GE90 family specifications

The General Electric GE90 engine family comprises two main variants. The are the GE90 standard, with five thrust ratings; and the GE90 Growth, with two thrust ratings. Their development, configuration & bypass ratios, thrust ratings, and emissions standards are examined.

The General Electric (GE) GE90 engine family powers about 650 active 777-200s/-300s. There are also another 330 777s on firm order which will be powered by GE90s, so almost 1,000 aircraft will be equipped with GE90 engines. The main models are the engine with the 123-inch fan, known as the GE90 'base' or 'standard' engine; and the engine with the 128.2-inch fan diameter, known as the GE90 'growth' engine. Each has several thrust ratings.

Engine concept

Development of the GE90 started in the mid- and late 1980s, after the CF6 family reached the limit of its thrust growth potential. The highest thrust-rated variant of the CF6-80E1 is the -80E1A3, rated at 68,530lbs thrust. The engine has a 96.2-inch fan diameter and a bypass ratio of 5.1:1.

The GE90 was developed solely for the 777 family. The initial variants of the 777-200 required engines with take-off thrust ratings of 76,000lbs (-76B), 77,600lbs (-77B), 85,000lbs (-85B) and 90,000lbs (-90B) *(see table, page 5)*. Aircraft could have maximum take-off weights (MTOWs) of 506,000lbs, 515,000lbs and 535,000lbs, although only 535,000lbs was selected by airlines. Aircraft with MTOWs up to 535,000lbs had standard fuel capacities of 31,000US Gallons (USG).

The 777-200ER has a higher fuel capacity of 45,220USG, and higher corresponding MTOWs of 580,000lbs, 590,000lbs, 632,500lbs and 656,000lbs. The GE90 engine options for these were rated at 85,000lbs (-85B), 90,000lbs (-90B) and 93,700lbs (-94B) *(see table, page 5)*. The 93,700lbs (-94B) engine was also available for the 777-300, which had a stretched fuselage, a fuel capacity of 44,700USG and MTOWs of 580,000lbs to 660,000lbs. No airlines chose this airframe-engine combination.

There are therefore five thrust ratings for the GE90 standard. This engine was one of three options for 777 customers, the other two being the Rolls-Royce Trent 800 family and the Pratt & Whitney PW4000-112 family.

The GE90 standard is no longer manufactured. Of all the 777-200/-200ERs built, there remain 169 in active service with GE90 standard engines. There are just four aircraft with -76B engines, 28 with -85B engines, 73 with -90B engines, and 64 with -94B engines.

Later developments of the 777-200 and -300 were ultra-long-range variants called the -200LR and -300ER. These aircraft have MTOWs of 760,700-775,000lbs and fuel capacities of 47,890USG and 53,440USG, so they required higher take-off thrusts of 110,100lbs (-110B) and 115,000lbs (-115B). This makes them the highest rated civil airliner turbofan engines. The GE90 growth engine is the only option for the 777-200LR, -200F and -300ER.

The GE90 growth has been more successful than the GE90 standard. Relatively few 777-200LRs have been ordered, with just 54 in service and another four on firm order. Most of these 58 have the -110B engine, although 11 have the higher-rated -115B. There are 65 777-200Fs in service, and another 62 on firm order. All 127 aircraft have the -110B engine. There are 357 777-300ERs in service and another 262 on firm order, making a total of 619 aircraft. All have the -115B engine.

GE90 standard

The 777-200, -200ER and -300 are powered by the GE90 'base' or 'standard' engine, with a fan diameter of 123 inches

One particular technology developed for the GE90 was swept, wide-chord fan blades made with composite materials. These blades allow the wide-diameter fan to turn at a relatively high RPMs.

and thrust ratings of 76,000lbs to 93,700lbs *(see table, page 5)*. Conceiving an engine that was capable of delivering this amount of thrust required the GE90 to have a higher overall pressure ratio than the CF6-80C2 and -80E1 families. The CF6-80E1 has an overall pressure ratio of 34.8:1.

The GE90's high pressure compressor (HPC) is one of its most important features. Its design and configuration is central to the GE90 'standard' achieving an overall pressure ratio of 35-41:1 *(see table, this page)*. The significance of a high overall pressure ratio is that the higher the overall pressure, the more efficient is the cycle of inducting air, compressing it, heating it and expelling it. Each engine design therefore aims to reach as high an overall pressure ratio as possible. The overall effect is for thrust to be generated more efficiently, so that a lower amount of fuel is used for the same thrust.

The GE90 standard's HPC is central to the engine's high pressure ratio. It has 10 stages, four fewer than the CF6-80E1. Despite its shorter length, the GE90's HPC design allows it to generate a high enough pressure ratio. This reduces the number of stages, and therefore the number of blades and vanes.

GE also developed the GE90's combustor to be shorter than the CF6's, so the GE90's core is overall shorter. This gives the engine stiffness, which reduces flexing so that there is less rub between the tips of blades and the inner walls of the engine casing. This improves durability.

A third factor contributing to the GE90's short core engine is the use of a three-stage low pressure compressor (LPC) or booster. This compares to a four-stage configuration for the CF6-80C2/-80E1 engine.

Similar to the CF6-80C2/-80E1, the GE90 standard uses a two-stage HPT, a feature necessary to extract enough power to turn the engine's large fan.

The GE90 standard's bypass ratio is 8.7:1. This compares to the CF6-80E1's bypass ratio of 5.1:1. The GE90 achieves this higher bypass ratio, and therefore lower specific fuel consumption (sfc) and noise emissions, through the use of a wider intake fan.

This larger fan requires a six-stage low pressure turbine (LPT) to turn it, compared to a five-stage LPT used for the CF6-80E1.

GENERAL ELECTRIC GE90 FAMILY SPECIFICATIONS TABLE

Engine Model	GE90-76B	GE90-77B	GE90-85B	GE90-90B	GE90-95B
Thrust rating-lbs	76,000	77,000	84,700	90,000	93,700
Fan diameter (inches)	123	123	123	123	123
Fan blades	22	22	22	22	22
Bypass ratio	8.7:1	8.7:1	8.7:1	8.7:1	8.7:1
Overall pressure ratio	35:1	36:1	38:1	40:1	41:1
Flat rate temp-deg C.	33	30	30	30	30
NOx CAEP VI margin	19%	19%	14%	15%	13%
Application	777-200	777-200	777-200/ 777-200ER	777-200/ 777-200ER	777-200ER/ 777-300
Engine configuration					
Fan stages	1	1	1	1	1
LPC stages	3	3	3	3	3
HPC stages	10	10	10	10	10
HPT stages	2	2	2	2	2
LPT stages	6	6	6	6	6

Engine Model	GE90-110B	GE90-115B
Thrust rating-lbs	110,100	115,300
Fan diameter (inches)	128.23	128.2
Fan blades	22	22
Bypass ratio	7.2:1	7.2:1
Overall pressure ratio	40:1	42:1
Flat rate temp-deg C.	33	30
NOx CAEP VI margin	8%	6%
Application	777-200LR/ 777-200F	777-200LR/ 777-300ER
Engine configuration		
Fan stages	1	1
LPC stages	4	4
HPC stages	9	9
HPT stages	2	2
LPT stages	6	6

Specific technologies

Several new technologies were developed for the GE90 standard. The first of these was curved, wide-chord fan blades for the intake fan. The tip speed of fan blades is limited by aerodynamics, and the problem of generating a shock wave if the air speed at the tips of the blades exceeds the speed of sound. This shock wave limits a fan's efficiency, so the fan's rotational speed has to be limited. The wider the fan, the lower the rotational speed or revolutions per minute (RPM).

The GE90's wider fan compared to the CF6-80E1, for example, meant that it would have to turn at lower RPMs. This would compromise the engine's efficiency. More LPC and LPT stages, for example, would be required to turn a larger fan.

GE overcame these limitations by developing modern generation fan blades for the GE90. These had a three-dimensional (3-D) aerodynamic shape, and were wide-chord, snubberless blades.

The design was made possible by the use of various composite materials. Besides allowing the fan to turn at a relatively high RPM for its diameter, it also has fewer fan blades than the CF6-80C2's/-80E1's fan. That is, both main GE90 variants have 22 fan blades, compared to the CF6-80C2's 38 blades. The aerodynamic efficiency and light weight of the fan blades mean that the fan requires less energy to turn it than a fan of conventional design would.

Another bonus of the use of composite materials in the GE90's fan blades was that the intake fan is more resistant to foreign object damage.

A second major technology used in the GE90 was several generations of 3-D aerodynamic airfoils in the core engine. There are three main groups of GE90 variants.

The first group comprises the GE90 standard variants rated at 76,000lbs, 85,000lbs and 90,000lbs thrust. These engines had the same component configuration, and different thrust ratings

The GE90 Growth engine is the only engine powering the 777-200LR/-300ER. There are more than 480 aircraft in operation, and another 330 aircraft on firm order. These aircraft are in operation on long-haul and ultra long-haul routes.

are simply achieved through the use of the full authority digital engine control (FADEC). These used the first generation 3-D airfoils in the HPC.

The second group is the GE90 standard engine that employs second generation 3-D aerodynamic airfoils in the HPC to allow the engine to achieve a higher thrust rating of 93,700lbs. The main benefit of these airfoils is that they have the effect of lowering the core engine temperature, which increases the engine's removal interval, and reduces fuel burn compared to the previous GE90 standard engines.

Once this engine was put into production, second generation 3-D aerodynamic airfoils could also be used in lower-rated standard engines to improve their aerodynamic efficiency.

Following the introduction of the second generation 3-D aerodynamic airfoils, GE introduced a performance improvement program (PIP), whereby the second generation HPC airfoils can be installed in the earlier-built -76B, -85B and -90B engines. These engines can be kept at their original thrust ratings, but can also be uprated to a -94B engine if required. Some airlines have installed these parts, but kept the engines at a -85B rating.

The second group of GE90 variants is the higher rated -110B and -115B engines with a 128.2 inch diameter fan.

A third main technology was the development of a dual annular combustor (DAC). This utilises two rings of annular burners, rather than a standard single ring of burners. This has the effect of burning more fuel in a shorter combustor length, with the benefit of reducing fuel burn and NOx and CO_2 emissions.

The engine's high bypass ratio and overall pressure ratio not only contributes to it having a low sfc, but also means it has lower noise emissions than earlier generation turbofans. The GE90-76B has a 13.2-14.6 EPNdB margin for Stage IV noise compliance.

The GE90 standard also has a high flat-rating temperature. This is the outside air temperature up to which the engine maintains maximum thrust. Above this temperature, thrust has to be reduced for the exhaust gas temperature (EGT) not to exceed the redline limit. The GE90-76B has a flat rate temperature of 33 degrees centigrade, while all other GE90 standard variants are flat-rated at 30 degrees. This will allow the engine to operate at maximum thrust in most environments.

GE90 growth

The GE90-110B and -115B are rated at 110,000lbs and 115,000lbs. The 777-300ER is powered solely by the -115B, and the -200F solely by the -110B. The majority of 777-200LRs are powered by the -110B, although a small number of aircraft are powered by the -115B.

Several major changes were made to the GE90 standard to acquire the required thrust ratings. The key factor was the utilisation of a larger intake fan with a diameter of 128.2 inches. The diameter of the core engine is the same as the GE90 standard's core engine. The difference to the -110B/-115B's core engine is that it has an additional LPC stage to increase core flow, which is required to turn the larger fan at the optimum speeds required. It also, however, has one less HPC stage. A consequence of the higher coreflow is that the GE90-110B/-115B have a lower bypass ratio of 7.2:1 *(see table, page 5)* compared to 8.7:1 for the GE90 standard. The -110B/-115B's fan uses the same fan blade technology and same number of fan blades as the GE90 standard engine. The -110B/-115B's larger fan diameter means it has a 12% higher airflow than the GE90 standard's fan. This is a contributing factor to the growth engine's higher thrust rating.

The GE90-110B/-115B have an overall pressure ratio of 40-42:1 *(see table, page 5)*.

While the -94B utilised second generation 3-D aerodynamic airfoils in the HPC, the -110B/-115B utilised a third generation of refined 3-D aerodynamic airfoils in the HPC. The -110B/-115B also use new materials and airfoils in the turbine, in particular 3-D aerodynamic HPT blades and vanes.

Another feature of the -110B/-115B is improved aerodynamic airfoils in the LPT. This allowed the GE90 growth engines to utilise the same six-stage LPT, although the base engine has a slightly more efficient LPT.

GE wanted to use the same bearings in the growth -110B and -115B variants. The problem this posed was that a larger fan requires more energy to turn it, and this can require a thicker shaft. The need to maintain bearing design and the same shaft width as the GE90 standard meant that the growth engine's shaft required more torque, and so had to be stronger. This was achieved through the use of a new alloy.

The GE90-110B/-115B have NOx emissions margins of 8% and 6% relative to CAEP VI requirements. The GE90-110B is flat rated at 33 degrees centigrade, and the -115B flat rated at 30 degrees centigrade *(see table, page 5)*. AC