CF6-80C2 engine history and evolution

Paolo Lironi, senior technical manager at International Aviation Services Group Engine Services analyses the CF6-80C2 range of engines, one of the most successful engine families ever built. He looks at the family's pedigree, technical characteristics, in-service difficulties, maintenance costs, values and future.

All CF6 engines have a classic two-shaft design. The configuration mounts the low-pressure compressor (LPC) and low pressure turbine (LPT) on the same shaft as the intake fan. To better understand the great success of the CF6-80 model, it is necessary to review its predecessors in the CF6 range. The CF6 has its origins in the TF39 military engine, the power plant for the Galaxy C-5 military transport aircraft. Experience gained by GE on the TF39 was invaluable to the CF6 programme since it allowed the engine to be exposed to many of its initial teething problems, through a large number of flight hours under rigorous operating conditions. These problems were subsequently overcome.

The first of the CF6 engines was the CF6-6D which had sole supplier status on the DC-10-10 and was rated at 39,300 lb thrust. The CF6-6 series has four LPC stages, 16 HPC stages, two HPT stages and five LPT stages. With a fan diameter of 86.4 inches the -6D achieves a bypass ratio of 5.7. GE designed the CF6 to have reserve capability for growth without making major changes to the core engine and thanks to its higher bypass ratio, its fuel economy was better than many of its competitors. A later version, the CF6-6D1 was offered with thrust increased to 40,300 lb.

Subsequently, the CF6-50C series was designed and produced for the DC-10-30 and the first variants of the Airbus A300B, the -B2 and -B4 versions. However, few parts were common with the CF6-6 since major changes had been made to core engine design and configuration. Thanks to the improved aerodynamics, the HPC was shortened from 16 to 14 stages and the LPC stages were reduced to three. The LPC was also reduced by one stage and turbine cooling was also improved. Fan size was not changed from the original CF6-6 series but the primary flow had to be increased considerably, thus decreasing the bypass ratio to 4.26. The -50C was rated at 50,400 lb.

Since the CF6 was the only engine available to power the DC-10-10, most DC-10 operators later selected the CF6 to power their 747, 767, A300, A310 and MD-11 fleets. This allowed General Electric to increase its market share and take number one position from Pratt & Whitney in the widebody market.

The -50E is the same basic engine as the -50C, but it has variable stator vanes in the HPC. The -50E is rated at 51,800lbs, has a bypass ratio of 4.24, powers the DC-10-30 and was the first CF6 variant to power the 747. The -50C2B is the highest thrust variant of the -50 series and is rated at 53,200lbs. This version powers the highest gross weight variant of the DC-10-30 and higher gross weight models of the 747-200.

The next engine variant to come out of the CF6 stable was the CF6-80A. The CF6-80A series did not feature any major changes to core engine configuration fan diameter from the CF6-50 However, earlier models received criticism for being long, giving the engine a tendency for the shafts to bend in use. The consequence of this excessive bending was significant rubbing of blade tips resulting in a high rate of

CF6-80C2 characteristics and components

Characteristics	Components
LPC	1 fan 3 primary stages
HPC	14 primary stages 5 stages with variable stator vanes
HPT	2 primary stages
LPT	5 primary stages
Max diameter (inches)	106
Length (inches)	168
Dry weight (lb)	9.480 - 9,860
Overall pressure ratio at maximum power	27.1 - 31.8
Bypass ratio	5 - 5.31

engine performance deterioration and higher removal and overhaul rates.

The new -80A series had a shortened core making the engine stiffer and less prone to bending. The engine also had a re-matched turbine and improved cooling. The CF6-80A series was rated at lower thrusts than the CF6-50 series and powered the A310-200/-300 and early 767-200 and 767-300 models. The CF6-80A1 is rated at 46,900 lb takeoff thrust, while the CF6-80A2/A3 is rated at 48,800 lbs.

Development and technical characteristics

In IASG's view, GE really broke into the market with the CF6-80C2 series and this engine was the defining point in creating the leadership position which it has since attained. The CF6-80C2 series featured the first major changes to engine configuration since the development of the CF6-50 series. The CF6-80C2 has a larger fan and one additional LPC and LPT stage. Primary engine characteristics are listed in the table within this article.

Major technical characteristics:

- In order to minimise fuel consumption, and to control the engine stall margin, the engine is provided with a variable stator vane (VSV) system. The first five HPC stages can change stator vanes angle depending on the engine operating regime. The system is controlled by two fuel controlled actuators, moving the VSV levers.

- The engine is also equipped with a variable bleed valve (VBV) in the booster. Through this system, booster air is vented into the secondary flow when the engine is in the start phase.

- In order to optimise engine fuel consumption and minimise deterioration, the HPT and the LPT are cooled externally with air bled from the HPC. Through control valves managed by the main engine control (MEC) or full authority digital electronic control (FADEC), HPT and LPT tip clearances are optimised for each engine regime.

- The first versions of the engine were mechanically controlled with the MEC and the power management control (PMC) jointly acting as the engine controlling system. Mechanically controlled engines can have their thrust ratings changed by replacing the MEC and the PMC.

Later, the CF6-80C2B1F version (powering the B747-400) introduced the first FADEC system on the CF6 family. Such electronically controlled engines have additional sensors on the engine, allowing a more precise control of systems, thereby decreasing specific fuel consumption (SFC). On such engines the MEC and PMC are substituted by the electronic engine control (EEC). FADEC family models range from the CF6-80C2B1F to the CF6-80C2B8F.

One of the CF6-80C2's notable features was the new commonality concept. Each variant is interchangeable between all the aircraft types it powers and higher thrust ratings can be achieved by turning the engine at a faster rate to increase air flow. This can be easily done by changing the rating plug in the EEC. PMC-controlled engines cannot be modified to FADEC standards.

Technical issues

It is common knowledge that the majority of the technical issues on the engine are within the HPC. Over the past years, several airworthiness directives (ADs) have been issued to manage problems with HPC spools:

- **HPC 3-9 spool inspections/installation:** Cracks have been found on the 3-9 spool at shop visits since 1997. Improved spools have been proposed to operators and based on IASG experience, only a few engines with old spools remain in operation.
- **HPC 10-14 spool inspection of the stage 14 web:** This spool has evidenced cracking in the stage 14 web when inspected at piece part level leading to the scrapping of such parts. The problem has been known to GE since 2003 and inspections are in place at the shop visit level to detect these cracks. A new spool design is not yet available.
- **VSV stage 5 lever arms and HPC VSV new bushing and washer:** This is a primary cause of aborted take offs and in-flight shut-downs. There have been several instances of lever arm fracture

and bushing wear. In both instances, the vane is free to move in the flow path, either generating an engine stall or physically breaking-up and liberating debris into the gas path which leads to engine damage. Since 2002, GE has provided newly designed VSV lever arms and bushings. IASG experience shows that around 30 per cent of the engine population still have the old configuration. For pre-modification engines, a repetitive on-wing inspection has to be carried out. Bushings to the new design can be installed only in some locations with the engine on-wing although IASG believes that this practice only provides minor benefit.

■ **HPC stage 3 to 5 blades:** A new design of blades was introduced into service by GE and experience has shown that these are susceptible to impact damage and when FOD is experienced they can fracture and cause further internal engine damage. Since 2001, GE has required a regular on-wing inspection to be carried and replacement of the complete set of blades at first shop visit. The latest blades have improved geometry and materials to reduce stress and cracking and IASG believes that half of the engine population has been modified to the new standard.

More recent issues include:

■ **Stage 11 HPC rear case wear:** Wear has been found on the HPC case at the stage 11 vane rail track. This problem can lead to vane separation and internal engine damage. An on-wing inspection is required and an inspection has to be carried out when the engine is removed for a shop visit. The fix for this problem is the introduction of differently coated stage 11 vanes.

■ **Inlet gearbox (IGB) Teflon seal:** A similar problem of IDG Teflon seal leakage and failure has been experienced by CF6-50 operators. Some

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CF6-80 engines

Engine model	Thrust rating (lb)	No. of engines	Flat rated temp (°F)	No. of aircraft	a/c type
CF-80C2A1	59,000	12	86	6	A300B4-600
CF-80C2A2	53,500	158	111	79	A310-200/-300
CF-80C2A3	60,200	22	86	11	A300B4-600
CF-80C2A5	61,300	148	86	74	A300B4-600R
CF6-80C2A5F	61,300	84	86	42	A300B4-600R
CF6-80C2A8	59,000	52	95	26	A310-300
CF6-80C2B1	56,700	36	86	9	VC25, B747-300
CF6-80C2B1F	58,090	1108	90	277	B747-400
CF6-80C2B2	52,500	66	90	33	B767-200/-300
CF6-80C2B2F	52,700	80	90	40	B767-200/-300
CF6-80C2B4	57,900	46	90	23	B767-200/-300
CF6-80C2B4F	57,900	52	90	26	B767-200/-300
CF6-80C2B5F	60,800	52	86	13	B767-200/-300
CF6-80C2B6	60,800	240	86	120	B767-300
CF6-80C2B6F	60,800	266	86	133	B767-200/-300
CF6-80C2B7F	60,800	110	86	55	B767-200/-300
CF6-80C2B8F	61,960	74	86	37	B767-400
CF6-80C2D1F	61,960	351	86	117	MD11

IGB horizontal gear shafts have been found to be dis-bonding resulting in the loosening and separation of pieces of the Teflon seal. Ultimately, the scavenge screen becomes clogged or the IGB fills up with oil, leading to oil in the HPC and in the cabin. GE has indicated thresholds for IGB Teflon seal replacement at shop visit, depending on the hour-to-cycles ratio operated by the engine.

■ **Stage 1 HPT disk inspection:** This problem appeared in 2000 with some cracks being found on disks with particular part numbers during shop level inspections. Investors need to be aware that some part numbers are more likely to be scrapped because of this additional inspection being carried out during a shop visit.

■ **HP Stage 2 nozzle:** Old HPT nozzles were cracking in the outer platform producing rearward movement of the airfoil and inner platform causing contact with the leading edges of the HPT stage 2 blades, resulting in blade fracture. For a few years now, GE has made available a new material vane and IASG believes that all operators are replacing the vanes at the shop visit. Few engines have the old configuration still installed.

■ **Thicker LPT shroud:** This problem had already been experienced on CF6-50 engines with old LPT Stages 2, 3 and 4 shrouds not being efficient in containing of LPT blades. Since 2001, GE has released a thicker shroud to solve the problem. Operators are incorporating these modifications on an attrition basis although the LPT module is not accessed every shop visit.

■ **HPT stage 2 blades:** Certain blades with particular part numbers have experienced airfoil and shank separations. This is an old problem and GE has provided new blades since 1999. IASG believes that only a few engines have the old blades still installed.

■ **Turbine rear frame (TRF) oil coking:** Bearing failure as a result of oil starvation is a major issue on the engine and GE has issued several recommendations to operators on this subject. The main issue is the oil coke found on the TRF which causes clogging of the oil supply lines.

The CF6-80C2 is the most successful generation of the CF6 and has acquired the highest market share on all of the aircraft types it powers. It has also been at the forefront of 120 minute and 128 minute ETOPS flight qualification on the Airbus A300, A310-300 and B767-200/-300/-400. The CF6-80C2 series has thrust ratings between 52,000lb and 62,000lb.

All variants of the CF6-80C2 now have 180-minute ETOPS approval for the Airbus A300B4-600, A310-200/-300 and B767-200/-300/-400. With the exception of the A300, the CF6-80C2 has the majority market share on all widebody twins. The biggest factor in this dominance was Pratt & Whitney's requirement to develop a successor to the JT9D and its subsequent need to accumulate several thousand hours of operating experience with the PW4000 before it could be certified for ETOPS. The CF6-80C2 was certified for 180-minute ETOPS routes 12 months earlier than the PW4000 giving the CF6 a decisive lead in the market.

Value and maintenance cost

For the potential lessor and debt provider, the CF6-80C2 appears to be a robust asset with a strong market base which has a very good credit rating. Since the FADEC family is more recent and flexible, its value is proportionately higher. In IASG's experience, General Electric will not give significant discounts on new engines but will add value through 'concessions'. One should expect to pay in the region of $6,250,000 for a new engine depending on the manufacturer's concessions. Such concessions can be healthy and include significant discounts on spare parts, accessories and enhanced warranty coverage. A spare QEC will cost in the range of $750,000.

Although the engine had a very good reliability record at the beginning of its life, the -80C2 suffered several HPC spool problems, as mentioned above. Several ADs have been released to manage such problems but now that solutions are available the reliability of the -80C2 is increasing to even higher levels. CF6-80 maintenance shop visits will be few and far between as gas path deterioration is commendably low when the engine is utilised on long-haul operations.

When shop visits do occur, however, one should expect an invoice in the region of $1,600,000 to $1,800,000 for first run engines. Subsequent shop visits will see such invoices increase by 10 per cent. Maintenance reserves need to be in the region of $178 per cycle plus $115 to $165 per hour depending on engine thrust power de-rate policies, airframe weight, the particular application of the aircraft and the hours-to-cycle ratio of the lessee or loan recipient.

IASG has seen first-run engines stay on-wing for between 20,000 and 24,000 hours prior to requiring maintenance for performance restoration. Second and subsequent runs should achieve between 16,000 and 18,000 hours on-wing depending on the hours-to-cycle ratio and the operational environment.

Future

The future of the CF6-80C2 engine appears healthy for the next 10 years or so, or until such time that next generation engines proliferate with better operating economics. Only retrospective emissions and noise legislation could affect the natural operating economic life cycle of this engine and there are still some re-engine applications that have yet to be explored. There is fluidity in the market for the engines and for the aircraft in which they are installed and there is no predominant market monopoliser to deter would-be-investors or buyers.

The CF6 programme represents the most successful programme in GE's history. The current installed base, the number of orders in GE's books and the new versions released will guarantee that GE retains the lead in this market segment for the foreseeable future. The CF6 market is stable and wide and thus offers a good opportunity for investors.

The forgoing is a shortened version of a much larger IASG assessment of the CF6-80. In the event that any reader has questions relating to the CF6 family please do not hesitate to contact Paolo Lironi on email: *paolo@iasg.co.uk*. ■