CF6-80E: Past, present and future

Paolo Lironi, senior technical manager and head of powerplant consulting at IASG, investigates the latest derivative of arguably one of the most successful current build powerplants in the industry. He considers its composition, development, maintenance costs, values and future prospects.

The CF6-80E1 engine model was developed for the A330 family and is the highest thrust and most modern version of the CF6-80 family of engines to have been produced by General Electric (GE). The CF6 family represents the most successful project within GE and most probably within the whole aero-engine industry. The CF6-80E1 is a third generation derivative which has benefited from previous family applications, in particular from the CF6-80C2 engine model that has accumulated in excess of 120 million flying hours.

Powerplant description

The -E1 engine model has a classic two-shaft, high bypass-ratio, axial-flow turbofan design. The engine is composed of five main modules:

- The fan module consists of a 96-inch diameter fan frame, aluminium fan blades and a 4 stage booster. The fan frame is one of the two main structural parts of the engine;
- The core module is composed of a 14 stage high-pressure compressor driven by the high-pressure turbine, while the low-pressure shaft is driven by the low-pressure turbine. The high-pressure stator, the compressor rear frame, the combustion chamber and the stage 1 nozzle guide vanes are also part of the same module;
- The high-pressure turbine module has two stages and blades are made of different materials based on the same standard. The nozzle guide vanes are also part of the module;
- The low-pressure turbine module has five stages, one more than the -C2 model. The turbine frame is the second structural part of the engine;

Through the inlet gearbox, which is part of the fan module, torque is transferred to the accessory gearbox module where the engine-mounted components are installed. The accessory gearbox module is mounted on the bottom of the HP compressor to reduce engine ground clearance when the engine is installed.

The engine is equipped with a second-generation full authority digital electronic control (FADEC II). The main component in the computerised control system is the engine control unit (ECU). The ECU receives inputs from several sensors located on the engine, the air intake and the aircraft. These inputs are analysed and engine actuators are activated by the ECU to improve engine fuel consumption and to optimise engine airflow efficiency.

Technical development

The first version to be produced was the -E1A2, which was installed on the A330-300. The second version was the -E1A4, while the -E1A3 model was launched in 2002. In 2004, the -E1A4B was then proposed to customers. The latest version to be made available is the -E1A4B which has the capability to provide additional power for short periods of time (thrust bump). The launch operator of the -E1A2 was Air Inter of France which ordered 19 aircraft and then reduced its order to only four aircraft.

The -E1 version shares 60 per cent of core parts with the -C2 version. The

Table 1: Engine applications

Engine model	Thrust rating (lbs)	Number of Engines	Number of aircraft	Types of air-craft
CF6-80E1A2	68,000	42	21	A330-300
CF6-80E1A3	72,000	62	31	A330-200/300
CF6-80E1A4	70,000	48	24	A330-300/-200
CF6-80E1A4B	70,000	4	2	A330-300/-200

Table 2: Airbus A330 engine models

Engine model	No. of engines	No. of aircraft	Aircraft types
CF6-80E1A2	8	4	A330-201
CF6-80E1A4	26	13	A330-202
CF6-80E1A3	62	31	A330-203
PW4168A	102	51	A330-223
TRENT 772B-60	138	69	A330-243
CF6-80E1A2	38	19	A330-301
CF6-80E1A4	6	3	A330-302
CF6-80E1A3	8	4	A330-303
PW4164	16	8	A330-321
PW4168	52	26	A330-322
PW4168A	58	29	A330-323
TRENT 768-60	12	6	A330-341
TRENT 772-60	36	18	A330-342
TRENT 772B-60	70	35	A330-343

Table 3:CF6-80E1 operators

Airline	Total	Ordered	Delivered	Cancelled
Aer Lingus	14	7	7	0
Air Calin	4	2	2	0
Air France	16	8	8	0
Air France	14	8	6	0
Air Inter	4	15	4	9
Aer Inter Europe	0	0	0	0
China Airlines	16	14	2	0
Continental Airlines	0	13	0	13
Eva Air	15	10	5	0
GE Capital Aviation Services	1	3	0	2
ILFC	3	4	0	1
KLM Royal Dutch Airlines	6	6	0	0
Philippine Airlines	16	8	8	0
QANTAS	25	17	11	3
QATAR Airways	37	28	10	1
QATAR Amiri Flight	2	1	1	0
TAM Linhas Aereas	8	4	4	0
Turkish Airlines (THY)	5	5	0	0
AIR Madrid	2	0	2	0
Etihad	2	0	2	0

core section of the -E1A2 is the same of the -C2 engines. This particular engine model has the same strengths and problems as the C2 model, namely: HP compressor spool cracking; NGV cracking and sagging; and HP turbine disk cracking.

With the experience gained with -E1A2, when GE contemplated the increased thrust -E1A4 engine it realised that the hot section needed to be improved upon and modified to offer better levels of reliability. GE designed and tested a new high-pressure turbine module and this consisted of a revised design including a new HPT stage 1 disk and a new stage 2 disk and blades. Once tests were complete, GE proposed to operators that the name for the engine should become R88, after the new material used in the turbine section. This new turbine design was also installed on the CF6-80C2B8F engine model, powering the latest version of Boeing 767, the -400, operated by Delta Air Lines and Continental.

The HP compressor of the -E1A4 also had to be modified. Original production engines were manufactured with a two-part stage 10 - 14 HP compressor spool (a stage 10 HP compressor disk and an 11-14 HP compressor spool). Once the new one-part HP compressor stage 10-14 spool was introduced on the CF6-80C2 engine, it was transferred to the -E1 model.

Applications

The -E1 engine model can be installed on the Airbus A330-200 and -300 aircraft:

The same aircraft can be powered by a Rolls-Royce engine or a Pratt & Whitney engine. Fifteen airlines currently operate the -E1 engine model. In 2004 the largest operator of the -E1 was Air France, while Qatar Airways and Qantas were jointly second largest. If the orders and options are converted to orders, the biggest operators (Qatar, Air France/KLM and Qantas) will operate 48 per cent of the total fleet.

During early development, operators preferred the RR Trent 700 and PW4100 engine models to the CF6-80E1 on the A330 application. At the end of 2004, Rolls-Royce was leading on the A330 with 41 per cent of the market with P&W in second place and the CF6-80E1 in third position. But during 2004, GE won the largest percentage of A330 orders. Also, Air France and Qatar have significantly increased their orders, and KLM and China Airlines have been added to the customer list. This will mean that over the coming five years the majority of newly delivered A330s will be GE powered. It is evident from Figure 2 that GE has been pushing hard to increase sales of this engine model, in order to increase the operator base and fleet size. By the end of 2009, the picture could be very different to what it is today.

Main technical issues

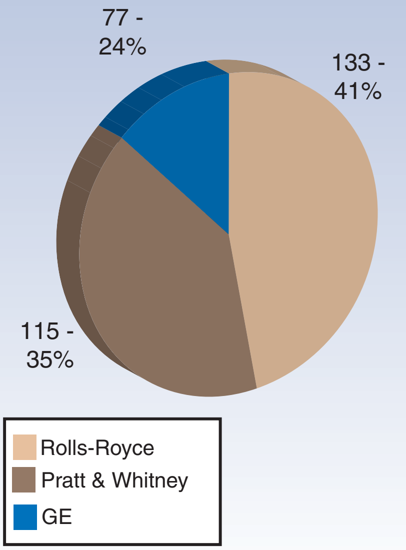
Since entry into service the engine has shown few significant problems. The core -80C2 engine has been extended to its design limit with an increase of 10 per cent in thrust on the largest thrust engines, the CF6-80C2B7F and CF6-80C2D1F. Typically, first run engines were accumulating 1,300 cycles / 5,200 hours. The main causes for removal were:

1 High vibration: Several operators experienced problems with vibration. Cabin comfort was the main issue.
2 Nozzle guide vanes (NGVs): This was a common problem on -80C2 engines. On the E1 fleet, one particular involved the severe sagging of stage 2 NGVs causing the HP turbine stage 2 blades to fail, and an uncontained failure on the LP turbine Module. Subsequently, the AD applicable to C2 engines was read across to E1 engines. Inspection and re-inspection intervals for borescope inspection were subsequently revised twice to ensure that the intervals were at their correct levels.

While the above problems have almost completely been eradicated, the following problems are still persisting:

1 Variable stator vanes (VSVs): This has been an ongoing problem for the CF6-80 family. The latest solution proposed to operators has not had sufficient feedback to confirm its validity, although first indications are encouraging. GE has requested operators to perform an on-wing inspection to monitor the deterioration of the VSV bushings. Two main problems are: wearing and fracture of lever arms whereby an uncontrolled vane could rotate freely and create an engine surge; and wear in the internal & external bushing VSV bushings which permitted vanes to liberate.
2 Fan mid shaft Teflon seal: Several CF6-80C2 engines have suffered from oil leakage at the fan mid-shaft seal. Since the basic design is similar to the CF6-50 engine model, the nature of the problem and the means of controlling it have been read across to the -80C2. There have been no problems of this

Figure 1: Number of A330 aircraft delivered - divided by engine model



source: IASG

nature on CF6-80E engines although magnetic chip detector inspection has been specified and if Teflon is found, the engine has to be repaired. Also, a 'Commercial engine service memorandum' has been issued by GE defining the threshold for inspections and parts replacement.

3 Turbine rear frame (TRF) cracking: Some of the highest cycle engines have experienced cracks in the TRF. Some parts had to be scrapped and GE has been working to increase allowable crack limits and to better understand the cause of the cracking. On-wing inspections are now requested. No final solution is available at this stage.

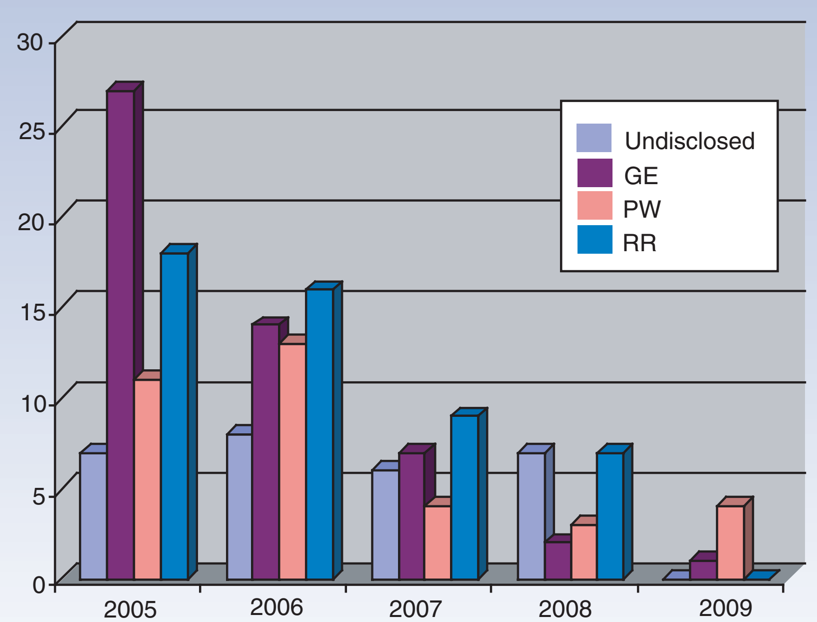
Maintenance costs

For several reasons IASG believes that the costs of maintenance for this engine are going to decrease over the coming years. First of all, there will be an increase in the number of flying engines. Then there will be other MROs offering maintenance on this engine model and competition will most likely drive costs down. Presently, only GE West Coast Operations and GE Caledonian have the complete capability of repairing CF6-80E1 engines. It should be noted, however, that the GE Caledonian test cell is not as yet certified to test the 80E1 and that engines therefore have to be transported to Snecma Paris for testing. IASG understands that GE is currently considering the possibility of having a third engine shop in Asia, possibly in cooperation with Eva Air.

There are no significant Airworthiness Directives or repetitive maintenance burdens affecting the -E1 variant. Even though the -E1 model shares a lot of parts with the more common -C2 engine, the -E1 version has not received significant interest from the MROs, probably because of the low fleet size. It is understood that part of the Air France - KLM deal for GE powered A330s was to create a fleet size which would allow Air France Industries (AFI) or KLM Maintenance to enter into the -E1 MRO market. The KLM engine shop has recently started performing work on the -E1 engine, while AFI has been designated a GE90 repair station. IASG believes that, based on scheduled removal rates, future shop visits should be sufficient to guarantee enough work for three shops worldwide. However, based on IASG estimations, no additional MRO will enter the market due to lack of work. GE, with KLM as an alternative to the OEM, will most probably dominate the future aftermarket.

From its experience, IASG notes the typical cost of a shop visit for this engine model is 10 per cent higher than a -C2 version. A typical shop visit is therefore in the region of $1.8 to $2.1 million, depending on shop loadings and prevailing commercial arrangements. GE is

Figure 2: Future A330 deliveries



source: IASG

believed to be promoting the upgrading of existing engines to the latest standard of HP turbine and HP compressor. Costs for the upgrades are being kept under wraps at this time although they will obviously apply to spare engines also. Maintenance costs per flight hour are in the region of $150 to $190 per hour plus $340 to $350 per cycle depending on sector lengths, thrust de-rate policy, operating weights and operating environment. LLP costs are likely to remain high because of the absence of a tertiary market.

Spare engines

Spare engines are owned by big operators and by GECAS. The cost of a new engine is around $12 million and small airlines within the A330 fleet cannot afford to carry such high capital costs. While there have been attempts to create spare engine pools they have been unsuccessful. Information on lease rates is difficult to come by but IASG has seen documented lease rates in the high $80,000 per month, depending upon the length of the lease and the number of engines involved. This is not an engine that IASG would advise engine lessors to invest in unless it is on a full payout basis with a view to part out values at the end of a long lease term.

Future

Over the coming years, the number of operators will increase but fleet size will remain relatively small. This should enable increased pooling of spare engines if airlines and alliances can come to a point where they share common ground. As can be seen from the deliveries to date and the predicted future deliveries, the -E1 is still in the first part of its product life cycle, even though it may be halfway through its technical life cycle. Based on the application and on the current fleet, IASG estimates that the engine model will be seen in future airports for at least the next 15 years, since it is compliant with the associated emissions and noise legislation up to that point and probably beyond.

IASG believe that the introduction of the Boeing 787 and Airbus A350 will threaten the longevity of the A330 to some degree. Boeing has selected the Rolls-Royce Trent 1000 and General Electric GEnx engine models on the B787 and Airbus has specified the GEnx engine for the A350. Consequently the -E1 will be a less interesting product and will be at the end of its technical life cycle within the next seven years. The residual value of the A330 and the installed -E1 powerplants will come under continued downward pressure when the B787 and A350 deliveries come on line.

Conclusions

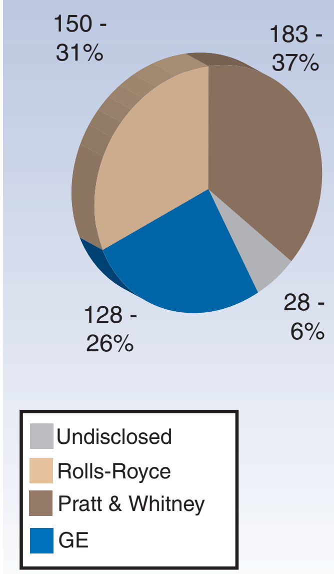
IASG notes the engine has had only minor problems during the introductory phase.

General Electric has been marketing the engine heavily to increase the installed base. As a result, all recent disclosed orders of the A330 are going GE's way and the majority of those that are undisclosed are likely to be GE powered. The customer base will increase and, in all probability, GE will dominate the associated spare engine and engine maintenance business.

Operators will need to agree long-term rates with GE or any other MRO that chooses to enter the -E1 market, to prevent prices from inflating unduly in years to come. Owners need to be vigilant with respect to future values and those engines on operating leases should not to be exposed to refurbishment costs without suitable terms and conditions being agreed with GE or the engine MRO.

IASG is of the opinion that the CF6 family represents the most successful programme in GE history. The current installed base, the number of orders in GE books and the new versions released will guarantee GE leadership of this market segment. The CF6 family market is stable and broad which may appear to be a guarantee for many investors. However, the powerful, technically competent and reliable CF6-80-E1 engines may be too niche for some investors, and operators need to be vigilant of aftermarket issues.

Figure 3: Deliveries at the end of 2009



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