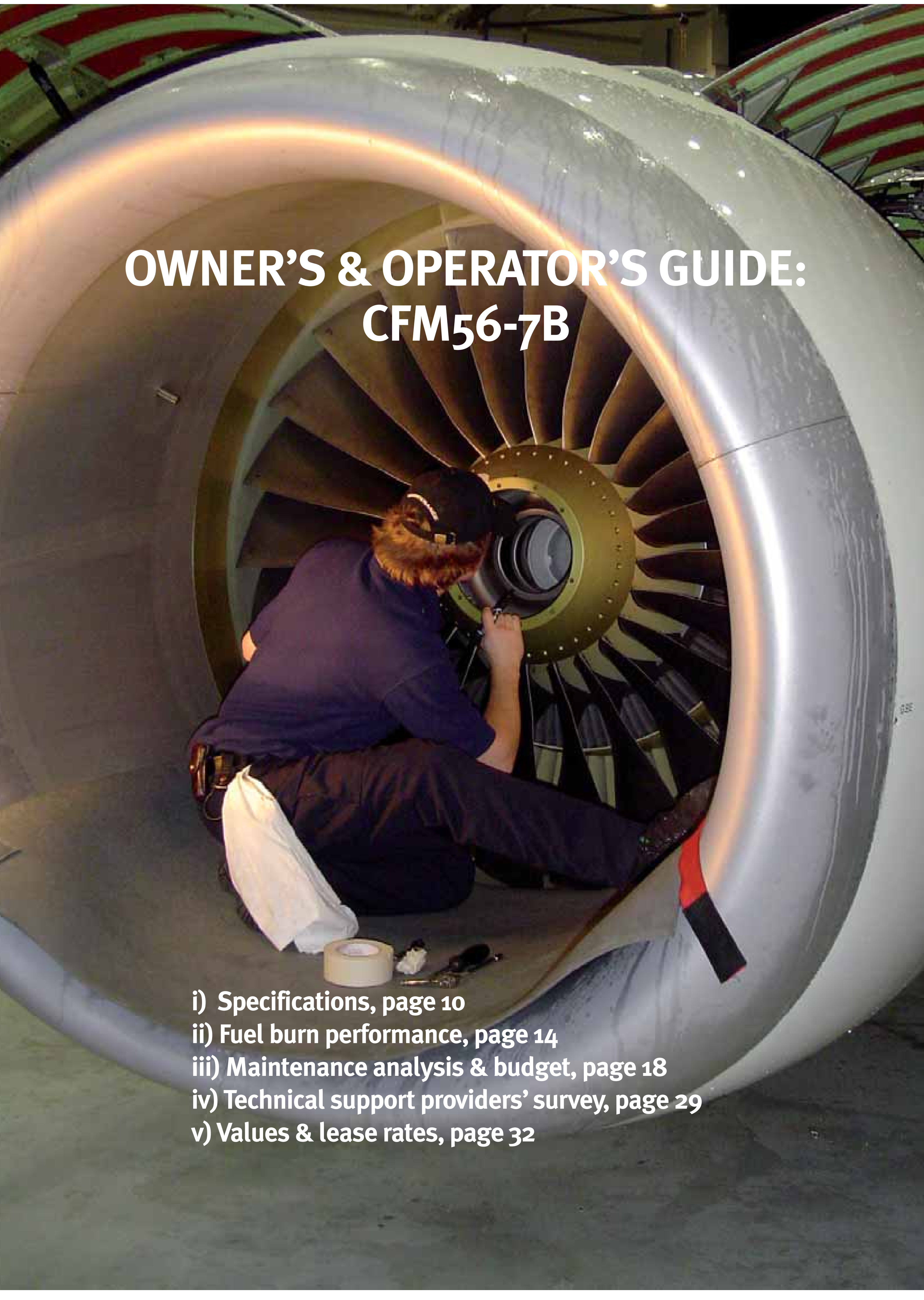

OWNER'S & OPERATOR'S GUIDE: CFM56-7B

CFM56-7B series specifications

The CFM56-7B has six main variants, with thrust ratings between 19,500lbs and 27,300lbs. These variants and the families features are described.

The CFM56-7B series has six main variants, each of which has several sub-variants. A description of the family is given, together with their thrust ratings, flat rating temperatures and exhaust gas temperature (EGT).

The CFM56-7B for the 737NG family is closely related to the CFM56-5B, which powers the Airbus A320 family. The first -7B engines went into service in 1997 on the first 737-700 with Southwest Airlines. There are almost 2,560 737NGs powered by these engines in service. There are another 2,200 CFM56-7B-powered 737NGs on firm order.

Model groupings

The CFM56-7B series uses a standard two-shaft design with a 61-inch diameter fan. Behind the fan is a three-stage low pressure compressor (LPC), a nine-stage high pressure compressor (HPC), a one-stage high pressure turbine (HPT), and a four-stage low pressure turbine (LPT) to drive the fan and LPC.

The CFM56-7B series has six thrust ratings ranging from 19,500lbs to 27,300lbs thrust *(see table, page 12)*. Bypass ratios vary from 5.5 for the lowest-thrust-rated version, to 5.1 for the highest-rated model.

There are essentially two hardware-differentiated groups: engines that were built prior to the Tech56 modification, and those that have the Tech56 modification. Engines with the Tech56 modification all have a '/3' suffix at the end of their model designation.

The Tech56 engines incorporate an improved-emissions single-annular combustor, a re-designed compressor, and re-designed HPT rotor. Both main production groups include sub-variants covering the six available thrust options.

The thrust version is indicated by a two-digit number immediately following 'CFM56-7B'. The pre-Tech56 thrust variants are therefore as follows: CFM56-7B18 (19,500lbs thrust); CFM56-7B20 (20,600lbs thrust); CFM56-7B22 (22,700lbs thrust); CFM56-7B24 (24,200lbs thrust); CFM56-7B26 (26,300lbs thrust); and CFM56-7B27 (27,300lbs thrust) *(see table, page 12)*. The post-Tech56 model designations and thrusts are exactly the same, except for addition of the '/3' suffix.

Within the two groups, the thrust rating is determined by the data entry plug of the full-authority digital engine control (FADEC) unit. The engine can therefore be easily and quickly re-rated, which facilitates its management and means that it can be used to extend removal intervals between shop visits. This means that the engine can first be used on the 737-900 with one of the highest thrust ratings, and when its EGT margin has been exhausted it can be re-rated to a lower thrust rating as used by the 737-800, -700, and -600. This process allows it to regain some EGT margin that allows it to operate for an extended period.

Additionally, there are sub-variants with modified take-off power management and EGT capabilities for specific applications, such as the Boeing Business Jet. These options are indicated by additional suffixes (after the '/3') such as: 'A'; 'B1'; 'B2'; 'B3'; 'B1F'; and 'B2F'. For example, a 'CFM56-7B27/B1' is the same as -7B27, but with optimised power management at take-off. A 'CFM56-7B26/B1' is the same as a -7B26, but optimised for a business jet mission. Another example is the 'CFM56-7B27A' which is the same as the -7B27, except that it has increased capability for gearbox power extraction. Meanwhile a 'CFM56-7B26/3B2F' is the same as the -7B26/3B2, except for increased EGT limits, which are facilitated by modifications to the FADEC programming.

It should be noted that, unlike its CFM56-5B counterpart on the A320 family, the -7B series does not include an engine variant with a '/P' suffix. The '/P' engine incorporated a redesigned HPC compressor with '3-D aero' blades, a new HPT blade with increased cooling, and a redesigned LPT stage 1 nozzle. The equivalent modifications were already incorporated in baseline -7B engines. Today the '/P' standard has been superseded by the Tech56's '/3' enhancements, which were standard in production engines for the A320 and 737NG from 2007.

For the sake of completeness, it is also worth mentioning a rare '/2' variant which had earlier been offered on the CFM56-7 series. This uses a dual-annular combustor (DAC) for reduced NOx emissions. This option did not prove

There are six main variants of the CFM56-7B. Within each one there are several sub-variants, but the two main groups of engines are the original non-Tech56 modified engines and more recent Tech56 engines. The -7B26 is the most numerous in the global fleet of about 5,100 engines.

CFM56-7B SERIES THRUST RATING & SPECIFICATION DATA

Engine model	Thrust lbs	Flat rate temp	EGT redline (Indicated)	EGT redline (Actual)	Notes	737NGs in service
CFM56-7B18	19,500	30	950	857	Base 19,500lbs model	0
CFM56-7B/3	19,500	30	950	857	Tech56 insertion model	0
CFM56-7B20	20,600	30	950	884	Base 20,600lbs model	125
CFM56-7B20/2	20,600	30	950	894	Dual annular combustor model	0
CFM56-7B20/3	20,600	30	950	884	Tech56 insertion model	0
CFM56-7B22	22,700	30	950	886	Base 22,700lbs model	509
CFM56-7B22/2	22,700	30	950	896	Dual annular combustor model	0
CFM56-7B22/B1	22,700	36	950	886	Extended take-off flat temperature	0
CFM56-7B22/B2	22,700	50	950	920	Extended high altitude and temperature above corner point temperature	0
CFM56-7B22/3	22,700	30	950	886	Tech56 insertion model	4
CFM56-7B22/3B1	22,700	36	950	886	CFM56-7B22/B1 with Tech56	0
CFM56-7B22/3B2	22,700	50	950	920	CFM56-7B22/B2 with Tech56	0
CFM56-7B24	24,200	30	950	908	Base 24,200lbs model	481
CFM56-7B24/2	24,200	30	950	918	Dual annular combustor	0
CFM56-7B24/B1	24,200	41	950	908	Extended take-off flat temperature	0
CFM56-7B24/3	24,200	30	950	908	Tech56 insertion	24
CFM56-7B24/3B1	24,200	41	950	908	CFM56-7B24/B1 with Tech56	0
CFM56-7B26	26,300	30	950	920	Base 26,300lbs model	919
CFM56-7B26/2	26,300	30	950	930	Dual annular combustor	1
CFM56-7B26/B1	26,300	30	950	920	Extended take-off flat temperature	35
CFM56-7B26/B2	26,300	35	950	920	Extended high altitude and temperature above corner point temperature	0
CFM56-7B26/3	26,300	30	950	920	Tech56 insertion	53
CFM56-7B26/3B1	26,300	30	950	920	CFM56-7B26/B1 with Tech56	0
CFM56-7B26/3B2	26,300	35	950	920	CFM56-7B26/B2 with Tech56	0
CFM56-7B26/3F	26,300	30	950	940	CFM56-7B26/3 except for increased EGT limits	0
CFM56-7B26/3B2F	26,300	30	950	940	CFM56-7B26/3B2 except for increased EGT limits	0
CFM56-7B27	27,300	30	950	920	Base 27,300lbs model	314
CFM56-7B27/2	27,300	30	950	930	Dual annular combustor	0
CFM56-7B27/B1	27,300	30	950	920	Optimised power management take-off	78
CFM56-7B27/B3	27,300	30	950	920	Optimised power management take-off	2
CFM56-7B27A	27,300	30	950	920	Increased gearbox extraction	0
CFM56-7B27/3	27,300	30	950	920	Tech56 insertion	9
CFM56-7B27/3B1	27,300	30	950	920	CFM56-7B27/B1 with Tech56	0
CFM56-7B27/3B3	27,300	30	950	920	CFM56-7B27/B3 with Tech56	0
CFM56-7B27/3F	27,300	30	950	940	CFM56-7B27/3 except for increased EGT limits	0
CFM56-7B27/3B1F	27,300	30	950	940	CFM56-7B27/3B1 except for increased EGT limits	0

popular, however, and only one aircraft is listed with these engines, according the ACAS fleet database.

The specifications of all engine models are summarised *(see table, this page)*.

Flat rating and EGT calibration

Engine ratings are based on calibrated stand performance (sea level static). Take-off thrust is nominally independent of ambient temperature (or 'flat rated') up to ambient temperatures of International Standard Atmosphere (ISA) + 15°C (30°C) for all models, with some exceptions. The -7B22/B1 and -7B24/B1 are flat rated up to ISA + 21°C (36°C), the -7B24/B1 and -7B24/3B1 are flat rated up to ISA + 26°C (41°C), the -7B26/B2 is flat rated up to ISA + 20°C (35°C), and the -7B22/B2 and -7B22/3B2 are flat rated up to ISA + 35°C (50°C).

Furthermore, while the 'indicated' maximum permissible take-off EGT for all -7B series engines is 950°C, these take-off EGT redlines are accomplished in the engine control unit (ECU) software via an EGT 'shunt' and an EGT 'trim' applied to the actual value. The actual EGT and indicated take-off EGT redline value of 950°C for each of the models are summarised *(see table, this page)*.

The EGT shunt adds 30°C to actual measured engine EGT on CFM56-7B and -7B/3 series engines, while it adds 10°C to actual measured engine EGT on the CFM56-7B/3F series engines, and adds 20°C to the actual measured engine EGT on the CFM56-7B/2 series engines to provide an indicated EGT level.

This EGT shunt is triggered above a core speed of 8,500RPM for all CFM56 series engines. In addition, EGT 'trim', which is applied only under certain operating conditions, adds specific values to the indicated EGT levels. This EGT trim is only triggered from Mach 0 to 0.40, and when the core speed is greater than 11,200RPM. This function is only applicable for certain models.

It should also be noted that maximum continuous thrust, which is higher than take-off thrust, is nominally independent of ambient temperature (or flat rated) up to an ambient temperature of ISA + 10°C (25°C) for all models. Actual EGT is again adjusted using the shunting technique to realise the indicated maximum permissible maximum continuous EGT of 925°C for all engines. This EGT shunt is triggered above 8,500RPM core speed for all CFM56 series engines.

Tech56: 'Tech Insertion'

The major upgrade and new production standard of the CFM56-7B series is the 'Tech Insertion' (TI) upgrade, which entered into service in the middle of 2007. The package includes a new '3D-Aero' compressor blade design, an enhanced single-annular combustor, and an improved blade and low pressure nozzle design, which result in lower interaction losses between high and low pressure turbines.

According to Stephane Garson, general manager of product marketing Commercial Engines for the CFMI partner Snecma, TI aims to reduce

The six main CFM56-7B variants have the same basic hardware, and thrust rating is only changed through programming of the engine's FADEC unit. Engines rated with high thrusts can be re-rated down to lower thrusts after EGT margin is eroded to increase on-wing life.

maintenance costs by up to 12% (from better durability and time-on-wing). The improved engine will also burn up to 1% less fuel and exhibit a reduced performance deterioration rate. The newer standard is fully intermixable and interchangeable with existing configurations, and will also reduce NOx emissions by 20-30% (CAEP VI compliance certified).

Garson explains that the TI upgrade has created a new engine model called the '/3'. "At the time of entry into service, the catalogue price was the same as that of the previous model for the same thrust rating," explains Garson. "Moreover, when a customer wants to upgrade his engine to the /3 standard during a shop visit, the price of the new parts is the same as the price of the previous standard. For example, the price of the life limited parts (LLP) set remains unchanged whenever you buy a /3 standard or the previous standard."

According to Snecma, LLP lives for the TI package are as follows: the fan disc, booster spool and shaft are all 30,000EFC; in the HPC section, the front shaft, stage 1-2 spool, stage 3 disc, stage 4-9 spool and CDP seal are all 20,000EFC; in the HPT, the front shaft, front air seal, disc, and rear shaft are all 20,000EFC; and in the LPT section, the shaft, conical support, and stage 1-4 discs (each) are life-rated at 25,000EFC. In addition, the life-limits for the LPT stator LLPs (turbine rear-frame and LPT case) are dependent on the specific thrust variant.

EGT margin & OAT

As with other models of the CFM56, the -7B's FADEC is programmed to allow the engine to deliver its maximum thrust rating up to, but not exceeding, the 'flat-rate' corner point temperature. For all these engines, their EGTs increase at a rate of about 3.5 degrees per one degree increase in outside air temperature (OAT). The EGT therefore rises to a maximum allowable level, which is lower than the engine's red-line EGT. The latter is the actual EGT redline which varies between 857 and 940 degrees centigrade, and which must never be exceeded *(see table, page 12)*. The difference between the engine's actual EGT and the red-line temperature is the EGT margin, and is measured at the reference point of the corner point temperature. The engine will actually have a higher EGT margin for OATs lower than the corner point.

For OATs higher than the corner point temperature, the FADEC is programmed to keep the engine's EGT constant by reducing thrust output. This maintains a constant margin between the actual EGT and the certified red-line temperature, despite the higher OAT. The engine's EGT margin is therefore constant for all temperatures above the OAT. The engine's thrust is reduced, however, for OATs higher than the corner point temperature.

The EGT margin increases by about 3.5 degrees for every one degree drop in OAT below the corner point temperature, however.

Moreover, as the engine's condition deteriorates as a result of operation, the EGT, up to the corner point temperature, also gradually increases. The EGT margin therefore decreases by the same amount. The engine can remain in operation until the EGT margin has reduced to zero. The engine will still actually have some available EGT margin at OATs lower than the corner point temperature.

EGTs in operation are highest for the highest rated -7B27 engines, which therefore have the lowest EGT margin. Conversely, the lowest rated -7B18 has the highest EGT margin. It should be noted that to suit certain operations, particularly for the BBJ's low-cycle, high-thrust business-jet mission requirements (for short take-off field length and rapid hot-and-high climb-rate), CFMI offers versions of the -7B which have extended EGT capabilities, that is, maximum take-off thrust above the nominal flat-rate temperature of 30°C for the passenger applications. Examples of these extended flat-rate corner points include: CFM56-7B22/B1 with 36°C; CFM56-7B22/B2 with 50°C; CFM56-7B24/B1 with 41°C; CFM56-7B26/B2 with 35°C.

In general, EGT margins are at their highest levels when the engines are new. The rate at which EGT margins decline with engine deterioration determines life on-wing. The highest rated -7B27 models on the heaviest 737-900s can logically expect to have the shortest removal intervals. "The removal interval will depend on the thrust of the engine," says Garson. "-7B18 to -7B24 engines, with the lower ratings, will most likely see their removal interval driven by flight cycles on-wing when they reach their LLP life limit.

"The -7B26 and -7B27 engines, with the higher ratings, will in all probability see removal intervals driven by flight hours on-wing and EGT margin loss, when performance restoration will be requested. It obviously also depends on flight hours:flight cycle ratio," continues Garson.

Moreover, since the EGT margins of engines following shop visits are typically 60-80% of original levels, second and subsequent removal intervals are therefore shorter than the first intervals. High EGT margins of lower-rated variants allow engines to achieve lower maintenance costs, and allow aircraft to operate with fewer performance restrictions in high ambient temperatures compared to their higher-rated family members. AC

CFM56-7B fuel burn performance

The fuel burn performance of the four main 737NG variants are each assessed with their most popular variant of the CFM56-7B. The aircraft family has similar fuel burn efficiency to the A320 family.

The CFM56-7B series of engines powers all members of the 737-NG family, which comprises the 737-600, -700, -800 and 737-900. There are essentially two hardware-differentiated groups of the CFM56-7B: non-Tech56 modified engines; and Tech56 engines. Tech56 models all have a '/3' suffix at the end of the model designation. They incorporate an improved-emissions single-annular combustor, and a re-designed compressor and high pressure turbine (HPT) rotor. This analysis studies the performance of the most widespread of the two production standards, which is the pre-Tech56 variant, without the /3 suffix. Although there are six Federal Aviation Authority (FAA) certified thrust ratings of the CFM56-7B series *(see CFM56-7B specifications, page 10)*, this analysis examines only the following four thrust ratings: CFM56-7B22 (22,700lbs thrust), CFM56-7B24 (24,200lbs thrust), CFM56-7B26 (26,300lbs thrust), and CFM56-7B27 (27,300lbs thrust).

All engines within the pre-Tech56 subgroup have identical hardware, and the thrust capabilities are merely 'paper changes', which means that different thrust ratings depend on the operator-specific contract and certification documentation. The result is that airlines can choose from various permutations of different engine thrust ratings and different aircraft maximum take-off weights (MTOWs). Only where mission demands dictate the highest possible thrust level, such as hot-and-high departure or limited runway length profiles, will an operator be prepared to pay for the most powerful thrust option.

In this fuel burn analysis of aircraft powered by CFM56-7Bs, only one base engine for each aircraft model is studied. The reason that alternative thrust options are not included is that they would make very little difference, if any, to the sector fuel burn results, given that the aircraft and engine hardware are identical.

Sectors analysed

The route used to analyse these different aircraft is Toronto (YYZ) to Atlanta (ATL). Aircraft performance has been analysed in both directions to illustrate the effects of wind speed and direction on the actual distance flown, also referred to as equivalent still air distance (ESAD). The chosen city-pair is typical of many 737 family operations, since this sector has a block time of about one hour and 40 minutes when flying at a long-range cruise speed of Mach 0.79. In this case the diversion or alternate airports used are Nashville (BNA) when travelling to Atlanta, and Pittsburgh (PIT) when travelling to Toronto.

The flight profiles in each case are based on domestic FAR flight rules, which include standard assumptions on fuel reserves, diversion fuel (for the alternate airports mentioned above), plus contingency fuel, and a taxi time of 20 minutes for the whole sector. This is included in block time. Actual flight time is affected by wind speed and direction, and 85% reliability winds and 50% reliability temperatures for the month of June have been used in the flight plans performed by Jeppesen. The midday departure temperature at YYZ is assumed as 18°C, and 24°C at ATL. The results of these missions *(see table, page 15)* show that the YYZ-ATL route has a headwind component of 12-13 knots, while for the ATL-YYZ return sector there is no net wind component, shown by a value of zero. Therefore the 671nm ESAD distance for this ATL-YYZ sector is identical to the tracked distance. According Jeppesen, this is based on

There are many possible combinations of 737NG airframe variants and CFM56-7B variants. Higher thrusts are only required in conditions where better field performance is necessary. Fuel burn for a particular variant of the 737NG varies with actual take-off weight rather than engine variant.

FUEL BURN PERFORMANCE OF CFM56-7B SERIES

City-pair variant	Aircraft	Engine model	MTOW lbs	TOW lbs	Fuel burn USG	Block time mins	Passenger payload	ESAD nm	Fuel per seat	Wind speed
YYZ-ATL	737-600	CFM56-7B22	143,500	126,031	1,482	116	29,040	691	11.23	-13
YYZ-ATL	737-700	CFM56-7B24	154,500	132,853	1,514	116	32,780	691	10.16	-13
YYZ-ATL	737-800	CFM56-7B26	174,200	149,230	1,581	116	41,580	691	8.37	-13
YYZ-ATL	737-900	CFM56-7B27	187,700	160,284	1,637	118	47,300	691	7.62	-12
ATL-YYZ	737-600	CFM56-7B22	143,500	126,111	1,474	114	29,040	671	11.16	0
ATL-YYZ	737-700	CFM56-7B24	154,500	132,889	1,502	113	32,780	671	10.08	0
ATL-YYZ	737-800	CFM56-7B26	174,200	149,266	1,558	114	41,580	671	8.25	0
ATL-YYZ	737-900	CFM56-7B27	187,700	160,291	1,607	115	47,300	671	7.47	0

Source: Jeppesen

historical average winds for the month of June with 85% reliability. The company also notes that winds vary slightly only if taking historical average winds for the months before May or after July.

The aircraft analysed have been assumed to have typical high-density passenger payloads, which are: 132 passengers for the 737-600; 149 for the 737-700; 189 for the 737-800; and 215 for the 737-900 *(see table, this page)*. The standard weight for each passenger plus baggage is assumed to be 220lbs, and no additional underfloor cargo is carried. The payload carried in both directions by each aircraft is therefore: 29,040lbs for the 737-600; 32,780lbs for the 737-700; 41,580lbs for the 737-800; and 47,300lbs for the 737-900.

On the YYZ-ATL route, the 13-knot headwind increases the tracked distance of 671nm to an ESAD of 691nm. This route has a block time of 116-118 minutes *(see table, this page)*. On the ATL-YYZ route, with a zero net wind component, the 671nm is the same as the ESAD. This route has a block time of 113-114 minutes. On each of the routes, these variations in block duration are accounted for by non-wind-related factors such as differences in take-off, cruise, climb and descent profiles respective to each aircraft model.

Fuel burn performance

The fuel burn for each aircraft/engine combination and the consequent burn per passenger are shown *(see table, this page)*. The fuel burn performance of the different aircraft-engine variants is compared on the YYZ-ATL sector.

The data show that for the respective 737NG models the fuel burn increases in relation to actual take-off weights (ATOWs) and aircraft size. The 737-600, which is the smallest aircraft here in terms of overall length has both the lowest operating empty weight (OEW), of 81,360lbs, and the lowest ATOW, of 126,031lbs. On the YYZ-ATL sector, its resultant fuel burn is 1,482USG. This compares with 1,514USG for the larger 737-700, which has a heavier OEW of 84,000lbs and ATOW of 132,853lbs *(see table, this page)*.

The longer 737-800 has an OEW of 90,710lbs and an ATOW of 149,230lbs. This aircraft exhibits a fuel burn of 1,581USG. The largest of the 737NG models is the stretched 737-900. This has the highest OEW (95,400lbs) and highest ATOW (160,284lbs). On the YYZ-ATL sector its resultant fuel burn is 1,637USG *(see table, this page)*.

In the reverse direction on the ATL-YYZ sector, the fuel burn for each aircraft/engine combination and the consequent burn per passenger are shown *(see table, this page)*. As with the outward sector, the data show that for the respective 737NG models, the fuel burn increases in relation to ATOWs and aircraft size. The 737-600's fuel burn is 1,474USG. This compares with 1,502USG for the 737-700, 1,558USG for the 737-800, and 1,607USG for the 737-900. These fuel burn values are slightly lower than for the corresponding aircraft on the outward sector. This is due to the longer ESAD arising from the lack of a headwind component on the ATL-YYZ sector.

Economics

The results *(see table, this page)* also show fuel burn per passenger and fuel burn per passenger-mile, using the ESAD (rather than the tracked distance). As the aircraft size and weight increases, so too does the required engine thrust, as does the quantity of overall fuel consumed. Conversely, the fuel burn per passenger is nevertheless lowest with the largest aircraft which holds the most passengers: the 737-900.

Taking the YYZ-ATL sector, the CFM56-7B22-powered 737-600 carrying 132 passengers burns the most fuel per passenger: 11.23USG. This compares with the CFM56-7B24-powered 737-700 carrying 149 passengers with a fuel burn of 10.16USG per passenger. Fuel burns per passenger decrease further with the larger models. The CFM56-7B26-powered 737-800 with 189 passengers burns 8.37USG per passenger, while the CFM56-7B27-powered 737-900 with 215 passengers burns the least per passenger, only 7.62USG.

Furthermore, at current jet-fuel prices of about $4 per USG, the cost of fuel burned per passenger averages as follows: $44.6 for the 737-600; $40.4 for the 737-700; $33.2 for the 737-800; and $30.2 for the 737-900.

In summary, the 737-900, as a stretch of the 737-800, delivers the best fuel efficiency and lowest fuel burn per passenger. Meanwhile, the 737-600, which is a fuselage 'shrink' that still shares the same engine hardware, wingbox and landing gear of the larger versions, delivers the highest fuel-burn per passenger.

When considered in terms of fuel burn per passenger per mile, the 737NG family has similar fuel efficiency to the A320 family. This means that the 737-700, -800 and -900 have similar seat numbers to the A319, A320 and A321 similar lower fuel burn per passenger per mile when ESAD is considered *(see CFM56-5A/5B fuel burn performance, Aircraft Commerce, February/March 2007, page 13)*. AC

CFM56-7B maintenance analysis & budget

Most CFM56-7B variants have high EGT margins and can achieve long on-wing intervals. The Tech56 modification will lower maintenance costs.

The CFM56-7B has become one of the most ubiquitous engines, with more than 2,550 737NGs in operation, and another 2,200 on order. The industry can therefore expect to see almost 10,000 CFM56-7Bs in service within five to seven years. The CFM56-7B is operated in many large fleets with airlines worldwide. Operations experience a wide range of ambient temperatures from minus 20 to more than 40 degrees centigrade. The maintenance costs of the -7B's six variants are analysed here at typical rates of utilisation and engine flight hour (EFH) to engine flight cycle (EFC) ratio.

CFM56-7B in operation

The 737NG's range gives it the flexibility to operate a mixture of short- and medium-haul operations economically. Average annual utilisation is 3,000-3,200 flight hours (FH). Average flight cycle (FC) time is 1.9FH, with most operations ranging from 1.8FH to 2.05FH. The oldest aircraft have now accumulated more than 36,000FH and 28,000FC. These rates of utilisation and FC times are typical of the 737NG's larger carriers. The majority of 737NGs are -700 and -800 variants, accounting for about 2,400 aircraft. There are only about 70 of the smallest -600 model, and 75 of the -900, in service.

The 737-700 is powered by the -7B20 rated at 20,600lbs thrust, the -7B22 rated at 22,700lbs thrust, the -7B24 rated at 24,200lbs thrust, and the -7B26 rated at 26,300lbs thrust. The 737-800 is powered by the -7B24, the -7B26, and the -7B27 rated at 27,300lbs thrust.

There are no -B18s in service. There are 90 -700s powered by the -7B20, 485 powered by the -7B22 and 344 by the -7B24. A small number are powered by the -7B26 and -7B27.

Of 1,400 -800s in service, 155 are powered by the -7B24, 906 are powered by the -7B26, and 337 by the -7B27.

The extremes of operation are engines operating at EFH:EFC ratios of 0.9EFH, and as high as 3.0EFH.

UK low-cost carrier easyJet operates the -7B20 on a fleet of 30 737-700s at an average EFC time of 1.57EFH. Southwest in the US has a large fleet of -7B24s powering more than 300 737-700s and has an EFH:EFC ratio of 1.71. More than 50 of these are powered by Tech56 Insertion engines. The operator also manages an average take-off de-rate of about 10%, despite operating in a hot environment.

KLM has a longer EFC time of 1.80EFH, and operates a mixed fleet of Tech Insertion -7B24 engines on six 737-800s and non-Tech Insertion -7B24 and -7B26 engines on 20 737-800s/-900s. The airline manages a de-rate of 12-14%.

UK charter operator XL Airways is an example of one of the longer EFC times. The airline has 18 aircraft, 15 of which are powered by -7B26 engines. The other three are Tech Insertion -7B26/27 engines. The airline has an average EFC time of 2.84EFH and an average de-rate across its operation of 10%.

EGT margin

Exhaust gas temperature (EGT) margin is a main consideration for engine performance and maintenance. EGT margin erosion is generally the most influential factor in maintenance removal intervals for short-haul engines, while the effect of hardware deterioration is greater on engines used on medium-haul operations.

The -7B series has generally been designed with a high EGT margin capability, with the intention to limit the influence of EGT margin erosion as a main removal cause for maintenance shop visits.

Initial EGT margins are highest for the lowest rated -7B18 and -7B20 engines at 125-130 degrees for new engines *(see table, page 19)*. The medium-rated -7B22 has an initial EGT margin of 103 degrees, and the higher rated -7B24 has a margin of 100 degrees. The -7B26 and -7B27 have initial EGT margins of 80 and 55-60 degrees *(see table, page 19)*.

As with all engines, EGT margin deteriorates during operation. Rates of deterioration are highest in the first 1,000EFC of operation as blade tips and seals are worn and clearances increase. This leads to leakage around blade tips and causes EGT margin to erode. EGT margin deterioration rates slow down after the first 1,000-2,000EFC on-wing. The initial EGT margin and rate of EGT margin loss can be a leading factor in determining the length of time the engine can remain on-wing until EGT margin is fully eroded for some engines. Engines with higher initial EGT margins can

Operations of the CFM56-7B span a wide variety of EFC times, with some operators averaging close to 3.0EFH.

remain on-wing for longer intervals, and deterioration of hardware usually drives removals before all EGT margin is eroded.

Shop visit maintenance will restore hardware and clearances between blade tips and engine casings. Most of the original EGT margin will therefore be restored. The restored EGT margin will be lower than the original for a new engine, so EGT margin and its erosion will become a more important factor in driving engine removals when they are mature. "TAP Maintenance & Engineering guarantees to restore at least 75% of an engine's initial EGT margin following a shop visit," says Antonio Ferreira, CFM56 powerplant engineer at TAP Maintenance & Engineering. "Restored EGT margins are usually higher, and we can often achieve margins on the -7B26 and -7B27 that were higher than the initial margins."

Typical restored EGT margins are summarised *(see table, this page)*. They do not reflect the margins on engines which have had the Tech56 upgrade *(see CFM56-7B specifications, page 10)*. Ferreira comments that this adds about 10 degrees of EGT margin to new and restored engines. "The Tech 56 modification is only generally necessary for higher rated -7B engines which have lower EGT margins. All new production engines have the Tech 56 modification. The problem is that operators will end up with a mix of Tech 56 and non-modified engines in their fleets, which they will have to standardise to minimise the number of spare engines and inventories of parts."

CFM56-7B EGT MARGINS

Engine variant	-7B18	-7B20	-7B22	-7B24	-7B26	-7B27
Thrust lbs	19,500	20,600	22,700	24,200	26,300	27,300
Initial EGT margin (deg C)	125-130	125-130	105	100	60	55
Restored EGT margin (deg C)	88-104	88-104	74-84	70-80	42-48	39-44

EGT margin erosion

EGT margin loss rates are highest during the first 1,000EFC on-wing, then reduce to a mature level after 3,000EFC on-wing. No only does the -7B series have generally high levels of EGT margin, but its mature rates of EGT margin are lower and more stable than older generation engines. "It would be possible for some engines to remain on-wing for up to 25,000EFC given their EGT margins and rate of EGT margin erosion, if it were not for limitations placed by life limited parts (LLPs) and mechanical deterioration," says Ferreira.

Initial rates of EGT margin loss are less for lower-rated engines. These are 8-12 degrees centigrade in the first 1,000EFC for the -7B18, -7B20 and -7B22 engines. "The mature rates then slow to 2.5-4.0 degrees per 1,000EFC for these lower-rated variants," says Markus Kleinhans, propulsion systems engineer at Lufthansa Technik.

At these rates of loss, the -7B20, with an initial margin of 130 degrees, could remain on-wing for up to 40,000EFC if EGT margin and engine performance were the only limiting factor.

The -7B22 would have slightly higher rates of EGT margin loss, but could still remain on-wing for up to 36,000-38,000EFC if EGT margin were the only limiting factor.

"Initial rates of EGT margin loss for the higher rated -7B24, -7B26 and -7B27 variants will be 11-15 degrees in the first 1,000EFC on-wing. Rates will then drop to 4-6 degrees per 1,000EFC thereafter," says Ferreira. "On this basis, the -7B24 could remain on-wing for 17,000-18,000EFC from its initial EGT margin of 100 degrees. The -7B26 could remain on-wing for 12,000-14,000EFC, and the highest-rated -7B27 could stay on-wing for 10,000-12,000EFC from its initial EGT margin of 60 degrees."

Restored EGT margin

As described, the restored EGT margins following a shop visit will not be at the same levels as for new engines. Restored EGT margins vary from 70% to 80% of initial margins *(see table, this page)*. They are therefore 88-104 degrees for -7B18/20 engines, 74-84 degrees for -7B22 engines, 70-80 degrees for -7B24 engines, 42-48 degrees for -7B26 engines, and 40-45 degrees for -7B27 engines.

The initial and mature rates of EGT margin erosion are similar to new engines. As a result, -7B18 and -7B20 engines could remain on-wing for 27,000-30,000EFC for second and mature intervals if the EGT margin were not a limiting factor. The -7B22 would have intervals of 22,000-25,000EFC if EGT margin were the only limiting factor.

The higher-rated -7B24 can expect to have second and mature intervals of 12,000-13,000EFC, depending on actual EGT margin erosion rates and the nature of operation. The -7B26 could expect to have removal intervals of 9,000-12,000EFC, and the -7B27 intervals of 8,000-10,000EFC.

Life limited parts

The CFM560-7B series has 18 LLPs. There are three in the fan and low pressure compressor (LPC) module: the fan disk, the booster spool and the fan shaft. The current list price of these three parts is $356,000.

There are nine LLPs in the high pressure spool: the high pressure compressor (HPC) forward shaft; the HPC stage 1-2 spool; the HPC stage 3 disk; the HPC stage 4-9 spool; the HPC CDP air seal; the high pressure turbine (HPT) front shaft; the HPT disk; and the HPT rear shaft *(see table, page 20)*. The current list price of these nine parts is $921,000.

The LPT module has six LLPs: the four disks for the low pressure turbine (LPT) stages; the LPT shaft; and the LPT conical support. The current list price of these six parts is $499,000.

The total cost for a shipset of LLPs is $1.775 million.

There are another two parts which are sometimes classified as LLPs: the LPT frame and the LPT case.

CFMI has a policy of setting target lives for all its engines, and starting with certified lives that in some cases are lower than target lives. The certified lives are then extended as operational experience is gained with the engine. The target lives for the LLPs in the HP spool are 20,000EFC, 25,000EFC for the parts in the LPT module, and 30,000EFC in the fan and booster module.

There are several part numbers for each LLP, and the actual certified lives for each LLP vary. In the case of some part numbers lives are shorter for higher-thrust-rated variants than they are for lower-thrust variants. Lives of earlier manufactured part numbers are also generally shorter than for more recent part numbers.

The LLPs used in those engines with the Tech56 or Tech Insertion upgrade built from 2007 onwards all have the target lives of 20,000EFC, 25,000EFC and 30,000EFC for the three main groups.

The lives are also shortened for engines with thrust bump ratings or those used on the business-jet version of the 737NG.

The current life limits of each LLP for each rating for non-Tech56 or non-Tech

CFM56-7B LLP LIVES - NON-TECH INSERTION ENGINES

Engine variant	-7B18	-7B20	-7B22	-7B24	-7B26	-7B27
Fan disk	17,900	17,900	17,900	17,900	17,900	17,900
Booster spool	23,600	23,600	23,600	23,600	23,600	23,600
Fan shaft	30,000	30,000	30,000	30,000	30,000	30,000
Forward shaft	20,000	20,000	20,000	20,000	20,000	20,000
Stage 1-2 spool	20,000	20,000	20,000	20,000	20,000	20,000
Stage 3 disk	20,000	20,000	20,000	20,000	20,000	20,000
Stage 4-9 spool	20,000	20,000	20,000	20,000	20,000	20,000
CDP seal	20,000	20,000	20,000	20,000	20,000	20,000
Front shaft	20,000	20,000	20,000	20,000	17,300	17,300
Front Air Seal	20,000	20,000	20,000	20,000	17,300	17,300
Disk	20,000	20,000	20,000	20,000	20,000	19,200
Rear shaft	20,000	20,000	20,000	20,000	20,000	20,000
Stage 1 disk	25,000	25,000	25,000	25,000	25,000	25,000
Stage 2 disk	25,000	25,000	25,000	25,000	25,000	25,000
Stage 3 disk	25,000	25,000	25,000	25,000	25,000	25,000
Stage 4 disk	25,000	25,000	25,000	25,000	25,000	23,900
Shaft	25,000	25,000	25,000	25,000	25,000	25,000
Conical support	25,000	25,000	25,000	25,000	25,000	16,300

Insertion engines are summarised *(see table, this page)*.

The fan disk has a life of 17,900EFC for all six variants. "Although this limit is short compared to the other two LLPs in the fan/LPC module, the fan/LPC can be easily separated from the rest of the engine, and the disk removed and replaced after taking out the fan blades without having to disassemble the module. This avoids an early shop visit," says Ferreira.

The booster spool LLP has a limit of 23,600EFC for all variants, except the -7B27 which has a limit of 22,900EFC. "The life of this part can easily be extended to 30,000EFC after an inspection, and so prevents an early disassembly and shop visit of this module," explains Ferreira.

The fan shaft is the only LLP in this module to have a life of 30,000EFC, and this applies to all thrust variants. The overall result is that full disassemblies and workscopes on the fan/booster module are only required about once every 30,000EFC.

The five LLPs in the HPC all have lives of 20,000EFC for all six thrust ratings. The four LLPs in the HPT module have lives of 20,000EFC in the case of the four lower-thrust-rated variants. While the rear shaft has a life of 20,000EFC for all ratings, the other three parts have shorter lives of 17,300EFC for the two highest-rated variants.

The LPT has relatively few limitations: the stage 4 disk and conical support in the -7B27, which have lives of 23,900EFC and 16,300EFC *(see table, this page)*.

1st removal causes & intervals

These life limits have to be considered together with possible removal intervals that EGT margins would allow. "Low-thrust engines, which includes those up to the -7B24, can operate up to their first LLP life limiter," explains David Beale, customer programme engineer at MTU Maintenance Hannover. "High-thrust engines, the -7B26 and -7B27, might become EGT-margin-limited after 12,000-18,000EFC on-wing, depending on their average EFC length, their operating environment, and rate of EGT margin deterioration. Engines that fly at 1.5EFH per EFC or longer, which are relatively long cycle times, will accumulate a high number of EFH on-wing and so will experience relatively high deterioration. One main removal driver will be the need to replace variable stator vane (VSV) bushings in the HPC."

-7B18, -7B20 & -7B22

Lower-rated -7B18/20 and -7B22 engines have sufficient EGT margin to operate beyond the highest life limits of fan and LPC module LLPs on their first on-wing interval. Besides the fan module, which is easily removable, the LLPs in the engine that would actually limit the removal interval are those in the HP modules that have lives of 20,000EFC. First shop-visit removals for these lower-rated engines are likely to be forced by expiry of LLPs in the two HP modules.

easyJet's experience is an average first removal interval of 15,000-18,000EFC, but the airline has a relatively short EFC time of 1.57EFH. The main removal causes are mechanical deterioration, but it does also have some removals forced by LLP expiry, so some intervals are up to 20,000EFC.

After a removal interval of 20,000EFC, engines would then have stub lives of 5,000EFC for their LPT LLPs and stub lives of 10,000EFC for their fan/LPC LLPs.

-7B24

The medium-rated -7B24 has enough EGT margin to allow it to operate for to up 18,000EFC for the first on-wing removal. This compares to LLP life limits of 20,000EFC. In some cases the engines may be able to remain on-wing for 20,000EFC, so removals for shop visits will be forced both by performance loss and LLP expiry. Southwest's -7B24 fleet achieves first and mature intervals of 20,000EFC, and removals are forced by LLP expiry.

The LLPs in the LPT would therefore have stub lives of 5,000-7,000EFC at the first removal, and parts in the fan and booster would have stub lives of 12,000EFC.

-7B26 & -7B27

The high-rated -7B26 and -7B27 will use all their EGT margin after 10,000-14,000EFC by their first removal, and so be left with stub lives of 6,000-10,000EFC in their HP modules. Most parts in the LPT module will have stub lives of 11,000-15,000EFC, while parts in the fan and LPC will have stub lives of 16,000-20,000EFC.

XL Airways, which operates at 2.84EFH per EFC, has averaged 10,000EFC for its first removal intervals, equal to almost 30,000EFH. Main removal causes are EGT margin loss and the need to replace HPC bushings.

The Tech56 modified engines are expected to have EGT margins about 10 degrees higher than those of non-modified engines. "This would allow the higher-rated -7B24, -7B26 and -7B27 engines to remain on-wing for about another 2,000EFC and possibly another 3,000EFC," explains Kleinhans.

This suggests that after modification the -7B26's first removal interval could be up to 16,000EFC, and the -7B27's up to 14,000EFC. The engines would therefore have stub lives of 4,000-6,000EFC in their HP modules, 9,000-11,000EFC in the LPT, and 14,000-16,000EFC in the fan and LPC.

The lower-rated -7B18 and -7B20 engines would also have higher EGT margin if they had the Tech56 modification, but they would be unable to make use of this because of the limits imposed by LLP lives.

Shop visit removal intervals for lower rated -7B variants are rarely due to EGT margin erosion. Engines can usually remain on-wing to the first LLP life limit.

"The prime cause for the first removal for all non-Tech56 -7Bs is LLP life expiry, especially in low- and medium-rated engines," says Ferreira. "The second, third and fourth main removal causes all relate to hardware deterioration. Few engines are removed due to loss of EGT margin and performance.

"The first of these removal causes relates to HPC rotor-stator contacts, as a result of wear to the bushings in the HPC. The second removal cause is problems with the fuel nozzle, and the third involves deterioration of the HPT blade," continues Ferreira. "There have been six different part numbers and configurations for the HPT blade since the engine was introduced. The sixth configuration is used on the Tech Insertion build-standard engines. Earlier blades had a casting problem, which resulted in poor cooling, and led to deterioration. This was hard to detect with a borescope inspection, and could only be detected by x-ray. Soft removal times of 16,000EFC, or 20,000EFC were therefore established for older HPT blade configurations. In some cases repairs had to be completed by 14,000EFC on-wing time. These lives placed a limit on removal intervals."

Kleinhans explains that the main removal drivers on higher-cycle-length engines are HPC rotor-stator contact due to VSV inner bushing wear and problems with HPT blades. Performance and loss of EGT margin are a main removal driver for -7B26 and -7B27 engines. "Engines with shorter EFC times are mainly removed due to LLP expiry, while a larger proportion of engines with longer average EFC times are removed due to hardware," says Kleinhans.

2nd removal intervals

The second removal intervals will be a compromise between the stub lives of remaining LLPs, and the probable restored EGT margin after the first shop visit and the interval it could allow. "The length of the on-wing interval after the first shop visit will depend a lot on the remaining lives of LLPs," says Beale. "Low-rated engines are likely to reach the next LLP life limit in the engine. High-thrust engines can typically reach 65% of their first-run removal interval, unless they also reach an LLP life limit. Second shop-visit workscopes must be customised because of the large number of variables that have to be considered."

Removals of high-thrust engines will be driven by EGT margin loss and LLP expiry because restored EGT margins are lower than new-build engines.

-7B18, -7B20 & -7B22

The restored EGT margins will allow on-wing intervals of 27,000-30,000EFC for the lowest-rated -7B18 and -7B20 engines. Operators would not be limited by EGT margin for the second removal interval, so the interval would just depend on remaining LLP lives. "As the stub lives of LPT and fan/booster parts at the first removal would be 5,000-10,000EFC, it makes sense to replace all LLPs at the first removal so as not to limit the second removal limit. The engines would therefore be capable of intervals of 20,000EFC for every removal," explains Ferreira. "The second interval could then be 15,000-20,000EFC." The fan/booster LLPs with stub lives of up to 10,000EFC could be used in higher-rated -7B26 and -7B27 engines, which may only be capable of removal intervals of this length.

-7B24

Non-Tech56 modified engines would have stub lives of 5,000-7,000EFC in the LPT and 12,000EFC in the fan/booster at the first removal.

The engine would be capable of 12,000-13,000EFC for the second removal interval, based on its restored EGT margin. The best policy would be to replace HP module and LPT LLPs at the first removal and shop visit, and leave the parts in the fan/booster to be replaced at the second removal and shop visit. The remaining life of these parts and the probable time on-wing due to EGT margin would be similar at 12,000EFC.

A probable scenario for non-Tech56 modified engines would be the replacement of HP and LPT parts at the first removal after 18,000-20,000EFC. The second removal would be limited to 10,000-12,000EFC by the stub lives of fan/booster LLPs. The fan/booster LLPs would be replaced at the second shop visit, at which stage the HP module LLPs would have stub lives of 8,000-10,000, and LPT LLPs would have stub lives of 13,000-15,000EFC.

The third removal interval would therefore be limited to 8,000-10,000EFC by the HP parts. The HP and LPT LLPs would be replaced at this shop visit, while the fan/booster LLPs would have a stub life of 20,000-22,000EFC at this stage.

The total accumulated time at the third shop visit would therefore be 38,000-40,000EFC.

There is a case for using the Tech56 modification on these medium-rated engines. The 10-degree higher EGT margin would allow another 2,000EFC on-wing time, and so a first interval of 20,000EFC. With a higher EGT margin, subsequent removal intervals could be as high as 15,000EFC. It may therefore be attractive to some operators to consider replacing all LLPs at the first shop visit, which would allow a second removal interval of 15,000EFC.

The HP and LPT module LLPs would therefore be replaced at the second shop visit, allowing a third removal interval of 15,000EFC, because of the remaining lives of parts in the fan/booster. The core and fan/booster LLPs would be replaced at this shop visit. The total of the three

There are three LLPs in the fan/LPC module with lives of 17,900-30,000EFC. The module can easily be separated from the rest of the engine, and have fan blades removed. The fan disk, lifed at 17,900EFC, can then be easily replaced. The booster spool, lifed at 23,600EFC, can have its life increased to 30,000EFC after an inspection.

intervals would be 50,000EFC, but a larger number of LLPs would have been replaced in the process. The LPT parts removed at the second shop visit would have stub lives of 10,000EFC, so they could be used in -7B26 and -7B27 engines that are only capable of intervals of similar lengths.

-7B26

Non-Tech56 -7B26s are capable of second and subsequent removal intervals of 9,000-10,000EFC, and -7B27 engines would be capable of 8,000-10,000EFC.

The -7B26 would be left with stub lives of 6,000EFC in its HP modules, 11,000EFC in its LPT, and 16,000EFC in its fan/booster at the first removal. The potential second run of 9,000-10,000EFC due to restored EGT margin means it would be best to replace HP LLPs at the first shop visit, but leave LPT and fan/booster LLPs.

After the second on-wing interval the LPT parts would be virtually used, and fan/booster parts would have a stub life of 5,000-7,000EFC. These two groups of parts would therefore be replaced at this stage. The HP LLPs would have a stub life of 9,000-11,000EFC, and so allow a third interval of the same length.

The Tech56 modification would allow a longer first interval of 16,000EFC, and a potential second interval of 12,000EFC. While the HP LLPs would clearly be replaced at the first shop visit, and the fan/booster LLPs could be left in to limit the second removal interval to 14,000EFC, the LPT parts would have a stub life of 9,000EFC at the first removal. Leaving them would limit the second removal to just 9,000EFC and a total accumulated time of 25,000EFC at the second removal. Replacing them at the first shop visit would allow a longer second interval of 12,000EFC, but this would then limit the third interval to 8,000EFC because of the remaining lives of the HP LLPs.

-7B27

The -7B27's first average removal interval of 11,000EFC will leave the engines with HP stub lives of 9,000EFC, LPT stub lives of 14,000EFC, and fan/booster stub lives of 19,000EFC. The second potential interval of 9,000EFC for non-Tech56 modified engines would mean all LLPs could be left at the first shop visit.

The second removal interval would be limited to 9,000EFC by the stub life of its HP LLPs, which coincides closely with the probable interval that would be allowed by its restored EGT margin. XL Airways, for example, expects its second removal interval to average about 7,000EFC, when operating at 2.85EFH per EFC. After 9,000EFC, the LPT LLPs would have a stub life of 5,000EFC, and so should be removed, while the fan/booster LLPs would have a stub life of 10,000EFC and so could be left in for the third interval. This would also be 9,000EFC, and be limited to 10,000EFC by LLP stub lives. The total accumulated time by the third interval would be 29,000EFC.

Tech56 modified engines would be capable of intervals that are 2,000-3,000EFC longer. First intervals could therefore be up to 13,000EFC, in which case LLPs in the HP modules would have a stub life of 7,000EFC and so be replaced. LPT and fan/booster LLPs would have stub lives of 12,000EFC and 17,000EFC, and so could be left for the second interval. The second interval, limited by HP module stub lives, would mean the core and LPT LLPs would have to be replaced at the second shop visit. The fan/LPC module LLPs would be left with a stub life of 10,000EFC, thereby limiting the third interval. The total accumulated time at the third interval would be 30,000EFC.

Shop visit workscopes

The workscopes required at each removal should fit the pattern of removals and LLP replacements as described. There are several levels of shop visit workscope, and the one used will depend on the time on-wing, the removal and the removal cause.

"If the engine is removed for loss of EGT margin or deterioration of the HPT or the fuel nozzles, then the engine can have a level 1 workscope. This is a repair without the need to carry out a full disassembly and any LLP replacement," says Ferreira. "This workscope would restore performance to allow it to reach LLP limits on the second interval. This would be a more likely scenario for high-rated engines.

"A level 2 workscope is a heavier visit for the core engine that involves full disassembly and LLP replacement. In some cases a level 2 workscope is required on the core without replacing LLPs. In the case of high-rated engines, 13,000-16,000EFC have been accumulated, and core LLPs need to be replaced. The stub life of 9,000-12,000EFC for LPT LLPs is the limit to the second interval," continues Ferreira. "In the case of low-rated engines the interval is likely to be 19,000-20,000EFC. Core LLPs should be replaced, and there is no sense in keeping LPT LLPs. The remaining life of fan/booster LLPs will determine if they are removed or left. If they are removed, the next interval will be limited by core LLPs to 20,000EFC. The fan/booster LLPs can be used on higher-rated engines for their later on-wing intervals.

"A level 3 workscope involves replacing LLPs for the whole engine," continues Ferreira. "In this case it is a full overhaul." This will be required for low-rated engines that have intervals of 20,000EFC.

Engine removals for shop visits will be a compromise between on-wing life that is possible with EGT margin and LLP limits. The workscope required on the HP modules, LPT and fan/LPC will depend on the utilisation of LLP lives and the subsequent removal interval that will be possible with the restored EGT margin.

-7B20/22

The workscope pattern for the first two removals for the -7B20 and -7B22 engines will involve a level 3 workscope, or an overhaul and full LLP replacement, at the first and second removals after intervals of up to 20,000EFC *(see table, page 26)*. While this includes the removal of fan/booster LLPs which have stub lives of up to 10,000EFC, these can be sold or used for other high-rated engines.

The lowest-rated -7B20 and -7B22 engines should continue with this relatively simple pattern of shop visits.

-7B24

The -7B24 will require a level 2 workscope on the core and LPT at the first removal after an interval of 18,000EFC *(see table, page 26)*. The core would require a full workscope to restore performance and replace LLPs, and the LPT would also require a full workscope to replace LLPs. The fan and booster module could be left until the second shop visit.

The second shop visit would require a level 1 workscope on the core engine, since LLPs would not require replacement, and a level 2 workscope on the fan/booster to replace their LLPs. The LPT could be left.

The third shop visit would be similar to the first.

In the case of Tech56 modified -7B24 engines, a level 3 workscope would be required at the first shop visit to completely disassemble the engine and replace all LLPs. A level 2 workscope would then be required at the second shop visit to completely disassemble the core and LPT, while the fan and LPC would be left. A level 2 workscope would again be required on the core and fan/booster modules at the third shop visit *(see table, page 26)*.

-7B26

The first run for the non-Tech56 -7B26 of 14,000EFC would require a level 2 workscope on the core for full disassembly and LLP replacement. The fan/booster and LPT would be left.

These two modules would then have level 2 workscopes at the second shop visit, while the core module would only require a level 2 workscope, without LLP replacement, to restore performance.

The core modules would require a level 2 workscope, with LLP replacement, at the third shop visit, while the fan/booster and LPT could again be left.

Tech56 modified -7B26 engines would follow the same basic shop visit workscope pattern as unmodified engines, although the modified engines would have longer shop visit intervals.

-7B27

The non-Tech56 modified -7B27 would only require a level 1 workscope on the core modules, and no other work on other modules after an interval of 11,000EFC. The second shop visit after another 9,000EFC on-wing would need level 2 workscopes on the core and LPT modules.

The third shop visit would require a level 1 workscope on the core to restore performance, and a level 2 workscope on the fan/LPC module.

The Tech56 modified -7B27 engines would still be limited by the HP LLP lives of 20,000EFC. The first two intervals would total 20,000EFC. The HP and LPT LLPs would be replaced at the second shop visit.

As the engine would be capable of mature intervals of up to 12,000EFC, it would be optimal to have a third interval of 10,000EFC and to replace fan/booster LLPs at this shop visit. The mature intervals would have to average 10,000EFC because of the lives of HP LLPs.

Workscope inputs

Workscope inputs comprise three main cost elements: labour; parts and materials; and sub-contract repairs. Different engine shops have different levels of hi-tech parts repair capability, and there is a trade between the cost of labour and materials versus the cost of repairs.

The total cost of a core performance restoration is $1.1-1.3 million. Total labour for such a shop visit will be 3,000MH for a level 1 workscope, and up to 3,500MH for a heavy shop visit. Using a standard labour rate of $70, this portion of the shop visit would cost $195,000-250,000.

The cost of materials for a core performance restoration is $650,000-900,000, depending on the level of workscope. The cost of sub-contract repairs can vary from $250,000 to $400,000, depending on the capability of the engine shop. The total cost for a level 1 core workscope will therefore be $1.2-1.3 million, and $1.5-1.6 million for a level 2 workscope.

A workscope for an LPT module will use 700-900MH, $200,000-250,000 for materials, and a further $50,000 for sub-contract repairs. The total cost for the workscope will therefore be $350,000-400,000 when using a standard labour rate of $70 per MH.

A fan/booster module workscope can use 400-450MH for labour. Materials will cost $100,000, and sub-contract repairs up to $40,000. The total cost of the workscope will be $170,000-180,000.

A full overhaul for the whole engine, or level 3 workscope, will use 5,000-5,500MH in labour. Materials will cost

CFM56-7B REMOVAL INTERVAL, SHOP VISIT WORKSCOPE & LLP REPLACEMENT PATTERN

Removal	Interval EFC	Accumulated EFC	Workscope content	Shop visit Cost-$	$/EFC	LLP replacement	LLP cost $	LLP $/EFC	Sub-total $/EFC	Unsched visits $/EFH	QEC $/EFH	Total $/EFH
-7B20/22												
1st	20,000	20,000	Full overhaul	1,950,000	98	All parts	1,775,000	89	186	20	10	127
2nd	20,000	40,000	Full overhaul	1,950,000	98	All parts	1,775,000	89	186	20	10	127
-7B24 Non-Tech56												
1st	18,000	18,000	Level 2 core & LPT	1,900,000	112	Core & LPT	1,420,000	91	202	20	10	136
2nd	12,000	30,000	level 1 core & level 2 Fan/LPC	1,425,000	128	Fan/LPC	356,000	83	211	20	10	141
3rd	8,000	38,000	Level 2 core & LPT	1,900,000	219	Core & LPT	1,420,000	83	302	20	10	189
-7B24 Tech56 modified												
1st	20,000	20,000	Full overhaul	2,000,000	100	All parts	1,775,000	89	189	20	10	130
2nd	15,000	35,000	Level 2 core & LPT	1,900,000	133	Core & LPT	1,420,000	106	221	20	10	146
3rd	15,000	50,000	Level 2 core& level 2 fan/LPC	1,725,000	127	Core & fan/LPC	1,277,000	93	221	20	10	146
-7B26												
1st	14,000	14,000	Level 2 core	1,550,000	134	Core	921,000	103	237	20	10	155
2nd	9,000	23,000	Level 2 core & LPT & fan/LPC	2,075,000	195	LPT & Fan/LPC	855,000	88	283	20	10	179
3rd	9,000	32,000	Level 2 core	1,550,000	197	Core	921,000	92	289	20	10	182
-7B26 Tech56 modified												
1st	16,000	16,000	Level 2 core	1,550,000	118	Core	921,000	92	209	20	10	140
2nd	9,000	25,000	Level 2 core, LPT & fan/LPC	1,775,000	160	LPT & fan/LPC	855,000	80	240	20	10	156
3rd	11,000	36,000	Level 2 core	1,550,000	166	Core	921,000	84	250	20	10	161
-7B27												
1st	11,000	11,000	Level 1 core	1,250,000	138	-	-	83	221	20	10	146
2nd	9,000	20,000	Level 2 core & LPT	1,900,000	196	Core & LPT	1,420,000	83	279	20	10	177
3rd	9,000	29,000	Level 1 core & level 2 fan/LPC	1,425,000	158	Fan/LPC	356,000	87	245	20	10	159
-7B27 Tech56 modified												
1st	12,000	12,000	Level 1 core	1,250,000	128	-	-	83	211	20	10	141
2nd	8,000	20,000	Level 2 core & LPT	1,900,000	217	Core & LPT	1,420,000	83	300	20	10	188
3rd	10,000	30,000	Level 1 core & level 2 fan/LPC	1,425,000	149	Fan/LPC	356,000	83	232	20	10	152

Planned shop visit engine maintenance reserves based on 1.9EFH per EFC.

$1.1-1.25 million, while the additional cost of sub-contract repairs will be $400,000-500,000. This will take the total cost of the shop visit to $1.85-2.1 million.

Unscheduled shop visits

Unscheduled shop visits fall into engine-related and non-engine-related events. Non-engine-related events are items such as birdstrikes and foreign object damage (FOD). Engine-related events are those where there is engine hardware failure. These can be further sub-divided into light and heavy events. Light events are issues such as oil leaks, hospital visits for damage on the HPC, and other minor incidents that do not require full engine disassembly.

Light engine-related events occur at a rate of once every 60,000FH/31,000EFC. They typically incur a cost of $250,000-300,000. A reserve of $5 per EFH should therefore be budgeted.

Heavy engine-related and non-engine-related events should be considered together because they require full engine disassembly. Heavy engine-related events are major issues that include bearing failures, which incur some of the highest shop visit costs of up to $2 million. Birdstrikes and FOD events can also incur similarly high shop visit costs. The two occur at a combined rate of once every 70,000-80,000EFH or 35,000-40,000EFC. This is equal to three or four times the interval of planned shop visits. One of these heavy events therefore replaces one of every three or four planned events. These heavy events usually have higher shop visit costs than planned events, so an allowance of half the cost of a heavy shop visit should be added for every three or four shop visits, equal to an additional $12-15 per EFH.

The total allowance for unscheduled shop visits should therefore be $20 per EFH.

Reducing shop visit costs

Shop visit costs can be mitigated to some degree by the use of parts manufacturer approval (PMA) parts. HEICO is one supplier of PMA parts for the CFM56-7B, and it manufactures all variety of parts for the engine. "We provide fasteners, washers, seals, as well as more expensive parts such as HPT and

Shop visit intervals mean LLPs cannot be fully utilised in all modules in the case of most engines. If managed, LLP reserves can be in the region of $90 per EFC.

LPT shrouds. We also provide parts for the engine's accessories, which include the starter motors, pneumatics and hydraulics," says Rick Stine, president of HEICO Parts Group. "We also have some blades and vanes available. Most of these are from the HPC, but we are also developing blades and vanes for the LPT. In total we manufacture more than 500 part numbers for the CFM56-7B, and are developing more. The possible savings we can provide for core engine parts are up to $100,000 per shop visit. Additional savings for parts used in engine accessories are about $8,000."

Maintenance reserves

Maintenance reserves per EFH are summarised for each engine variant *(see table, page 26)*. This includes engines which have had the Tech56 modification. The reserves are for engines operating at fleet average EFC lengths of 1.9EFH.

Basic reserves are a result of the planned shop visit intervals, shop visit workscopes and workscope patterns, and shop visit inputs. A common issue with all variants is that different modules have their LLPs replaced at different shop visits. Compromises have to be made with removal intervals that are possible with EGT margin and LLP life limits. This complicates the calculation of shop visit and LLP reserves.

An example is the -7B26 variant which has a level 2 core workscope and LLP replacement at the first shop visit, and a level 2 core workscope without LLP removal at the second shop visit.

The LPT and fan/LPC have level 2 workscope and LLP replacement at the second shop visit.

The reserves for the workscopes and LLP replacement for the LPT and fan/LPC are amortised over the first two intervals. The reserves for the core's two workscopes are amortised over the relevant intervals.

The need to compromise between possible removal intervals and LLP lives means that full LLP lives cannot be fully utilised, and parts are replaced early. This has the effect of raising LLP reserves.

An example of this is the -7B24 engine which has a first removal interval of 18,000EFC, and is capable of a second interval of up to 12,000EFC. The core LLPs are replaced slightly early at the first shop visit, and the fan/booster LLPs at the second visit after a total time of 30,000EFC. The LPT parts have to be replaced early at the first visit after 18,000EFC, therefore not utilising 7,000EFC of their life limit. This need to compromise also has the effect of making reserves increase and decrease between subsequent removals.

Average reserves for LLPs in all variants are $87-93 per EFC, suggesting that the average replacement interval for all parts is 19,000-20,000EFC.

A sub-total of reserves per EFC for shop visit inputs and LLP lives is calculated. These are then converted to rates per EFH at the EFC time of 1.9EFH. Additional costs for unscheduled visits of $20 per EFH, as described, and another $10 per EFH for quick engine change (QEC) repair and overhaul are added to get the total cost per EFH.

As expected, the -7B20/22 engines have the lowest overall reserves: $127 per EFH for the first two removals *(see table, page 26)*.

The -7B24 has reserves of $136-141 per EFH for the first two removals, but these rise to $189 per EFH as the engine matures and the third interval is limited to 8,000EFC by core LLP lives. Reserves for the fourth interval would be lower with just a workscope on the core at this shop visit.

The -7B24 with the Tech56 modification has more consistent first and mature shop visit removal intervals, and has lower overall reserves than unmodified -7B24 engines. Reserves for the modified -7B24 are $130-146 per EFH, which are $6-43 per EFH lower than non-Tech56 engines *(see table, page 26)*.

The -7B26 has reserves of $155-182 per EFH over its first three shop visits *(see table, page 26)*. This is up to $20 more per EFH more than the -7B24. The -7B26 benefits from the Tech56 modification by having longer removal intervals in some cases, and is overall able to achieve reserves that are $15-20 per EFH lower than those of unmodified engines.

The -7B27 has reserves of $146-159 per EFH, lower for some removal intervals than those of the -7B26 *(see table, page 26)*. This is explained by the -7B27 being able to better utilise its LLP lives, due to the effects of EGT margins on removal intervals. Reserves for the -7B27 modified with the Tech56 upgrade are $5-7 per EFH lower than those of non-modified engines.

Summary

The CFM56-7B has maintenance reserves in line with its -5B counterpart *(see CFM56-5A/5B maintenance analysis & budget, Aircraft Commerce, February/March, page 15)*. The possible planned removal intervals are long enough for just two or three removals to be experienced during its operating life on passenger jets. The engine has high EGT margins, but it also has good durability, and has experienced relatively few problems with degradation of hardware that previous generations have.

The engine clearly benefits from the Tech56 modification, since this lowers maintenance reserves by up to $40 per EFH, especially for mature engines which have lower restored EGT margins than their original EGT margins. AC

CFM56-7B technical support providers

There are about 5,100 CFM56-7Bs in operation. A global survey of six major levels of support identifies major global support providers.

This survey summarises the major aftermarket and technical support providers for the CFM56-7B family of turbofan engines. It is grouped into six sections covering the categories of technical support offered by each of the providers:

- Line maintenance and in-service operational support *(see first table, page 30)*.
- Engine management *(see second table, page 30)*.
- Engine provisioning *(see third table, page 30)*.
- Engine components *(see first table, page 31)*.
- Shop visit maintenance *(see second table, page 31)*.
- Specialist repairs *(see third table, page 31)*.

CFM56-7B overhaul market

In terms of total CFM56-7B engine overhauls, by far the largest number of contracts are awarded to shops managed by CFMI's aftermarket affiliates GE Engine Services (GEES) and Snecma Services, accounting for more than 43% of 6,458 engine overhaul contracts logged by FlightGlobal's ACAS maintenance database. GEES's proportion of the world total is almost 30% (1,928 logged contracts), while Snecma Services' is 13.5% (874 logged contracts).

GEES's CFM56-7B overhauls are undertaken at: Dallas, TX; Strother Field, KS; Cardiff, Wales; Prestwick, Scotland; and Selangor, Malaysia. Snecma Services' -7B overhauls take place at Villaroche, France; Brussels, Belgium; Casablanca, Morocco; and Sichuan, China.

The next most active -7B overhaulers are: Lufthansa Technik (634 contracts and 9.81% market share); MTU Maintenance (530 contracts, 8.2% market share and shops in Hannover, Canada and Zhuhai in China); Delta TechOps (472 contracts and 7.3% market share); and Pratt & Whitney Engine Services' Norway facility (260 contracts and 4% market share). Other -7B overhaul providers are: SR Technics; Turkish Technic, Jet Turbine Services (a division of Qantas); KLM E&M; ST Aerospace Engines; Iberia; TAP M&E; United Services, IHI Corporation, Bedek Aviation, Aerothrust and American Airlines.

Aftermarket outlook

"CFM56-7Bs are staying on-wing longer, but the shops are beginning to fill. Fleet demographics suggest there is a wave coming, so capacity will tighten a bit over the next three years, but not to the extent of there being a shortage. Capacity will be 'well balanced', but it will have to be ramped up," observes David Stewart, principal at AeroStrategy. "There is enough capacity either in place, or about to be put in place, to manage demand through to 2010. However, by 2016-2017 there will be a need for even more capacity.

"We expect 15% annual growth from 2007 to 2017," notes Stewart. "That's huge, but it is also a function of the engines' reliability. Relatively few are coming through the shops now, but all deliveries made from 1998 to 2007 will be generating shop visits over the coming decade. A 15% annual growth rate translates into a quadrupling of the number of events over the next decade."

The test cell capacity of CFM56-7B providers is a good indicator of the balance between capacity and demand. Test cell capacity in 2007 was sufficient for 500 annual engine shop visits. Any further capacity requirement for managing short-term peaks can be accommodated with extra shifts or overtime, but this will be manageable in 2007, according to Stewart.

Stewart notes that the additional capacity being planned over the next few years will double engine-shop capacity over the next three years. Pratt & Whitney's engine-shop ventures with both Turkish Technic and China Eastern in Shanghai will soon come on line. Other players reported to be adding CFM56-7B capacity include Iberia, TAP, ST Aerospace's Chinese venture (STATCO), Lufthansa Technik's expanded Hamburg engine facility, Aerothrust, and IAI-Bedek. Jet Turbine Services in Australia is also gearing up for CFM56-7B shop visits. Lufthansa Technik recently bought a 50% share in this facility which has capacity to service 600 GE and CFM56-7B engines for customers in the region, including Qantas's. Snecma Services was also reported to be setting up CFM56-7B capability in India, but according to AeroStrategy this is now on hold.

Overall, AeroStrategy reports an overall spend in 2007 of $864.3 million for -7B maintenance, repair and overhaul (MRO). The largest portion, $401.1 million, was spent in North America, followed by Western Europe ($212.8 million), Latin America ($72.8 million), China ($66.5 million), Africa ($38.5 million), Asia Pacific ($28 million), Middle East ($26.2 million), and India ($21 million). These figures correspond roughly to the geographical distribution and size of CFM56-7B fleets worldwide.

Industry perspectives

"We see pretty long on-wing times for first-run engines," says Thomas Böttger, director customer services and product sales at Lufthansa Technik (LHT). "It depends on where the engine is operating, but the demand is more than the industry was expecting, particularly with large fleets where engines were delivered close together. We therefore need a controlled and well planned approach for the first-run removal wave. We are now starting programmes to stagger engine removals, so as not to waste too much life limited parts (LLP) life and to avoid spending too much on spare engines. We will increase capacity at our Hamburg shop so we can be prepared for the demand. The first induction into the shop will probably be late this year or early next year."

LHT aims to develop its own repair solutions for the -7B and to supply parts manufacturer approval (PMA) parts. "We try to do whatever we can to keep the engine on-wing for as long as possible," says Böttger, "so we are educating operators on performing maintenance on-wing wherever feasible, and have on-wing support teams positioned globally.

Böttger says shop-visit drivers are generally not EGT-margin-related. LHT is seeing removals due to issues such as variable stator vanes (VSVs). "This part is becoming worn after 14,000-15,000 flying hours (FH), so we have developed a one-day, on-site repair to fix it because it cannot be replaced on-wing. This means not only that it is not necessary to bring the engine into the shop after only 14,000-17,000FH if the VSV needs work, but the engine could be good for another 8,000-10,000FH before the LLP life is reached," explains Böttger.

Katia Diebold-Widmer, head of marketing at MTU Maintenance Hannover, predicts about 650 shop visits worldwide in 2008, rising to 850-900 by 2010. "Although this is a sharp increase, I do not think there will be a shortage in

CFM56-7B LINE MAINTENANCE & IN-SERVICE OPERATIONAL SUPPORT

	On-wing maintenance	Line maintenance	Hospital repair/ Quick turn repairs	On-wing support	AOG/field services	Borescope inspection
American Airlines	Yes	Yes	Yes	Yes	Yes	Yes
China Airlines	Yes	Yes	Yes	Yes	Yes	Yes
Delta TechOps	Yes	Yes	Yes	Yes	Yes	Yes
GEES (various)	Yes	Yes	Yes	Yes	Yes	Yes
Iberia	Yes	Yes	Yes	Yes	Yes	Yes
Jet Turbine Services /Qantas	Yes	Yes	Yes	Yes	Yes	Yes
KLM Engineering & Maintenance	Yes	Yes	Yes	Yes	Yes	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes	Yes	Yes
MTU Maintenance	Yes	Yes	Yes	Yes	Yes	Yes
Snecma Services	Yes	Yes	Yes	Yes	Yes	Yes
TAP Maintenance & Engineering	Yes	Yes	Yes	Yes	Yes	Yes
Turkish Technic	Yes	Yes	Yes	Yes	Yes	Yes
United Services	Yes	Yes	Yes	Yes	Yes	Yes

CFM56-7B ENGINE MANAGEMENT

	Maintenance management & check planning	ADs/SBs management	Documentation management	Health/ condition monitoring
Aeroturbine	Yes	Yes	Yes	Yes
Delta TechOps	Yes	Yes	Yes	Yes
GA Telesis	Yes	Yes	Yes	Yes
GEES	Yes	Yes	Yes	Yes
IASG	Yes	Yes	Yes	Yes
KLM Engineering & Maintenance	Yes	Yes	Yes	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes
MTU Maintenance	Yes	Yes	Yes	Yes
Pratt & Whitney Engine Services	Yes	Yes	Yes	Yes
Snecma Services	Yes	Yes	Yes	Yes
SR Technics	Yes	Yes	Yes	Yes
TAP Maintenance & Engineering	Yes	Yes	Yes	Yes
Turkish Technic	Yes	Yes	Yes	Yes
Total Engine Support (TES-UK)	Yes	Yes	Yes	Yes
United Services	Yes	Yes	Yes	Yes

CFM56-7B ENGINE PROVISIONING

	Short-term leasing	Medium- & long-term leasing	Engine pooling	Sale & leasebacks
Aeroturbine	Yes	Yes	Yes	Yes
AAR Engine Sales & Leasing	Yes	Yes	Yes	Yes
AerCap Engine Leasing	Yes	Yes	Yes	Yes
Engine Lease Finance	Yes	Yes	-	Yes
GA Telesis	Yes	Yes	-	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes
Macquarie AirFinance	Yes	Yes	-	Yes
Magellan Group	Yes	Yes	-	Yes
Shannon Engine Support	Yes	Yes	Yes	Yes
Tradewinds	Yes	Yes	Yes	Yes
Willis Lease Finance	Yes	Yes	Yes	Yes

capacity, especially as many providers are adding capacity over the next few years."

One important issue is that there are not as many spare -7 engines available as there are for other engine types. "It will be critical for airlines without spares to first find an adequate source for them during their shop visits, either directly with the MRO shop or from an engine lessor," says Diebold-Widmer. Given the limited supply of spare engines, it will also be crucial for MRO providers to offer competitive turnaround times.

"We have two overhaul locations, in Hannover, and Zhuhai in China. We are also an original equipment manufacturer (OEM) licensed provider," notes Diebold-Widmer. "With about 40% of the CFM56 aftermarket under contract to both GE and Snecma, and 13% in-house 'airline captive', there is not much room for other providers. This is important because at present the world market is overcrowded with third-party shops."

Like other large engine MROs, MTU has been offering thrust-per-hour contracts for some years. "We are also targeting the largest 'non-captive' airlines. We offer everything up to our total engine care packages, which include standard engine MRO, fleet management, engine condition monitoring, and logistical services up to line replaceable unit (LRU) support," says Diebold-Widmer.

Designated engineering representative (DER) repair development is an important activity for MTU. "One of the areas we are looking at is airfoil replacement technologies. We would be investing in the high value parts, typically high pressure turbine (HPT) airfoils, but we are not planning to develop PMA parts or LLP repairs," continues Diebold-Widmer.

Both MTU's facilities are already fully equipped, and large enough to absorb the expected CFM56-7B shop-visit increase. "We have a flow-line for inducting the engines in Hannover, which means we can induct any engine at any time, and it makes no difference whether we induct a -7B, or PW2000 or V2500. We have also invested in a new test cell which will be operational by end of August 2008.

"The -7B market is characterised by large fleets and a plethora of small operators. There are only big fishes left, and there are only a few of those. Everyone seems to think CFM56-7B MRO is a big market, but given what is already captive, and how many providers are offering their services, it actually is not."

Dave Monasterio, CFM56 MRO programme manager at Pratt & Whitney Engine Services (PWES), notes: "We are very active on the CFM56-7B, as well as the overall CFM MRO business. We are competing in three to five campaigns a month with the rest of the MRO providers. We are very busy, especially at our engine centre in Norway, and expect to be as busy at our two engine centres in Shanghai and Turkey."

PWES has seen an increase in -7B work over the past three years. "About 60% of our work is now on the -7B, up from 30%, and we expect it to reach

70%. Today most of the new business in Norway relates to -7Bs.

"The -7Bs first went into service 10 years ago, so the early engines will be due for LLP replacement, especially the lower-thrust models rated at 22,000lbs and 24,000lbs thrust. We expect a large uptake in shop visits for the -7B in the next three to four years," continues Monasterio.

Shop visits will most likely be due to a combination of LLP expiry and EGT margin loss for engines rated at 26,000lbs or 27,000lbs, according to Monasterio. "A lot of the operators re-rate EGT-margin-limited engines, which extends their on-wing life until LLPs expire." AC

CFM56-7B ENGINE COMPONENTS

	QEC repair	QEC build-up & engine dressing	LRU repair	LRU pooling & logistics
Aeroturbine/AerCap	Yes	Yes	Yes	Yes
AirLiance Materials	-	-	-	Yes
Delta TechOps	Yes	Yes	Yes	Yes
GEES	Yes	Yes	Yes	Yes
KLM Maintenance & Engineering	Yes	Yes	Yes	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes
MTU Maintenance	Yes	Yes	Yes	Yes
Pratt & Whitney Engine Services	Yes	Yes	Yes	Yes
Snecma Services	Yes	Yes	Yes	Yes
Turkish Technic	Yes	Yes	Yes	-
Tradewinds	-	-	-	Yes
Unical	-	-	-	Yes

CFM56-7B SHOP VISIT MAINTENANCE

	Hot-section inspection	Module change	Module overhaul	Full overhaul	Disassembly/ build-up
Aerothrust	Yes	Yes	Yes	Yes	Yes
American Airlines Maintenance	Yes	Yes	Yes	Yes	Yes
Bedek Aviation (IAI)	Yes	Yes	Yes	Yes	Yes
China Airlines	Yes	Yes	Yes	Yes	Yes
Delta TechOps	Yes	Yes	Yes	Yes	Yes
GEES Dallas	Yes	Yes	Yes	Yes	Yes
GEES Strother	Yes	Yes	Yes	Yes	Yes
GEES Wales	Yes	Yes	Yes	Yes	Yes
GEES Malaysia	Yes	Yes	Yes	Yes	Yes
Iberia	Yes	Yes	Yes	Yes	Yes
Jet Turbine Services	Yes	Yes	Yes	Yes	Yes
KLM Engineering & Maintenance	Yes	Yes	Yes	Yes	Yes
Lufthansa Technik	Yes	Yes	Yes	Yes	Yes
Lufthansa Technik - Airmotive Ireland	Yes	Yes	Yes	Yes	Yes
MTU Maintenance Hannover	Yes	Yes	Yes	Yes	Yes
MTU Zuhai	Yes	Yes	Yes	Yes	Yes
Pratt & Whitney Norway	Yes	Yes	Yes	Yes	Yes
Pratt & Whitney Shanghai	Yes	Yes	Yes	Yes	Yes
Snecma Morocco Engine Services	Yes	Yes	Yes	Yes	Yes
Snecma Services Villaroche	Yes	Yes	Yes	Yes	Yes
SR Technics	Yes	Yes	Yes	Yes	Yes
SSAMC (Sichuan Snecma Aero Engine Maintenance Company)	Yes	Yes	Yes	Yes	Yes
ST Aerospace Engines	Yes	Yes	Yes	Yes	Yes
ST Aerospace Engines (STATCO, Xiamen)	Yes	Yes	Yes	Yes	Yes
TAP Maintenance & Engineering	Yes	Yes	Yes	Yes	Yes
Turkish Technic	Yes	Yes	Yes	Yes	Yes
United Services	Yes	Yes	Yes	Yes	Yes

CFM56-7B SPECIALIST REPAIRS

	Fan blade repair	Vanes & stator repair	Compressor blade repair	Turbine blade repair	Combustor repair	Casing repair	Seals repair	On-site DER authority	PMA parts approved
Airfoil Technologies	Yes	Yes	Yes	-	-	Yes	-	Yes	-
Airfoil Services Malaysia	-	-	Yes	Yes	-	-	-	Yes	-
Chromalloy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
GEES	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
GKN-Chemtronics	Yes	-	Yes	-	-	Yes	-	Yes	-
MTU Maintenance	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
Lufthansa Technik	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pratt & Whitney Services	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Snecma Services	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-
ST Aerospace Engines	-	Yes	Yes	Yes	-	-	-	Yes	-

CFM56-7B aftermarket & values

The CFM56-7B is a popular engine, and there are few spare units available on the market. Lease rates have held firm, while values have climbed steeply over the past two to three years.

The 737NG has become the second most numerous aircraft in operation, and with it the CFM56-7B has become one of the most popular engine types. The operational fleet exceeds 5,100 engines. Despite these large numbers, there are relatively few CFM56-7Bs available as spares.

The CFM56-7B has already established itself as a reliable powerplant, achieving removal intervals rarely seen with earlier generation engines *(see CFM56-7B maintenance analysis & budget, page 18)*. First removal intervals are commonly 18,000-20,000 engine flight cycles (EFC) for the lower rated -7B20 and -7B24 engines, which is equal to 27,000-38,000 engine flight hours (EFH). These intervals are explained by the fact that the engine has high exhaust gas temperature (EGT) margins and overall good durability, and because it is removed mainly when it has reached life limits for life limited parts (LLPs).

Higher-rated -7B26 and -7B27 engines, which account for about half the engines in operation, have shorter removal intervals of 9,000-12,000EFC, equal to 14,000-21,000EFH.

Most operators have annual utilisations of about 3,000 flight hours (FH), so first removals are happening only once the aircraft have reached five to nine years of age in many cases. Moreover, the majority of 737NG deliveries have been within the past five years. Engine removal and shop visit activity has therefore been low, and has only started to climb over the past three years. Global shop visit activity is estimated to have reached about 500 shop visits in 2007, and is expected to reach about 650 for the whole of 2008. Activity is predicted to climb further to reach 850-900 shop visits in 2010.

This steep climb in engine maintenance activity will clearly lead to an increased demand in spare engines, but there are signs that availability is already tight. "Shop visit demand has not yet solidified because the engines have long removal intervals, and most needs for spares are still covered by short-term leases," explains Andrew Pearce, director at MacQuarie Aviation Capital. "The main market is with small operators, since the large airlines are well supplied with spares. The number of shop visits is likely to double over the next two years, however."

Values of CFM56-7Bs, and of 737NGs, have firmed in recent years as the industry has gone from having surplus aircraft to experiencing a shortage. While availability of A320 family aircraft increased from 2001 to 2004, the supply of readily available 737NGs remained relatively tight, and all lessors and traders reported that any 737NGs and CFM56-7Bs that became available did not remain on the market for long.

Demand has in fact remained so strong that list prices for new CFM56-7Bs increased rapidly. These are about 12% higher for 2008 than they were in 2007. Some are reported to have paid more than 100% of the list price to get hold of engines. List prices for 2008 are about $9.2 million for bare -7B27 engines, $8.4 million for -7B26 engines, and $7.8 million for -7B24 engines. "Supply of engines dried up in 2005-2007," says Abdol Moabery, president and chief executive officer at GA Telesis. "This drove values up. While discounts were possible up to 2005, by 2006 deals were being done at higher than list price."

This high demand has had a direct impact on short- and long-term lease rates. Pearce estimates that short-term lease rates are at least $3,000 per day for terms of up to 12 months, which is equal to $90,000 per month. Rates are often close to $4,000 per day, or $120,000 per month.

Long-term lease rentals have also climbed, with Pearce now estimating monthly rentals at $60,000-70,000 for deals of three to five years.

Concerns are now being raised by the relentless rise in oil prices and the effect it is having on airline costs, the economy and demand for air travel, and airline fleet plans. Older aircraft types like the MD-80 and 737 Classics will obviously be parked or retired before any 737NGs are considered in capacity reduction plans.

Predictions of how high oil and fuel prices will affect the 737NG market are mixed. "Lease rentals for the CFM56-7B are unlikely to weaken because the

The CFM56-7B's long removal intervals has meant that shop visit activity has only started to climb in recent years. This kept supply of spare engines tight and pushed up lease rates.

The fast rise in fuel prices over the past year has weakened airlines' finances with a consequent increase in demand for sale and leaseback transactions. Supply of debt is limited, however, and debt margins have increased to as much as 250 basis points.

737NG will remain popular," says Dennis Smink, chief operating officer at SGI Aviation Services. "The old aircraft types will suffer in large numbers, but I predict the availability of 737NGs to remain tight. Early production engines are now on a climbing wave of shop visit activity and the next two years will be very busy for the CFM56-7B overhaul market and leasing business. This will clearly affect lease rates, and demand for spare engines is going to be high. Short-term leases, to provide cover for shop visits, are currently commanding rentals of $3,000-4,000 per day, and this does not include maintenance reserves. Long-term rentals are attracting lease rate factors of about 1% per month, which on list prices of $9.5 million for a bare engine is equivalent to $90,000-95,000 per month. Moreover, purchase discounts are hard to obtain. Going forward we expect lease rates to remain firm rather than weaken."

Pearce reiterates that the CFM56-7B maintenance market will mature over the next two to three years. This will coincide with a significant change in the fleet mix. Not only will older aircraft types be phased out over a short period, but demand for the 737NG and A320 could strengthen as airlines make every effort to acquire the most fuel-efficient aircraft. The downward pressure on passenger yields and upward pressure on fuel costs are also taking their toll on airline finances, and airlines are, as a result, seeking all ways possible to raise liquidity.

"We have seen a 300% increase in demand from airlines wanting to do sale and leaseback transactions on engines," says Moabery. "Airlines need liquidity and we are seeing a lot more opportunities to buy engines from operators. There have also been a few deferrals of 737NG deliveries, and so some engine production slots from CFM have opened up. Only the highest-rated engines are sold to lessors, however, and this means we are having to pay for -7B27 engines, which have list prices that are about $1.4 million more than -7B24 engines. At the same time, while demand is still strong, lease rates have softened a bit over the past three months because airlines are cutting back on aircraft utilisation slightly due to the changing economic conditions of the market."

Smink reports the same increase in interest from airlines in doing sale and leaseback transactions. "SGI Aviation Services first offers asset management services, and we can source spare engines for airlines. This is both in terms of buying and leasing. We offer pre-lease inspections, which include inspecting documents, maintenance records and LLP sheets. We also perform cashflow analyses of transactions, which consider rentals and maintenance reserves, and also negotiate return conditions with the lessors on behalf of the airlines. We can also negotiate maintenance reserves, and also sell engines for airlines that are restructuring.

"We also arrange sale and leaseback transactions, but while there is high demand for these from airlines that want to raise liquidity, there is less debt available to finance these transactions," continues Smink. "The equity levels required by debt providers have increased to 25-30%, and lessors need this first. Once the quick engine change (QEC) has been taken into consideration, equity can be up to about $3.2 million on a dressed -7B27 engine. Sourcing debt remains a problem. The credit crunch over the past year has meant that some financial institutions are unable to provide debt, while others are now wary of lending to the industry because of the poorer credit ratings of some operators, and the industry's difficulties with high fuel prices as a whole.

"Terms for sale and leaseback transactions are seven to 10 years. Lease rental factors of 1% per month are equal to about $90,000 for a new engine," continues Smink. "A used engine that is three or four years old can be bought for about $7 million, and it can be expected to have lease rates of $70,000-75,000 per month. There can be good margins for lenders, but there is the risk that the cost of debt could go up as global interest rates rise. Debt is already expensive, with margins now 250 basis points over base rates. This can mean that a lessor is paying 7% annual interest on the 70-75% debt portion of the purchase price, and these payments have to be funded from lease rentals. These high debt margins compare with margins of about 80 basis points from a few years ago. Debt balloons are also becoming harder to negotiate, so sale and leaseback transactions are actually becoming more difficult to justify for lessors, despite the growing interest from airlines." AC