Aircraft on display

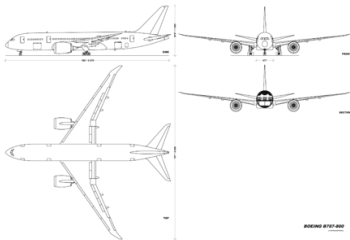
- N787BA (ZA001) – Chubu Centrair Airport in Nagoya, Japan—first prototype aircraft<sup>[397]</sup>
- N787EX (ZA002) – Pima Air & Space Museum in Tucson, Arizona—second prototype aircraft<sup>[398]</sup>
- N787BX (ZA003) – Museum of Flight in Seattle, Washington—third prototype aircraft<sup>[399][400]</sup>

## Specifications

### External image

Boeing 787 cutaway

 Cutaway drawing (<https://www.flickr.com/photos/flightglobal/15849702316/>) from *Flight International*



Schematic of the Boeing 787-8: side, top, front, cross-section views



787 characteristics<sup>[401]</sup>

Model	787-8	787-9	787-10
Cockpit crew	Two		
Seating	242 <span> </span> : 24J @85" + 218Y @32" max. 359, exit limit 381	290 <span> </span> : 28J @85" + 262Y @32" max. 406, exit limit 420	330 <span> </span> : 32J @85" + 298Y @32" max. 440, exit limit 440
Length	186 <span> </span> ft 1 <span> </span> in (56.72 <span> </span> m)	206 <span> </span> ft 1 <span> </span> in (62.81 <span> </span> m)	224 <span> </span> ft (68.28 <span> </span> m)
Wingspan	197 <span> </span> ft 3 <span> </span> in (60.12 <span> </span> m)		
Mean Chord <sup>[402]</sup>	246.9 <span> </span> in / 6.27 <span> </span> m		
Aspect ratio <sup>[402]</sup>	9.59		
Wing area <sup>[402]</sup>	4,058 <span> </span> sq <span> </span> ft (377 <span> </span> m²)		
Wing sweep	32.2 <span> </span> degrees <sup>[403]</sup>		
Height <sup>[253]</sup>	55 <span> </span> ft 10 <span> </span> in (17.02 <span> </span> m)		
Fuselage dimensions	Height: 19 <span> </span> ft 6 <span> </span> in (5.94 <span> </span> m), Width: 18 <span> </span> ft 11 <span> </span> in (5.77 <span> </span> m)		
Cabin width	18 <span> </span> ft 0 <span> </span> in (5.49 <span> </span> m) <sup>[404]</sup>		
Cargo capacity	4,826 <span> </span> ft³ / 136.7 <span> </span> m³ 28 LD3 or 9 (88×125) pallets	6,090 <span> </span> ft³ / 172.5 <span> </span> m³ 36 LD3 or 11 (96×125) pallets	6,722 <span> </span> ft³ / 191.4 <span> </span> m³ 40 LD3 or 13 (96×125) pallets
Maximum takeoff weight	502,500 <span> </span> lb / 227,930 <span> </span> kg	560,000 <span> </span> lb / 254,011 <span> </span> kg	560,000 <span> </span> lb / 254,011 <span> </span> kg
Maximum landing weight	380,000 <span> </span> lb / 172,365 <span> </span> kg	425,000 <span> </span> lb / 192,777 <span> </span> kg	445,000 <span> </span> lb / 201,849 <span> </span> kg
Maximum zero-fuel weight	355,000 <span> </span> lb / 161,025 <span> </span> kg	400,000 <span> </span> lb / 181,437 <span> </span> kg	425,000 <span> </span> lb / 192,777 <span> </span> kg
Operating empty weight	264,500 <span> </span> lb / 119,950 <span> </span> kg	284,000 <span> </span> lb / 128,850 <span> </span> kg	
Cruising speed	Mach 0.85 (488 <span> </span> kn; 903 <span> </span> km/h)		
Maximum speed	Mach 0.90 / 350 <span> </span> kn (648 <span> </span> km/h) equivalent airspeed <sup>[402]</sup>		
Range at typical seating <sup>[253]</sup>	7,355 <span> </span> nmi (13,621 <span> </span> km)	7,635 <span> </span> nmi (14,140 <span> </span> km)	6,430 <span> </span> nmi (11,908 <span> </span> km)
Takeoff distance MTOW (ISA, SL)	10,300 <span> </span> ft (3,100 <span> </span> m) hi thrust: 8,500 <span> </span> ft (2,600 <span> </span> m)	9,400 <span> </span> ft (2,900 <span> </span> m)	
Fuel capacity	33,340 US gal / 126,206 L 223,378 <span> </span> lb / 101,323 <span> </span> kg	33,384 US gal / 126,372 L 223,673 <span> </span> lb / 101,456 <span> </span> kg	
Service ceiling	43,000 <span> </span> ft (13,100 <span> </span> m) <sup>[404]</sup>		
Engines (×2)	General Electric GEnx-1B <i>or</i> Rolls-Royce Trent 1000		
Thrust (×2)	64,000 <span> </span> lbf (280 <span> </span> kN)	71,000 <span> </span> lbf (320 <span> </span> kN)	76,000 <span> </span> lbf (340 <span> </span> kN)

See also

- Competition between Airbus and Boeing

Related development

- Boeing Sonic Cruiser
- Boeing 747-8

Aircraft of comparable role, configuration and era

- Airbus A330neo
- Airbus A350 XWB

Related lists

- List of jet airliners

Footnotes

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