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Pratt & Whitney PW1000G

The **Pratt & Whitney PW1000G** is a high-bypass geared turbofan engine family, currently selected as the exclusive engine for the Airbus A220, Mitsubishi SpaceJet, and Embraer's second generation E-Jets, and as an option on the Irkut MC-21 and Airbus A320neo. The project was previously known as the **Geared Turbofan** (**GTF**), and originally the **Advanced Technology Fan Integrator** (**ATFI**). The engine is expected to deliver reductions in fuel use and ground noise when used in next-generation aircraft. The PW1000G engine first entered commercial use in January 2016 with Lufthansa's first commercial Airbus A320neo flight.[3]

PW1000G

Type	Geared turbofan
National origin	United States
Manufacturer	Pratt & Whitney
First run	November 2007
Major applications	Airbus A220 Airbus A320neo family Embraer E-Jets E2 Irkut MC-21 Mitsubishi SpaceJet
Program cost	$10 billion[1]
Unit cost	$12 million[2]

Contents

Development

In Summer 1993 Pratt & Whitney started to test its 53,000 lbf (240 kN) ADP demonstrator at the NASA Ames wind tunnel with a 4:1, 40,000 hp (30,000 kW) gearbox. Its 118.2 in (300 cm) fan with 18 reversing pitch composite blades had a 15:1 bypass ratio. It was to cut fuel consumption by 6–7%, emissions by 15% and generate less noise due to lower fan tip speed of 950 ft/s (290 m/s) down from 1,400 ft/s (430 m/s) in conventional 5:1 bypass turbofans. Limited by weight and drag, this was mitigated by using 40% composites by weight up from 15% otherwise. P&W was planning to run in 1994 a flight weight 60,000 hp (45,000 kW) gearbox for 75,000 lbf (330 kN) of thrust.[4]

P&W first attempted to build a geared turbofan starting around 1998, with the PW8000,[5] targeted for the 25,000–35,000 lbf (110–160 kN) range. This essentially was an upgrade of the existing PW6000 that replaced the fan section with a gearing system and new single-stage fan,[6] and aimed for 8–10% lower operating costs, or

$600,000 per aircraft annually.


Mockup with compressor and turbine cutaway

It had an 11:1 bypass ratio (twice the V2500), a 40:1 overall pressure ratio, and 13 stages instead of 22[7] in the V2500 for similar thrusts. Preliminary development was to end by June 1, the first test for 10 months later and certification 20 months after for $400 million. Pratt had tested gearboxes for 950 hours for $350 million in the previous decade and aimed for 99.5% efficiency. The ADP gearbox was 30% more powerful and the reversing pitch fan was not retained for the PW8000. Pratt was to control 60% of the program, shared with IAE partners MTU and FiatAvio but not Rolls-Royce, but possibly Volvo and MHI.[8]

Its LP turbine ran at 9,160 rpm, reduced by 3:1 for a 3,250 rpm fan having a 1,050 ft/s (320 m/s) blade tip speed down from 1,400 ft/s (430 m/s), dropping noise to 30 EPNdB cumulated below Stage 3 requirements. The 76–79 in (190–200 cm) fan had 20 titanium blades, and moved 1,369 lb (621 kg) of air per second in climb. The conventional 3-stage LP compressor was followed by a 5-stage, 12:1 HP compressor fitted with 700 blades inspired by the military ATEGG program's low aspect-ratio airfoils. A floatwall/TALON combustor was followed by a single stage HP turbine and a counter rotating 3-stage LP turbine with 400 blades, both CFD optimized. The gearbox could handle 50 hp/lb (82 kW/kg). Eight engines would have been used for certification.[9]

After several years, the PW8000 project was left basically abandoned.[10]

Soon afterwards the ATFI project appeared, using a PW308 core but with a new gearbox and a single-stage fan. It had its first run on March 16, 2001. This led to the Geared Turbofan (GTF) program, which was based around a newly designed core jointly developed with German MTU Aero Engines.

In addition to the geared turbofan, the initial designs included a variable-area fan nozzle (VAFN), which allows improvements in propulsive efficiency across a range of the flight envelope.[11] However, the VAFN has since been dropped from production designs due to high system weight.

The first ground test of the Pratt & Whitney geared turbofan was performed in November 2007 at West Palm Beach, Florida.[12]

In July 2008, the GTF was renamed *PW1000G*, the first in a new line of "PurePower" engines.[13] Pratt & Whitney claims the PW1000G is 16% more fuel efficient than current engines used on regional jets and single-aisle jets, as well as being up to 75% quieter.[14]

Flight testing


Flight testing on a 747SP, in #2 position

The engine was first tested on the Pratt & Whitney Boeing 747SP on July 11, 2008 through mid-August 2008, totaling 12 flights and 43.5 flight hours.[15] It then flew starting October 14, 2008 on an Airbus A340-600 in Toulouse on the number two pylon.[16] Testing of the CSeries bound PW1524G model began in October 2010.[17] The PW1500G engine successfully achieved Transport Canada type certification on February 20, 2013.[18] The A320 engine, the PW1100G, had made its first static engine test run on November 1, 2012, [19] and was first tested on the 747SP on May 15, 2013.[20]

The first flight test on one of its intended production airframes, the Bombardier CSeries (Airbus A220), was on September 16, 2013.[21] The first flight of the Airbus A320neo followed on September 25, 2014.[22] The PW1100G engine successfully achieved FAA type certification on December 19, 2014.[23] The fourth variant of the engine, the PW1900G, first flew on November 3, 2015 from Mirabel in Canada fitted to the Boeing 747SP test aircraft.[24]

Production

At the start of its production in 2016, each GTF was costing PW $10m to build, more than the sale price, but should become less than $2m per engine.[25] MTU provides the first four stages of the high-pressure compressor, the low-pressure turbine and other components. In October 2016, MTU started to deliver the engine assembled on its line to Airbus.[26]

Underneath the wing of an A220 with cowlings open

In November 2016, Pratt had fixed the issue of engine start time and wanted to deliver 150 powerplants by the year-end, 50 fewer than originally planned. This was because of low yield of fan blades when less than one-third were passing inspection at the start of the year compared to 75% success for the latest. 350–400 engine deliveries were targeted for 2017. Fuel-burn performance was 16% better than the IAE V2500 baseline, on target, and even 18% better in best cases.[27]

The troubled introduction made customers choose the CFM LEAP which won 396 plane orders compared to 39 from January through early August 2017 to power the A320neo: 46% of the GTF-powered A320neos were out of service for at least one week in July 2017 compared with just 9% of those using the LEAP, while its market share fell from 45% to 40% in 2016 but 1,523 planes (29%) were still undecided and Pratt have an 8,000 engine orderbook including 1,000 non-Airbus planes.[28]

On 24 October 2017, a 99.8% dispatch reliability was attained and Pratt remained on track to deliver 350 to 400 engines in 2017, as 254 have been delivered including 120 in the third quarter, but 12–15% were diverted for spares as the carbon air seal and combustor liners were wearing out quickly, requiring engine removals to change the part.[29] P&W expects to deliver over 2,500 GTFs from 2018 to 2020, more than 10,000 engines by 2025.[30]

After 15 PW1200Gs for the Mitsubishi MRJ development were built in Mirabel and Middletown, Mitsubishi Heavy Industries started final assembly in Nagoya in mid 2018 for the MRJ 2020 introduction. Icing, thermal environment, stall, drainage, performance, operability and other development tests were completed. MHI manufactures the combustor and high-pressure turbine disks.[31] The first engine was completed by November 2019.[32]

Ultra high-bypass version

In 2010, Pratt & Whitney launched the development of an ultra high-bypass version, with a ratio significantly higher than the PW1100G's 12.2:1 for the A320neo, to improve fuel consumption by 20% compared to a CFM56-7 and reduced noise relative to the FAA's Stage 4 by 25 dB. In 2012, wind tunnel tests were completed on an earlier version of the fan and in 2015, 275h of testing were completed on a fan rig. More than 175h of ground testing of key components were completed in October 2017, on a shorter duct inlet, a part of the nacelle and a fan with lower-pressure ratio blades, significantly fewer than the 20 blades of the PW1100G. The US FAA Continuous Lower Energy, Emissions and Noise (CLEEN) program sponsors the tests, with its technologies to be validated in a flight test campaign. It could power the Boeing New Midsize Airplane in the mid-2020s and Airbus' response, and would compete against the Rolls-Royce UltraFan and a CFM LEAP higher-thrust version.[33]

Design

By putting a 3:1 gearbox between the fan and the low-pressure spool, each spins at its optimal speed: 4,000–5,000 RPM for the fan and 12,000–15,000 RPM for the spool, the high-pressure spool spinning at more than 20,000 RPM. The 30,000-horsepower (22,000-kilowatt) gearbox is designed as a lifetime item with no scheduled maintenance other than changing oil.[34] The A320 PW1100G fan has 20 blades, down from 36 in the CFM56-5B.[35]

As the higher bypass ratio and gear leverage a higher propulsive efficiency, there is less need for a high performance engine core than the CFM LEAP, leaving a larger fuel burn gain margin of 5–7% over the next decade, averaging 1% per year combined with gear ratio tweaks.[36] It has up to 25,000 cycles LLPs, 25% better than others at 20,000 cycles, reducing maintenance costs, and the fan gear has no limit.[37]

The family of engines generates 15,000 to 33,000 lbf (67 to 147 kN) of thrust. It uses gearboxes rated between 16,000 hp (12,000 kW) and 32,000 hp (24,000 kW).[38]

The PW1431G variant for the Irkut MC-21 has a compression ratio of 42, and it has a specific fuel consumption (SFC) at cruise of 0.52–0.53 kg/kgf-thrust/hr.[39]

Operational history

Introduction

Lufthansa was the first to fly the PW1000G-powered A320neo in early 2016

The first delivery to a commercial operator, an A320neo to Lufthansa, occurred on January 20, 2016.[40] As of early August 2017, Pratt was supporting 75 aircraft: 59 Airbus A320neos with PW1100Gs and 16 Airbus A220s with PW1500Gs.[41] In January 2018, it reached 500,000 flight hours on a fleet of 135 aircraft flown by 21 operators.[42] Due to teething problems, overall losses on the GTF program rose to $1.2 billion.[43]

In May 2018, after receiving and operating five A320neos, Spirit Airlines confirms a fuel burn reduction better than the 15% promised, perhaps by 1%–2%. Air Lease Corporation's A320neos deliveries are 11 months late but its executive chairman Steven Udvar-Hazy believes 12–18 months will be needed to get back to normal.[44]

Starting times

The first delivery was to Lufthansa instead of Qatar Airways due to rotor bow, or thermal bowing, due to asymmetrical cooling after shut-down on the previous flight. Differences in temperature across the shaft section supporting the rotor lead to different thermal deformation of the shaft material, causing the rotor axis to bend; this results in an offset between the center of gravity of the bowed rotor and the bearing axis, causing a slight imbalance and potentially reducing the tight clearance between the rotor blade tips and the compressor wall. All production standard engines now feature a damper on the third and fourth shaft bearings to help stiffen the shaft and data from engines in service and under accelerated testing is expected to gradually reduce engine start times. According to P&W President Bob Leduc, "by the time we get to June (2016), it will be down to 200 seconds for start time and by the time we get to December (2016) we will be down to 150 seconds for start time".[45]

In an earnings briefing on 26 July the CEO of Pratt & Whitney's parent company United Technologies Gregory Hayes stated when asked about the start up issues on the PW1100G-JM; "On the technical stuff, I would tell you it is in the rearview mirror. The start time with the software drops have been pretty well addressed".[46] Airbus group chief Tom Enders said while releasing Airbus's 2016 first half financial results that the first upgraded "golden engine" would be delivered to Lufthansa in early August 2016.[47]

Initially, the PW1000G start up sequence took about seven minutes, compared to one to two and a half minute startups on the similar CFM56 and IAE V2500 engines; hardware fixes and software upgrades decreased the time required by a little over a minute, and cooling down both engines at the same time saved slightly over two minutes, for a total reduction of three and a half minutes. These modifications were included on new-build engines, as well as retrofitting existing units. Pratt & Whitney continued to improve start up times, with fuel-nozzle modifications and oil filling procedure changes expected to save another minute when introduced by the end of 2017.[48]

To create a better seal and reduce cooling time by 1 min, a cubic boron nitride coating was applied to the 11 integrally bladed rotors tips: the A321neo production engines start times will be similar to the V2500.[49]

Engine removals

As IndiGo and Go Air operate in a humid, hot, polluted and salty environment, 42 engines were prematurely removed from those companies' aircraft by 24 February, with more to come and after certain warnings, mandatory checks, and possible repairs are due after only three flight hours instead of ten : 28 engine removals were due to an air seal leakage in the third bearing, allowing metal particles to enter the oil system, triggering detectors. Pratt & Whitney discovered these issues in 2015 and revised the design in 2016 after the 160th engine with improved bearing compartments and damping for the third and fourth bearings to offset the rotor-bow, with the repairs retrofitted on-wing after testing at Airbus and Pratt.[48] Boosting durability of the third bearing compartment air seal, the upgraded carbon seal package was certified on April 12 and can be retrofited over a typical night stop.[50]

IndiGo A320neo waiting for its engines

Thirteen engine removals were due to borescope inspections revealing blocked cooling holes in combustion chamber panels, apparently due to saltier air, and Pratt & Whitney developed and tested a more durable combustor design to address a tone problem, with the fix to be introduced in September.[48] Spirit Airlines reported that the bleed air system froze shut on occasion due to cold temperatures on four of its five A320neos, a problem also experienced by IndiGo, leading Spirit to impose a 30,000 feet (9,100 m) ceiling on their aircraft.[51] To avoid troubles with the P&W1100G engines, JetBlue Airways switched its first three Airbus A321neos in 2018 to A321ceos, deferring delivery of its first A321neos to 2019 among its order for 60.[52]

In 2017, IndiGo had to ground seven planes, two in May, four in June and one in July after, their engines out of service, waiting for upgrades: a lack of spare parts—grounding also All Nippon Airways and Hong Kong Express Airways A320s—has been compounded by a new Indian tax on goods and services impeding imports.[53] With removals without sufficient spare engines available, the airline had to ground as many as nine jets on some days, operations disruptions are understood by Pratt & Whitney which struggles to fix glitches and sent compensation while design changes could take a year and sorting out the issue one and a half years.[54] Indigo had to replace 69 engines from mid 2016 till early 2018.[55]

Knife edge seal

In February 2018, after in-flight failures of PW1100G with its high pressure compressor aft hub modified – apparently problems of its knife edge seal, the EASA and Airbus grounded some A320neo family aircraft until they are fitted with spares.[56] Later, Airbus decided to stop accepting additional PW1100G engines for A320neo aircraft.[57] Despite the part failure that could hold up engine deliveries to Airbus until April, P&W reaffirmed its 2018 delivery goal of doubling its 2017 rate of 374 engines as nearly 100 engines delivered to Airbus are problematic, including 43 in service.[58]

To solve the issue, a revised configuration with a mature and approved design will be released from early March engine deliveries.[59] The EASA and FAA imposed flying A320neos with mixed engines and forbid ETOPS, but the Indian DGCA went further and grounded all A320neo with an affected engine.[60] The design flaw will cost Pratt & Whitney $50 million to resolve.[61] P&W will replace the seals in the 55 engines delivered to Airbus and in the 43 in-service GTFs, as the target of 750 deliveries in 2018 seems more remote.[30]

Engine vibrations

By September 2018, the A320neo's PW1100Gs were experiencing increasing engine vibrations, sometimes before 1,000 flight hours and mostly at high power settings in the climb phase, requiring an early engine change. Lufthansa's A320neos were grounded 254 days since first delivery, 13 times worse than for its A320ceos, 78% of the time due to engine issues as 14 unplanned engine changes were made. In September 2018 its A320neos utilization was half of its A320ceos. By the end of November, Airbus planned to explain the root cause and give an in-depth analysis by the end of 2018.[62] Pratt & Whitney stated the A220's and Embraer E2's PW1500G/PW1900Gs are free from the issue and that less than 2% of PW1100Gs are affected while 182 GTF-powered A320/A321neos have been delivered.[63]

By October 2018 about 10 P&W-powered A320neos were typically grounded for repairs at any given time.[64] On 21 January 2019 an IndiGo flight returned to the airport shortly after takeoff after the pilot observed high vibration in one of its PW1100G-JM engines.[65]

Excessive corrosion

Pratt & Whitney has reduced life limits on PW1500G (installed on the Airbus A220) and PW1900G (installed on Embraer E190/E195-E20) high-pressure compressor front hubs after corrosion was discovered during routine engine overhaul. This corrosion reduces the low-cycle fatigue capability and may lead to cracking before the component reaches its life limit.[66]

In-flight failures

PW1100G failures

Indian airline IndiGo reported four incidents involving in-flight engine stall during climb followed by shutdown, which occurred on the 24th, 25th and 26th of October 2019. The cause of the shutdowns has been traced to problems with the Low-Pressure Turbine (LPT).[67] On 1 November 2019 the Indian Directorate General of Civil Aviation (DGCA) asked IndiGo to replace engines on all of the 98 A320 Neo airplanes it currently operates by January 31, 2020 and suggested to defer future deliveries until the existing fleet is re-engined.[68] Later DGCA extended the deadline to May 31, 2020.[69]

PW1500G failures

The PW1500G powers the Airbus A220

On 25 July 2019, an Airbus A220-300 of Swiss International Air Lines had an engine inflight shutdown (IFSD) and diverted to Paris–Charles de Gaulle.[70] The low-pressure compressor of its PW1500G disintegrated while climbing through 32,000ft.[71]

On 16 September 2019, a similar accident happened just before reaching 35,000ft and the crew returned to Geneva. The inspection has shown that "stage-one rotor in the low-pressure compressor had separated and there was a hole in the compressor case".[72] On September 26, 2019 the FAA issued an Airworthiness Directive mandating borescope inspections on the engines.[73]

On 15 October 2019, another engine failed and the crew diverted to Paris-Charles de Gaulle, Swiss withdrew its fleet for inspection.[74] Swiss returned some aircraft to flight status the same day after engine checks and planned to restore flight operations by 17 October.[75] A software update may cause damaging vibrations of fast-moving parts, causing the failures.[76]

After those engine failures, Transport Canada issued an emergency airworthiness directive limiting the power to 94% of N1 above 29,000 ft (8,800 m), disengaging the autothrottle for the climb over this altitude before engaging it again in cruise.[77] For the PW1500G, N1 is the Low Pressure Spool, with a nominal speed of 10,600 RPM, with the fan geared with a ratio of 1:3.0625 (nominal speed 3461 RPM).[78] The top of climb is the most demanding point aerodynamically for a turbofan, where the compressor spins the fastest.[79] The directive states that "high altitude climbs at higher thrust settings for engines with certain thrust ratings" may be a contributor to the failures, and cautions that "this condition, if not corrected, could lead to an uncontained failure of the engine and damage to the aeroplane".[80] The EASA adopted the directive, and others are expected to follow.[81]

The engines involved in the July and September incidents had 154 and 230 cycles, respectively, while the October failure occurred to an engine with 1,654 cycles since new but within 300 cycles after an electronic engine-control update. Pratt & Whitney recommends inspections on engines with up to 300 cycles after the update.[82]

Another PW1500G suffered an uncontained engine failure, on 12 February 2020 aboard A220-300 belonging to Air Baltic during flight BT-677 from Riga, Latvia to Malaga, Spain [83]

Applications

- Airbus A320neo: PW1100G[84][85]
- Irkut MC-21: PW1400G[86]
- Airbus A220: PW1500G[87] (exclusive)
- Embraer E-Jet E2 family : PW1700G & PW1900G [88][89] (exclusive)
- Mitsubishi Regional Jet: PW1200G[90][91] (exclusive)

It has been proposed for the Sukhoi Superjet 130,[92] and the Rekkof Aircraft F-120NG.[93]

Specifications

The PW1000G Family[94]

Model	PW1100G[95]	PW1400G	PW1500G[96]	PW1900G	PW1700G	PW1200G
Fan Diameter	81 in (206 cm), 20 blades		73 in (185 cm), 18 blades		56 in (142 cm), 18 blades	
Bypass ratio	12.5:1	12:1			9:1	
Static Thrust	24,000–35,000 lbf 110–160 kN	28,000–31,000 lbf 120–140 kN	19,000–23,300 lbf 85–104 kN	17,000–23,000 lbf 76–102 kN	15,000–17,000 lbf 67–76 kN	15,000 lbf 67 kN
Compressor	Axial flow, 1 geared fan, 3 stage LPC, 8 stage HPC				same except 2 stage LPC	
Combustor	Talon-X Lean-Burn Combustor[97]					
Turbine	Axial flow, 2-stage HP, 3-stage LP					
Application	A320neo family	Irkut MC-21	A220 family	E-Jet E2 190/195	E-Jet E2 175	SpaceJet M90/M100
Service entry	25 January 2016	2021	15 July 2016	24 April 2018	2021	2021
Type Certificate Data sheet						
Model	PW1100G[98]	PW1400G[98]	PW1500G[99]	PW1900G[99]		PW1200G[100]
Length[a]	133.898 in / 3.401 m		125.4 in / 3.184 m		113.5 in (2.88 m)	
fan case diameter	87.566 in / 2.224 m		79.0 in / 2.006 m		62 in (1.57 m)	
weight	6300 lb / 2857.6 kg		4800 lb / 2177 kg		3,800 lb (1,724 kg)	
Takeoff thrust	30/33G: 33,110 lbf / 147.28 kN 27G: 27,075 lbf / 120.43 kN 24/22G: 24,240 lbf / 107.82 kN	PW1431G: 31,572 lbf 140.39 kN	19G: 19,775 lbf / 87.96 kN 21G: 21,970 lbf / 97.73 kN 24/25G: 24,400 lbf / 108.54 kN	19G: 20,860 lbf / 92.79 kN 21G: 22,550 lbf / 100.31 kN 22/23G: 23,815 lbf / 105.93 kN	PW1217G: 19,190 lbf 85.4 kN	
Thrust-to-weight ratio	3.85 – 5.26	5.01	4.12 – 5.08	4.35 – 4.96	5.05	

See also

Related development

- Pratt & Whitney/Allison 578-DX
- IAE SuperFan
- Pratt & Whitney Canada PW800

Comparable engines

- CFM International LEAP
- under development
  - Aviadvigatel PD-14
  - ACAE CJ-1000A
- geared turbofan
  - Garrett TFE731
  - Honeywell ALF 502/LF 507
  - Turbomeca Aspin/Astafan

Related lists

- List of aircraft engines

Notes

a. fan spinner face to aft flange

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