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FINDING THE NARROW TARGET OF SUCCESSFUL LARGE RJ OPERATIONS

Potential markets for 70- to 115-seat RJs | Technology to assist aircraft turnaround processes
CFM56-7B maintenance management & budgets | Appropriate parts & components for cabin maintenance
Configuring an M&E system for MRO providers | 737NG freighter conversion programmes

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The CFM56-7B has now been built to three production standards. The engine has demonstrated long on-wing durability, and this results in long shop visit removal intervals. Potential shop visit patterns, shop visit inputs and costs, and resulting maintenance reserves are examined.

CFM56-7B maintenance management & shop visit inputs & reserves

The CFM56-7B has become the most successful commercial jet engine to date. As the only engine to power the 737NG platform, it was fitted on 7,070 aircraft built from 1997 to 2019. Not only is the CFM56-7B operated in large numbers worldwide, but it has also proved to be highly reliable in most operational cases. With the oldest engines having been retired, and the youngest engines having almost a complete operating life ahead of them, an assessment of the engine's in-service performance and maintenance requirements is made. This is an update on the last detailed analysis of the CFM56-7B's maintenance from 2013 *(see Long-term CFM56-7B maintenance costs, Aircraft Commerce, April/May 2013, page 43)*.

CFM56-7B fleet

Most 737NG applications are commercial jetliners, but some are used as a business jet and for military purposes.

The CFM56-7B family has six main variants, each with its own thrust rating, ranging from 18,000lbs to 27,300lbs, available for the four main 737NG family members: the 737-600, -700, -800 and -900.

The engine airfoil, disk and shaft hardware are identical for all six ratings. The thrust rating is changed via the engine's full authority digital engine control (FADEC) unit.

Each variant is designated the -7BXX; the last two digits denote the engine's thrust rating in thousands of pounds.

The lowest rating is 18,000lbs of thrust, provided by the -7B18 variant, but no airline or operator has specified this thrust rating to date.

The second variant is the -7B20, with a thrust rating of 20,600lbs. Only 149 aircraft have been equipped with this rating, the smallest number of all ratings in the fleet. This powers 47 737-600s and 102 737-700s.

The third variant is the -7B22, rated at 22,700lbs thrust. This has equipped 714 aircraft to date: 22 -600s and 692 737-700s.

The other three variants are the most numerous. The -7B24 is rated at 24,200lbs thrust, and powers 309 737-700s, 901 -800s and 28 737-900s.

The -7B26 is the most popular variant, and has equipped 3,938 aircraft: 78 737-700s, 3,564 737-800s, and 296 -900s.

The -7B27 is rated at 27,300lbs, and was fitted to 1,031 aircraft: 102 737-700s, 700 737-800s, and 229 737-900s.

Production of the 737NG family therefore totalled 7,070 aircraft as follows: 69 -600 series aircraft; 1,283 -700 series; 5,165 -800 series; and 553 of the largest -900 series. The 600 series ceased production in 2006, while production of the other three series continued until 2018 and 2019.

Build standards

There are, however, three main build standards for the CFM56-7B, designated by a suffix. While the engines of these three build standards have identical hardware for the six variants and thrust ratings, the hardware is upgraded for the second and third main build standards.

Engines with the first build standard are referred to as baseline engines, and are designated simply with a -7BXX. There were 2,269 aircraft fitted with baseline engines.

The first major upgrade modification and programme for the -7B engine series was released by CFM in 2007, and is referred to as the Tech Insertion upgrade. This is designated as -7B3XX/3, and was introduced on the production line, as well as being a retrofit programme installed during a shop visit (SV). There were 1,463 aircraft equipped with /3 engines. Most are -7B24, -7B26 and -7B27 engines powering 1,263 aircraft *(see table, page 24)*.

The Tech Insertion modification has a new shipset of airfoils and other parts to most modules, including: an enhanced singular annular combustor (SAC); and redesigned high pressure compressor (HPC) and high pressure turbine (HPT) blades and stators. The blades in the HPC module were 3-D aero blades, added to improve the engine's fuel burn efficiency.

The low pressure turbine (LPT) blades were also improved and the LPT first stage nozzle was redesigned. Overall, the Tech Insertion upgrade reduced fuel burn by about 1%. The upgrade programme also effected a small increase in exhaust gas temperature (EGT) margin.

"The main purpose of the Tech Insertion programme was to reduce fuel burn and make the engine more durable," says Francesco Baccarani, vice president of technical at SGI Aviation.

The second modification and upgrade programme is referred to as the Evolution upgrade. "These are designated as -7BXX/E engines, and the same modification is known as the performance improvement programme (PIP) used in the -5B series," says Baccarani. This was introduced from 2011 on the production line. It was also retrofittable in an SV. The upgrade included modifications to the outlet guide vane (OGV) in the HPT, new HPT blades, and changes to the forward and outer air seals. The number of HPT blades was also reduced from 80 to 76. There were also changes to the LPT blades and stators, and the casing.

"The /E modification programme

CFM56-7B-POWERED 737NG FLEET PRODUCTION

737NG series	-600	-700	-800	-900	TOTAL
CFM56-7B20	29	84			113
CFM56-7B20/3	14	18			32
CFM56-7B20/E	4				4
TOTAL -7B20	**47**	**102**			**149**
CFM56-7B22	22	517			539
CFM56-7B22/3		168			168
CFM56-7B22/E		7			7
TOTAL -7B22	**22**	**692**			**714**
CFM56-7B24		230	157	19	406
CFM56-7B24/3		35	223		258
CFM56-7B24/E		44	521	9	574
TOTAL -7B24		**309**	**901**	**28**	**1,238**
CFM56-7B26		50	884	24	958
CFM56-7B26/3		16	742	89	847
CFM56-7B26/E		12	1,938	183	2,133
TOTAL -7B26		**78**	**3,564**	**296**	**3,938**
CFM56-7B27		68	185		253
CFM56-7B27/3		23	137	2	162
CFM56-7B27/E		11	378	227	616
TOTAL -7B27		**102**	**700**	**229**	**1,031**
TOTAL PRODUCTION	**69**	**1,283**	**5,165**	**553**	**7,070**

CFM56-7B-POWERED 737NG FLEET STATUS END FEBRUARY2021

737NG series	Active	Storage	Retired	Written off	Military/ special	TOTAL
CFM56-7B20	59	23	31			113
CFM56-7B22	319	151	67	2		539
CFM56-7B24	248	108	41	6	3	406
CFM56-7B26	545	329	40	6	38	958
CFM56-7B27	105	64	8	2	74	253
TOTAL BASE ENGINES	**1,276**	**675**	**187**	**16**	**115**	**2,269**
CFM56-7B20/3	11	5	15		1	32
CFM56-7B22/3	145	17	4		2	168
CFM56-7B24/3	209	43	5	1		258
CFM56-7B26/3	593	243		4	3	843
CFM56-7B27/3	70	40	2	3	47	162
TOTAL -/3 ENGINES	**1,028**	**348**	**26**	**8**	**53**	**1,463**
CFM56-7B20/E			4			4
CFM56-7B22/E	6				1	7
CFM56-7B24/E	500	69	1	2	2	574
CFM5607B26/E	1,800	320		1	16	2,133
CFM56-7B27/E	445	41			130	616
TOTAL /E ENGINES	**2,751**	**430**	**5**	**3**	**149**	**3,338**
OVERALL TOTAL	**5,055**	**1,453**	**218**	**27**	**317**	**7,070**

reduced fuel burn by a further 1.6%, and also increased EGT margin by a few degrees centigrade," says Baccarani. "It is too early at this stage to say if the /E programme has actually made the engine more durable and allowed longer removal intervals. This is because the first /E engines were built in 2011, so only a few have got to their first removal. A few -7B26/E engines, however, have got close to 20,000 engine flight cycles (EFC) for their first removal interval."

There were 3,338 aircraft equipped with /E engines, the most numerous of the three build standards. This includes 574 aircraft with -7B24 engines, 2,133 aircraft with -7B26 engines, and 616 aircraft with -7B27 engines *(see table, this page)*.

Most of the 737NG fleet are -800 and -900 series aircraft equipped with /3 and /E engines. This group totals 4,449 aircraft, equal to 63% of the fleet. Moreover, 510 of 553 737-900s are fitted with /3 and /E engines. Similarly, 3,939 of 5,165 737-800s have /3 and /E engines, equal to 76% of the -800 fleet. In contrast, only 26% of 737-700s have /3 and /E engines, while the remaining 74% have baseline engines.

Most larger aircraft with higher-rated engines have /3 and /E engine variants that have higher EGT margins, so they are capable of longer removal intervals.

CFM56-7B in operation

Of the 7,070 737NGs built with CFM56-7B engines, 317 are corporate or military jets. This leaves 6,753 commercial aircraft.

The fleet of commercial aircraft that are either active or in storage includes 1,951 aircraft with baseline engines, 1,376 with /3 engines, and 3,181 aircraft with /E engines. This totals 6,508 aircraft *(see second table, this page)*.

While large numbers of 737NGs were built, the Covid-19 pandemic and resulting crisis since early 2020 has seen large numbers of commercial aircraft parked, put into storage or retired. As of the end of February 2020, there were 5,055 active commercial aircraft, most of which are in passenger configuration. A further 1,453 were in storage and parked, 218 had been retired, and 27 had been written off.

Of the 6,441 aircraft that were active before the start of the pandemic, 21.5% were subsequently stored or parked (1,362) or retired (24); these accounted for 1,386 of the 1,453 aircraft in storage or parked at the end of February 2021.

Of these 1,453 aircraft, 778 are fitted with /3 and /E engines (53%). The portion of /3- and /E-equipped aircraft in storage is small compared to the portion of stored aircraft with baseline engines. This reflects the younger age and higher performance capability of the /3 and /E engines, which airlines value because of their longer removal intervals.

In addition to the reduced number of active aircraft during the Covid-19 pandemic, airlines have been operating aircraft at lower rates of utilisation than in 2018 and 2019. All measures have been taken to minimise maintenance inputs to save cash. For example, airlines have swapped engines between aircraft. Engines with maintenance life or 'green time' have been taken from parked and stored aircraft and installed on active aircraft. This raises the issue of how many engines are left with green time available, and when that number might reduce to a critical level.

Other issues to consider are that the utilisation of all or a high percentage of engines with available green time will result in a sudden bow wave of SV activity. A large portion of the youngest /3 and /E engines have not yet been through their first engine SV, and a surge in maintenance activity could result in a shortage of maintenance slots for engines.

A further consideration is traffic

The CFM56-7B powers more than 7,000 737NGs, many of which are operated in large fleets in temperature environments. Typical annual utilisation rate is 1,600-1,800EFC. Many aircraft operate at 1.7-1.8FH per FC.

recovery and fleet renewal. To date the only full traffic recovery for a market that uses the 737NG on a large scale is the Chinese domestic market. The other major narrowbody markets are Europe, North America and South America. Only steady and relatively high rates of traffic recovery during the spring and summer of 2021 will see a large portion of the 1,362 commercial aircraft in storage return to active service.

Before the Covid-19 pandemic, aircraft operated at annual rates of utilisation of at last 2,500 flight hours (FH), with many aircraft achieving up to 3,000FH per year. Typical average FC time is 1.50-1.75FH, and annual utilisation in FH per year generally increases with longer average FC times. Most aircraft in operation with scheduled services will achieve annual utilisations of 2,600-3,000FH, equal to 1,650-1,750FC per year. Some airlines, like those operating for tour operators such as Tui, achieve higher rates of utilisation of 3,000-3,500FH per year. The highest levels of total time are 77,000FH and 49,000FC.

The first aircraft entered service in late 1997 and early 1998.

737 MAX effect

The other factor that will affect CFM56-7B maintenance activity and the availability of modules and complete engines with green time available, is the number of parked 737 MAXs that are due to be brought back into operation, and the number of 737 MAXs on order and due for delivery over the next two years.

There were 145 737 MAXs in storage in North America, 97 in China, 72 in Europe and 77 in other parts of the world at the end of February 2021. Stored aircraft in North America include those for American Airlines, Southwest, United Airlines and Westjet. These all operate 737NGs. The 97 aircraft in China are for Air China and 12 other carriers. Many of these operate the 737NG.

737 MAXs parked for European carriers include LOT Polish, Icelandair, Tui and Turkish. These all operate 737NGs as well. The same applies to several carriers in the Asia Pacific.

A large number of the 737 MAXs that will be reactivated over the next few months were originally ordered to replace 737NGs. In addition to parked aircraft, 3,955 737 MAXs are on firm order, including 722 aircraft for North America, 771 for Europe, 1,022 for the Asia Pacific, 209 for China, and 323 for Central and South America.

The large number of 737 MAXs due for reactivation and delivery, and the limited recovery in traffic, indicates there is a high chance that many of the 1,453 parked 737NGs will not go back into operation. This would have the effect of retiring a large number of 737NGs, and putting all their CFM56-7Bs on to the used market, thereby providing a sustained supply of green-time modules and engines to satisfy the maintenance market.

Maintenance management

The CFM56-5B and -7B are known for having a high EGT margin, due mainly to the relatively large core engine. Initial EGT margins for new engines are high for the three thrust ratings of 20,600-24,200lbs, and moderate for the two higher thrust ratings. The /3 and /E modification and improvement programmes have increased EGT margin.

The implications of high EGT margins are that planned removal intervals can be relatively long, to the point that they can potentially be as long as the certified lives of core engine life limited parts (LLPs) at 20,000EFC. “Most -7B variants are not usually removed due to EGT margin erosion,” says Baccarani. “If all variants up to the -7B26 are operated in a temperate environment, EGT margin erosion is unlikely to be the reason for removal. It is only an issue for the -7B27 variant, or if engines are operated in a hot and sandy environment, such as the Middle East.

“In most cases, the engines are capable of long removal intervals, and the main removal causes are usually hardware deterioration and LLP life limits,” adds Baccarani.

LLP lives

When the -7B was first introduced into service, the life limits of parts in its four main modules were not uniform. The target lives for HPC and HPT LLPs were 20,000EFC, 30,000EFC for the fan/low pressure compressor (LPC), and 25,000EFC for parts in the LPT.

Many parts in these four modules had lives shorter than these. The fan disk in the fan/LPC module had several part numbers (P/Ns) with lives of 15,500-27,600EFC. The booster spool had some P/Ns with certified lives of 20,900-25,600EFC. There were also a few parts in the HPT spool with lives of 16,600-18,900EFC. These parts installed in earlier-built engines would have triggered removals for SVs by LLP expiry. Later P/Ns for LLPs in the same position had lives certified at the full target limits.

The fan/LPC has three parts, all with certified life limits at 30,000EFC. This shipset of parts has a 2020/21 list price of $876,000.

The two core engine modules have nine parts: two seals, three shaft segments, and one HPT and three HPC disks. The five HPC parts have uniform lives of 20,000EFC and a 2020/21 shipset list price of $1.086 million. The four HPT parts also have lives of 20,000EFC and a 2020/21 list price of $1.16 million.

The LPT module has six parts that include four disks, one shaft and a conical support. These have uniform lives of 25,000EFC and a 2020/21 shipset list price of $1.21 million.

The total shipset of 18 parts for the whole engine has a 2020/21 list price of $4.34 million, compared to a 2013 shipset list price of $2.52 million. The list price has increased at an annual rate of about 7%.

Only baseline CFM56-7B engines are mature in maintenance terms. Many Tech Insertion /3 engines have yet to have their first shop visit, despite being about 10 years old. Low- and medium-rated engines can have first removal intervals close to 20,000EFC.

EGT margins

The -7B's core engine is relatively large, and is a main factor in the high initial EGT margin for each variant. For baseline engines, this is up to 130 degrees centigrade for the -7B20 variant, 100-105 degrees centigrade for -7B24 variants, 80-85 degrees centigrade for the -7B26 variant, and lower at 52-64 degrees for the -7B27 variant. These baseline engines are no longer manufactured, with the -7BXX/3 Tech Insertion engines coming off the production line from 2007.

"The EGT margin erosion rate has generally been shown to be 10-15 degrees centigrade for the first 1,000EFC on-wing as clearances open up and blade tips experience initial wear," says Baccarani. "The EGT margin loss rate then settles down to a steady rate of 4-5 degrees per 1,000EFC for most variants, being lower for the lowest-rated engines. If engines get to the point where they have about 10 degrees centigrade of EGT margin left, then the rate of loss accelerates as all hardware has deteriorated beyond a certain level."

Such EGT margins and margin erosion rates can allow a first removal interval of up to a full 20,000EFC of core engine LLP lives for the -7B20, -7B22 and -7B24 variants; and even for some -7B26 engines. "Most -7B variants will be removed earlier than the full 20,000EFC LLP limit because of the effects of such long intervals on parts that have to be replaced at the SV, compared to those that are repaired," says Baccarani. "The percentage of parts replaced at the SV can increase exponentially when the on-wing interval has passed its optimum point. Most variants will be removed when hardware has been known to have deteriorated to a particular degree, as confirmed by borescope inspections. The -7B24 and -7B26 typically achieve average first removal intervals of 16,000-17,000EFC, while the highest rated -7B27 has shorter intervals of 10,000-13,000EFC *(see table, page 31)*. It is these first removal intervals and the LLP lives in each module that will determine the subsequent removal intervals and SV workscopes."

The /3 and /E modification and upgrade programmes were partly intended to improve the engine's durability through improved performance. This included a predicted increase in EGT margin of 10-15 degrees. This was intended to extend planned removal intervals.

"There is little benefit in increased removal interval for low- and medium-rated engines. The -7B26 maybe gets an average of another 500EFC on-wing," says Glenford Marston, chief executive officer at AeroNorway.

Others generally agree. "There is a small benefit in terms of longer first and second planned removal intervals," says Jamie Devin, director of business development, at Global Engine Maintenance. "These can be in the order of 1,000EFC for /3 engines compared to the baseline standard for the -7B26 and -7B27 variants. The benefit is generally larger for the -7B24 and the lower-rated variants."

There is so far little information about the relative performance of /E engines. "There is not much of an increase in removal interval in the case of most variants," says Baccarani. "This is because of the already high performance of the /3 and baseline engines. It is also too early for most /E engines, since the oldest were built in 2011, and many younger ones have not completed their first intervals."

Marston makes the point that Middle Eastern operators need the increase in performance that the /E modification can provide. "We expect the intervals to be about 10,000EFC, compared to 8,500-9,500EFC for the baseline and /3 engines," says Marston.

Restored EGT margins

Restored EGT margin is mainly determined by the workscope performed at the first SV. This is particularly related to the status of hardware in the two core engine or high pressure (HP) modules.

In the case of most variants up to the -7B26, the first SV will include a full overhaul or a heavy workscope of the HP modules because of the need to replace LLPs and the main airfoil components.

This will at least include replacing HPT blades, which have a soft life limit of 20,000EFC in the case of baseline and /3 engines, and 25,000EFC in the case of /E engines. "The aim will be to repair other major airfoils, such as the nozzle guide vanes (NGVs) and LPT nozzles, and the first stage stators in the LPT, and HPC blades and vanes," says Baccarani.

The restored EGT margin of a CFM56-7B following an SV is 15-30 degrees lower than the original EGT margin of the new engine. The actual difference depends on the first removal interval and the following SV. A small repair SV, such as a top case repair to the HPC, only achieves a recovery of 5-15 degrees.

The restored EGT margin for the -7B20 following such workscopes has been 100-110 degrees centigrade in many cases at the start of the second interval following installation, 85 degrees in the case of the -7B22 variant, slightly lower at 80 degrees for the -7B24, and 60-68 degrees for the -7B26.

In the case of the -7B27, a lower initial EGT margin is more likely to result in a medium-length removal interval of 10,000-13,000EFC. The SV workscope following this removal is therefore more likely to be a performance restoration, given that a second similar interval will take the HP modules to LLP limits.

The restored installed EGT margin for the -7B27 following the first SV has been 40-45 degrees.

If a restored EGT margin is 10-20 degrees lower than the initial margin, this means that the second planned interval will be 2,000-5,000EFC shorter than the first interval. This has implications for the higher-rated -7B26 and -7B27 variants. This issue also illustrates the benefit of the /3 Tech Insertion and /E Evolution upgrades and modifications.

The EGT margin of most variants is high enough to make SV patterns and management predictable. LLP life limits mainly determine the SV planned removal and workscope patterns of the different variants.

Shop visit patterns

The approximate pattern of possible SVs and resulting SV workscopes and replacement of LLP shipsets can be forecast, based on likely planned removal intervals. Potential removal intervals can be based on EGT margin and EGT margin erosion rate where appropriate, LLP life limits, and typical removal causes. These intervals can, however, be interrupted by engine and non-engine unplanned events, such as birdstrikes, bearing failures, and the premature degradation of airfoils and other engine parts. Severe events can lead to heavy workscopes being required that can compromise a planned removal interval and SV pattern going forward.

Baseline engines

Low- & medium-rated variants

The -7B20, -7B22 and -7B24 variants have potential removals of close to or even at the HP LLP life limits of 20,000EFC. That is, the -7B24's initial EGT margin of 100-105 degrees and the EGT margin erosion rate of 4.5 degrees centigrade per 1,000EFC can result in first removal intervals close to 20,000EFC in some cases, but median intervals are shorter at 17,000-19,000EFC for most engines. The first removal interval for most engines is 18,000-19,000EFC *(see table, page 31)*. "This is equal to eight to nine years of operation at typical rates of utilisation. This length of removal interval will require a full disassembly of the core engine to allow replacement of core engine LLPs," says Baccarani.

"The engines are mainly removed due to hot section deterioration," continues Baccarani. "The first SV will require the replacement of most HPT blades, which have soft lives of 20,000EFC and a list price of $1.4 million for a shipset. The combustion chamber will also require at least a repair, as will the NGVs, and the stage 1 LPT nozzles that sit between the HPT blades and the stage 1 LPT blades."

Careful consideration has to be given to the removal interval, because of the effects of the exponential increase in SV costs due to parts replacement by allowing the interval to be too long. The current list price of all airfoils in the HPT, and the stage 1 LPT nozzles, is more than $5.3 million. A small portion of parts repair rather than replacement will therefore clearly reduce SV costs, and will result in a lower amortised cost per EFC.

The subsequent second interval following this first workscope will be limited to 8,000-9,000EFC if the LLPs in the LPT are not replaced at the first SV, but will potentially be 13,000-14,000EFC if they are replaced. "In general there is little market for LLPs removed from the LPT if they have remaining lives of 7,000EFC or less. A first interval of up to 18,000EFC would mean that the LPT is left until the second removal, which would be limited to 7,000EFC and a total time of 25,000EFC because of LPT parts lives. The second SV would therefore involve the disassembly of the LPT and replacement of all LLPs *(see table, page 31)*. The restored EGT margin of 80-85 degrees would allow a longer interval of up to 13,000EFC if the LPT was not the limiting factor.

"The fan/LPC can be left. It would have remaining LLP lives of just over 5,000EFC at this stage, so it would restrict the third removal to the LLP life and come due at a total time of 29,000-30,000EFC," says Baccarani. "The fan/LPC can easily be removed and have a workscope on its own without affecting the other modules. The core engine, however, would have had a total time of 12,000-14,000EFC, at this stage and so require a second workscope at

The fan/LPC module on the CFM56-7B can be removed from the rest of the engine relatively easily. This allows the fan/LPC to have its own shop visit input, while the rest of the engine can be left.

the third SV. Most HPC and HPC airfoils would have a scrap rate of 20-30%, while it could be higher at 50% for HPT blades and NGVs. Total time at this stage will be close to the 30,000EFC limit of the fan/LPC LLP life limits."

Total time by this stage will be about 17 years of operation. New core LLPs at the third SV would allow a fourth interval of up to 18,000EFC. This would take the engine to a total time of 47,000EFC, equal to 26 years of operation. If an SV were actually required at this stage it would involve full core and LPT disassembly for LLP replacement *(see table, page 31)*.

This first removal and workscope pattern for the -7B20/22/24 implies that an alternative and more efficient policy for the first SV will be to overhaul the LPT in addition to the core engine modules. This is to allow replacement of LLPs in the LPT to avoid limiting the second interval.

The second interval could therefore be up to the full life limit of LLPs in the fan/LPC, at a total time of 30,000EFC. This limit would mean the second interval would be about 12,000EFC, which is also within what the restored EGT margin would allow. The core engine would thus have a second workscope at this stage. From this SV onwards, the interval permitted by EGT margin would be 13,000-16,000EFC.

The remaining core module LLPs installed in the first SV would limit the third removal interval to just 7,000-8,000EFC. The engine would have reached a total time of 37,000-38,000EFC by this stage, equal to 20-21 years of operation. If any SV work is required at this stage it would be full workscopes on the core and the LPT which would have accumulated a total time of 21,000-22,000EFC *(see table, page 31)*. These two modules would require LLP replacement if further operation was required. The engine could remain on-wing for 16,000-18,000EFC to a fourth removal.

"This age implies that in most cases a full workscope will not necessarily be needed. The engine would be regarded as a 'sunset' engine." says Baccarani. "If the engine was to be considered for further operation, such as with a freight operator, then from this point onwards the cost of maintenance could be reduced by using used serviceable material (USM), parts taken from scrap engines and then repaired, or modules from other engines with maintenance life remaining."

A simpler strategy for these lower-rated variants is to have an interval as close as possible to core engine LLP life limits of 20,000EFC, and have full workscopes and LLP replacement on all modules. In theory this would also apply to the second workscope at a total time of 38,000-40,000EFC, equal to 21 years of operation *(see table, page 31)*. Such a workscope would allow the engine to operate for up to 17,000-18,000EFC for its third removal interval and a total time of 55,000-58,000EFC over a lifetime of 30 years.

-7B26

In the case of the -7B26, the first removal interval has been 12,000-16,000EFC for most engines, and often closer to 16,000EFC.

The implications of this for the second and third SVs are mainly related to the remaining LLP lives at the first removal, and therefore what workscope is performed at this stage. The remaining LLP lives are 4,000-8,000EFC in the core, and 9,000-13,000EFC in the LPT.

The restored EGT margins following an SV are high enough for the -7B26 engines to remain on-wing for 9,000-14,000EFC for the second interval. This would therefore allow a second interval up to a total time of 25,000EFC; the LPT life limit.

The workscope at the first SV would therefore require a complete core module disassembly to allow the replacement of LLPs. The second SV would then come at a total time of 21,000-25,000EFC, at which point all LLPs in the LPT would be replaced.

At this stage there are two choices with respect to the decision of when to replace LLPs in the fan/LPC.

The first option would be to leave the fan/LPC at the second SV. This is at a total time of 21,000-25,000EFC, so it can restrict the third removal interval to 5,000-9,000EFC and up to a total time of 30,000EFC. At this point the fan/LPC would require a full workscope to allow LLP replacement. Moreover, the total time accumulated during the second and third removal intervals would be 18,000-19,000EFC, so the LLPs in the core modules would also require replacement for the second time. The engine would have operated for 17 years at this point.

The likely interval of 9,000-13,000EFC for a fourth interval would take LLPs installed in the LPT to a minimum total time of 14,000EFC, in which case the module would not require an SV after the next removal; but up to a total LPT time of about 24,000EFC, which would force an SV due to expiry of LLPs in the LPT.

Engine total time at this stage would be 39,000-45,000EFC; equal to an operational life of 20-25 years. Like the -7B24 and other lower-rated variants, this raises the issue of what maintenance would actually be required at this stage.

The second option at the second removal, at a total time of 21,000-25,000EFC, is for the fan/LPC to have a full SV workscope to replace LLPs early at a total time close to 25,000EFC. This is together with the LLPs in the LPT at the same SV.

The likely interval of 10,000-14,000EFC for the third removal interval would take total time for LLPs in the core modules, installed at the first SV, to 19,000-20,000EFC, and so force a removal for LLP replacement at this stage.

At this stage the engine would have a total time of 32,000-34,000EFC, after 19 years in service. This higher possible total time raises the question of what maintenance would be required and would be worth performing at this stage.

The parts in the LPT and the fan/LPC, installed at the second SV, would have accumulated a total time of 9,000-10,000EFC at third removal, so they could be left in place for a fourth removal interval.

The fourth removal interval would be limited to 15,000EFC by parts in the LPT, and a total time of 25,000EFC. The engine would have a total time of 43,000-48,000EFC at this stage, after 24-27 years of operation. The LLPs in the fan/LPC and LPT would have both accumulated about 21,000EFC since installation at the second SV. The LPT parts would theoretically require replacement at this stage to prevent limiting the subsequent fifth removal interval. At this age, however, a variety of other low-cost options would be available.

-7B27

The baseline -7B27 variant is the one that has EGT margin as a main removal driver. The engine is generally capable of first removal intervals of 10,000-13,000EFC. At this stage, the workscope has to consider the likely second removal interval than can be achieved. The restored EGT margin of 40-50 degrees centigrade will allow an interval of 7,000-10,000EFC in most cases.

This would take the engine total time to 17,000-20,000EFC. This implies the first removal interval would require a higher core workscope to recover as much EGT margin as possible, but the LLPs would not be replaced at this stage.

The second removal after a total time of 17,000-20,000EFC would force a full disassembly of the core modules for LLP replacement. The decision on whether to also disassemble and replace LLPs in the LPT depends on the total time at this stage, plus the likely third removal interval.

The third removal interval will be similar to the second, at 7,000-10,000EFC. If total time at the second SV is at 17,000EFC or less, then a full workscope on the LPT can be left until after the third removal interval at a total time of 24,000-25,000EFC. This would then also raise the issue of when to perform a full workscope on the fan/LPC. The fourth interval would be limited to 5,000-6,000EFC because of fan/LPC life limits. The engine would have been in operation for about 17 years, so a full workscope on the fan/LPC would be required to replace LLPs.

A fifth interval of up to 8,000EFC would be possible because of remaining core module LLP life limits. Total time of 38,000EFC at this stage would be equal to about 21 years of operation. A full core workscope would be required at this stage if the engine were to continue in operation *(see table, page 31)*. Low-cost options could be used as alternatives.

An alternative removal and workscope pattern could result if the total time at the second SV is long at 18,000EFC or higher. In this case, both the core and LPT should be disassembled for LLPs to be replaced.

The third interval of another 7,000-10,000EFC would take total time to 28,000-30,000EFC, and so fan/LPC disassembly for LLP replacement would be performed at this stage *(see table, page 31)*. The engine would have been in operation for 16-17 years at this stage.

A fourth interval, again of 7,000-10,000EFC would be possible. Total time at this stage would be 33,000-39,000EFC *(see table, page 31)*, equal to 18-22 years of operation. As in all cases of engines of this age, the options of using USM or time-continued modules to reduce the overall costs of maintenance and avoidance of LLP replacement are likely to be considered.

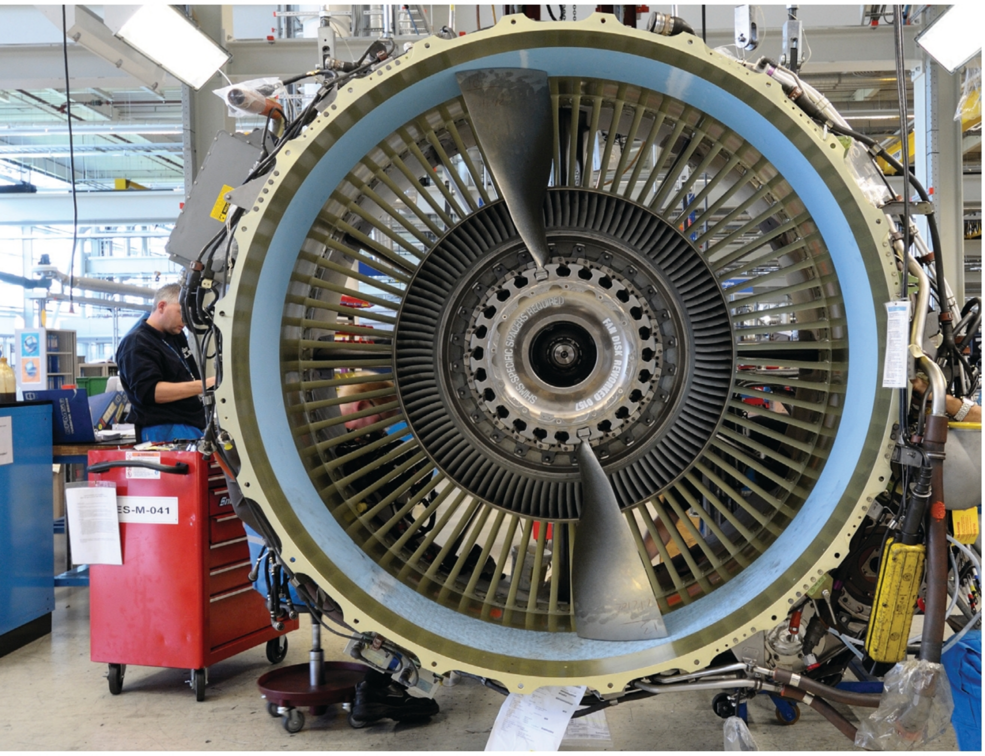
Baseline shop visit inputs

SV inputs have to consider two main issues: the percentage of parts that require replacement as a result of parts being scrapped; and the remaining portion of parts that can be repaired. The repair costs for each airfoil account for a relatively small percentage of the list price in most cases. SV costs are reduced as the scrap rate of parts falls.

"Parts repairs and replacement are the largest elements of SV costs. There is also labour," says Devin. "In addition to these two main elements, about a further $200,000 should be added to each SV for the cost of consumables and expendables, component inspections, use of the test cell, and transport."

HP/core modules

The modules with the highest SV costs are the HPC, combustor and HPT. There are 80 HPT blades, and list price is about $18,000 per blade and $1.4 million for a shipset. The other expensive component in the HPT module is the NGVs. These have



Fan/LPC and LPT modules can have removal and shop visit intervals as long as their LLP limits of 30,000EFC and 25,000EFC. It is possible for the fan/LPC to have just one scheduled shop visit in the engine's full operational life.

a list price of about $84,000 per unit, and there are 20 in a shipset, so a complete shipset has a list price of $1.8 million.

Other high cost items in the HPT include the HPT stage 1 shroud at about $303,000 for a shipset, and the HPT/LPT nozzle support. All HPC, combustor, and HPT airfoils and main parts have a list price of about $4.6 million. There are also the LPT stage 1 nozzles, that are between the HPT stage 1 blades and the LPT stage 1 blades. The shipset has a list price of about $0.7 million.

The probable planned removal intervals means SVs for the HP modules will fall into the three categories of: short intervals at 7,000-10,000EFC; medium-time intervals at 11,000-15,000EFC; and high time intervals at 17,000-20,000EFC.

"In the case of the NGVs, on a small rate of parts scrappage is experienced, and a high rate of parts repair usually occurs," says Simon Mermod, director at Jet Engine Management. "The portion of NGVs repaired can be up to 100% for low- and medium-time intervals, and can still be at about 80% for high-time engines. This will clearly save a lot of costs at SVs. Repairs can cost $5,000-6,000 per unit, although this can increase to about $25,000 in the case of high-time engines."

In the case of HPT blades, 100% will have to be replaced because of the 20,000EFC soft time. Marston comments that this can reduce to 45-55% replacement rate for low- and medium-time engines.

"HPT shrouds typically have a scrap rate of 30-50%, and a repair cost equal to about 25% of list price," says Mermod.

A combustion chamber repair will cost $65,000-120,000, and varies with removal interval.

In the case of the HPC, which has nine stages, the scrap rate for the first stage blades is in the region of 70%. "Vanes only have scrap rates as low as 10%, and blades in all the remaining eight stages will have scrap rates of about 30% in the case of longer intervals," says Mermod. "These rates will vary with removal interval. The repair costs average at approximately 15% of list price, but are higher for blades of some stages at up to 25-30%."

Overall, the cost of parts repairs in core module SVs for low-time intervals will be about $900,000, while the cost of new parts will be about $730,000, taking total materials costs to about $1.63 million. About 3,000 MH will be required for labour, and if charged at $100/MH will take the total cost to about $1.95 million.

As the rate of parts scrappage rises and parts repair reduces with the increased removal interval, the total material cost increases. Total materials for core modules following a medium interval will be about $2.3 million, and about $3.4 million following a long interval. The labour used will be 3,000-3,500MH. Total SV costs will be about $2.6 million for a medium interval, and $3.8 million for a long interval. "These are broad costs, and clearly depend on operating environment and thrust rating," says Devin. "The portion of parts that have to be replaced can rise exponentially for engines operated in a hot environment."

These costs apply to engines that have operated in a temperate climate. "Engines that operate in a hot or sandy environment will have intervals as much as 50% shorter, and a higher portion of parts will have to be replaced," says Marston.

LP modules

In the case of the fan/LPC, most planned SVs will be after a high time close to the LLP limits, at about 29,000EFC. The scrap rate of parts is usually low. This will be in the order of 10% for most LPC airfoils. "The only thing that causes scrapping of parts is foreign object damage (FOD)," says Mermod. Repair costs are also relatively low. Cost of repairs will be about $305,000, and new parts in the region of $136,000. Labour consumption will be up to 600MH, taking total cost for an SV on the module to about $500,000."

Similarly, the LPT will undergo an SV after a high time close to LLP limits of 25,000EFC. Most intervals will be 21,000-24,000EFC. "The scrap rates of LPT airfoils that are typically seen are low, at about 15% for the first stage blades, and then about 10% for the other three stages," says Mermod. "Sulphidation is the usual cause of LPT airfoil scrappage, and so the scrap rate increases with removal interval."

The list price of all airfoils is about $3.7 million. The LPT nozzle shipset has a list price of about $695,000, while a shipset of each LPT stage blades is more than $300,000. The scrap rate therefore has a big influence on the total cost of the SV. Taking typical scrap rates and repair costs into consideration, total material costs can be about $1.17 million. An allowance of about 900MH is made for labour, bringing the total SV cost to $1.26 million.

Maintenance reserves

Maintenance reserves are the main costs of shop visit inputs and the installation of new LLPs amortised over removals intervals. These reserves do not include or take into consideration unscheduled events, and the costs related to the quick engine change (QEC) kit and components. The reserves also do not take into consideration the potential effect of the re-sale of time-continued modules or LLPs on reducing the reserves per EFC.

Maintenance reserves per EFC will vary for each interval between removals and SVs. This is first because the workscope after each SV will differ, and the content and therefore cost of each is highly variable *(see table, page 31)*.

In addition to this, the cost of an SV workscope can be amortised over one or

CFM56-7B BASELINE ENGINES - REMOVAL & SHOP VISIT WORKSCOPE PATTERN

Engine variant	Removal interval EFC	Total time EFC	Workscope content	Shop visit cost - $ '000	LLP replacement	LLP cost - $ '000	Total reserve $/EFC
-7B20/22/24							
1st	18,000	18,000-19,000	High core	3,800	Core modules	2,249	486
2nd	7,000-8,000	24,000-25,000	LPT	1,265	LPT	1,211	549
3rd	5,000-6,000	29,000-30,000	Medium core & Fan/LPC	3,100	Core & Fan/LPC	3,125	552
4th	18,000	47,000-48,000	High core & LPT	5,060	Core & LPT	3,460	511
1st	18,000-19,000	18,000-19,000	High core & LPT	5,060	Core & LPT	3,460	496
2nd	12,000-13,000	29,000-30,000	Medium core & Fan/LPC	3,325	Fan/LPC	876	491
3rd	7,000-8,000	37,000-38,000	Low core & LPT	3,546	Core & LPT	3,460	528
1st	19,000-20,000	19,000-20,000	All	5,500	All	4,337	518
2nd	19,000-20,000	38,000-40,000	Variable	Variable	Variable	Variable	Variable
-7B26							
1st	12,000-16,000	12,000-16,000	Medium core	2,625	Core	2,249	504
2nd	9,000-14,000	21,000-25,000	LPT	1,262	LPT	1,211	485
3rd	5,000-9,000	27,000-30,000	Medium core & Fan/LPC	3,125	Core & Fan/LPC	3,125	379
4th	9,000-14,000	39,000-45,000	Core perf restore	2,625	N/A	N/A	220
1st	12,000-16,000	12,000-16,000	Core	2,625	Core	2,249	513
2nd	9,000-14,000	21,000-25,000	Fan/LPC & LPT	1,762	Fan/LPC & LPT	2,087	500
3rd	9,000-10,000	32,000-34,000	Core	3,800	Core	2,249	449
4th	11,000-14,000	42,000-48,000	Medium core restore & LPT	3,887	LPT	1,211	315
-7B27							
1st	10,000-13,000	10,000-13,000	Medium core perf restore	2,625			521
2nd	7,000-10,000	16,000-17,000	Low core	1,930	Core	2,249	558
3rd	7,000-10,000	24,000-25,000	LPT	1,262	LPT	1,211	460
4th	5,000-6,000	30,000	Fan/LPC	500	Fan/LPC	876	357
5th	8,000	38,000	High core	3,800	Core	2,249	310
1st	10,000-13,000	10,000-13,000	Medium core perf restore	2,625			501
2nd	7,000-10,000	18,000-20,000	Low core & LPT	3,200	Core & LPT	3,460	518
3rd	7,000-10,000	28,000-30,000	Fan/LPC	500	Fan/LPC	876	239
4th	7,000-10,000	34,000-39,000	Variable	Variable	Variable	Variable	Variable

several intervals. As an example to explain this, a full core workscope of $3.6-3.8 million can be amortised over a single interval of 18,000EFC, equal to a rate of $200-211 per EFC. A workscope on the LPT costing about $1.26 million can be amortised over two or three intervals totalling close to 24,000EFC, equal to a rate of $53 per EFC.

The reserve rate per EFC for each module would then likely increase over subsequent removal intervals. This is mainly because reserves for core module maintenance per EFC increase as intervals and SVs progress. This is a result of shorter intervals, even though the costs of a smaller SV are lower compared to a workscope following a longer interval.

The estimated costs of the core, fan/LPC and LPT workscopes were each amortised over the relevant intervals according to the SV pattern and associated intervals *(see table, this page)*.

In most cases these at first increase after the first interval, mainly due to subsequent intervals being shorter. As the engine increases with age and has passed through three SVs, and approaches a total time of 38,000-40,000EFC and an operational life of 21-22 years in many cases, airlines then have the option of not performing any further maintenance on a number of modules. This is because the airline, if it has full control of the maintenance management, will have the choice of not performing maintenance and

The portion of airfoils that have to be replaced the and portion which can be repaired has the biggest influence on each shop visit cost. Some of the most expensive parts are HPT blades, nozzle guide vanes, and LPT nozzles.

LLP replacement on some modules if it thought there was no viable aftermarket for the engine at an age of 25 years.

A particular example is the fan/LPC, which has maintenance mainly driven by LLP expiry after 30,000EFC. The module may therefore only require one SV on the engine's operational life. The second would come due at a total time of 57,000-59,000EFC, which is likely to be after the engine has been retired. If the airline has the flexibility, it could save costs by not performing this second SV and LLP replacement. Given the cost of an SV on the fan/LPC is about $0.5 million and LLPs have a list price of about 876,000, this saving would be equal to a reserve of $47 per EFC for the last operational years of its life. The same can apply to other modules as the engine gets older, and the airline considers whether to perform full maintenance, and so pay full reserves, or retire the engine when the next major SV or LLP replacement comes due and so reduce reserves paid in the last few years of operation.

As an alternative to not performing maintenance, and to scrapping the engine, the airline has the option of sourcing green-time modules. In this case the reserve would be the purchase price of the green-time module amortised over the interval achieved. Because of the large numbers of 737NGs, there may be a high supply of green-time engines and modules available when engines still in operation come due their fourth or fifth SV at a total time of 45,000-50,000EFC.

Mermod explains that the market rate for a green-time module would be the pro-rate value of its LLPs, and a portion of the SV cost that would be incurred if it were performed. Taking a fan/LPC at half LLP life as an example, its pro-rate LLPs would be valued at about $450,000, and half the cost of an SV would be about $250,000. The module would therefore have a market value of about $700,000. An increased supply of green-time engines on the aftermarket will reduce their pro-rate values.

Another alternative to green time modules is the use of USM, or repaired parts in SVs. Mermod estimates that these cost about 70% of list price for items such as HPT blades and NGVs. They can be at a slightly lower pro-rate value for simpler airfoils. In the case of HPT blades, use of USM HPT blades can save several hundred thousand dollars, especially for medium- and high-time core SVs.

The use of USM would be suitable for consideration for engines that are in the last years of the their operational life, and where the longest possible removal intervals are not necessary.

Tech Insertion 3/ engines

It is generally accepted that /3 engines operated in a temperate environment have EGT margins about five degrees higher than baseline engines, so that they can achieve removal intervals that are about 1,000EFC longer. This clearly allows engines on their first interval to achieve removal times close to the LLP limit of 20,000EFC.

"In some cases it has been reported that /3 engines have recorded initial EGT margins 15-20 degrees higher than baseline engines," says Devin.

Low- & medium-rated variants

The implications of higher EGT margins, as well as slightly lower EGT margin erosion, are that first run removal intervals for the -7B20/3, -7B22/3 and -7B24/3 engines are long, at 16,000-20,000EFC. Most engine shops report that LLP expiry and life limits are the main removal driver for these engines.

Average removal intervals are about 1,000EFC longer than baseline engines, and so about 19,000EFC. This clearly indicates that the workscope following the first removal will be a complete core engine disassembly to allow LLP replacement. The workscope on the core module airfoils will also be extensive.

Tech Insertion or /3 engines at these low and medium thrust ratings are generally viewed as having second and subsequent removal intervals of 13,000-18,000EFC. Again, this is about 1,000EFC longer than baseline engines. There is relatively little fleet performance data for many engine shops to use, however. Israel Aircraft Industries says that it has so far only seen /3 engines for their first removal and SV, and because the fleet is still relatively young very few /3 engines have had their second SV.

The range of 13,000-18,000EFC means the engine can remain on-wing all the way to the 30,000EFC limit of the fan/LPC. This would be another 10,000-12,000EFC after the first removal interval. As with baseline engines, one choice is performing the LPT workscope and LLP replacement early to allow the second interval to take the total time up to 30,000EFC for fan/LPC disassembly and LLP replacement *(see table, page 33)*.

Following a full core and LPT workscope at the first SV, the total time after two SVs would therefore be close to 30,000EFC. The fan/LPC would come due at the second SV.

The third removal would be limited by core LLPs, and so come due after a total time of 39,000-40,000EFC, when the engine would have been in operation for about 22 years. With the engine's age, the full workscopes on the core and LPT modules could be reduced by using USM or green time modules at this stage.

The second option after the first removal is to have two successive short intervals of 5,000-6,000EFC each for the second and third removals. The full LPT

CFM56-7B TECH INSERTION /3 ENGINES - REMOVAL & SHOP VISIT WORKSCOPE PATTERN

Engine variant	Removal interval EFC	Total time EFC	Workscope content	Shop visit cost - $ '000	LLP replacement	LLP cost - $ '000	Total reserve $/EFC
-7B20/22/24/3							
1st	19,000	19,000	High core & LPT	5,062	Core & LPT	3,460	505
2nd	10,000-12,000	29,000-30,000	Fan/LPC	500	Fan/LPC	876	438
3rd	8,000-10,000	39,000-40,000	High core	3,800	Core	3,460	382
1st	19,000	19,000	High core	3,800	Core	2,249	468
2nd	5,000-6,000	24,000-25,000	LPT	1,262	LPT	1,211	465
3rd	5,000-6,000	29,000-30,000	Fan/LPC	500	Fan/LPC	876	362
4th	10,000-11,000	39,000-40,000	High core	3,800	Core	2,249	315
1st	19,000-20,000	19,000-20,000	All	5,500	All	4,337	518
2nd	19,000-20,000	38,000-40,000	All	5,500	All	4,337	518
-7B26/3							
1st	14,000-17,000	14,000-17,000	High core	3,800	Core	2,249	538
2nd	8,000-11,000	24,000-25,000	Fan/LPC & LPT	1,762	Fan/LPC & LPT	2,087	477
3rd	11,000-12,000	35,000-37,000	High core	3,800	Core	2,249	318
4th	13,000	48,000-50,000	Variable	Variable	Variable		Variable
1st	18,000-19,000	18,000-19,000	High core & LPT	5,100	Core & LPT	3,460	515
2nd	10,000-12,000	29,000-30,000	Fan/LPC	500	Fan/LPC	876	496
3rd	8,000-10,000	39,000-40,000	High core & LPT	5,100	Core	2,249	486
4th	15,000	54,000-55,000	Variable	Variable	Variable		Variable
-7B27/3							
1st	11,000-14,000	11,000-14,000	Core perf restore	2,625			484
2nd	8,000-12,000	19,000-20,000	Core & LPT	3,200	Core & LPT	3,460	475
3rd	9,000-11,000	29,000-30,000	Fan/LPC	500	Fan/LPC	876	525
4th	9,000-10,000	38,000-40,000	High core & LPT	5,100	Core & LPT	3,460	298
5th	10,000-12,000	49,000-50,000	Core perf restore	1,930			241

workscope would therefore be performed at the second SV; and the fan/LPC performed at the third SV, after a total time of close to 30,000EFC. This would be equal to an operational life of about 17 years.

A fourth interval would therefore be limited to 10,000-11,000EFC by the core module LLPs and a total time of 39,000-40,000EFC *(see table, this page)*. At this stage the engine would have been operational for 22-23 years. Full maintenance, if used, would involve carrying out a full core workscope, including LLP replacement.

A third available option is running the engine to the full core LLP limit of up to 20,000EFC, carrying out full workscopes and replacing LLPs on all modules *(see table, this page)*.

-7B26/3 engines

As with -7B22/3 and -7B24/3 engines, the -7B26/3 benefits from intervals that are about 1,000EFC longer than for its -7B26 counterpart. The range for first and second removal intervals is 14,000-17,000EFC and 11,000-15,000EFC. The combined likely first and second removal intervals will determine the most likely workscopes at those removals.

The most efficient workscope pattern for the -7B26/3 to go through is that followed by the baseline -7B26. The -7B26/3 will have slightly longer intervals, but these will not be long enough to change the workscope pattern.

The first SV for the -7B26/3 will therefore be a full workscope and LLP replacement on the core engine. This will be at an average of 16,000EFC. If longer intervals of 18,000EFC are experienced, then an alternative SV pattern, such as the -7B24/3 could be followed.

The second SV after an interval of 8,000-9,000EFC and a total time of 24,000-25,000EFC will have the full workscopes on both LP modules for LLP replacement *(see table, this page)*.

This will allow the third interval to be up to core module limits, so after 11,000-12,000EFC. The HP modules will therefore require a full workscope and LLP replacement. By this stage the engine's total time will be 35,000-37,000EFC, after 19-20 years of operation. As with other engines, the actual workscope and maintenance that will be performed will be dependent on the availability and value of USM and green-time modules and engines.

The oldest 737NGs are 24 years old. This factor and the large number of parked and stored 737NGs means that the supply of green time or time-continued engines and modules, and the availability of USM airfoils could sharply increase over the next few years. This will provide airlines with an opportunity to make large savings in CFM56-7B maintenance costs.

A fourth interval of about 13,000EFC would be possible, subject to the limits of LLPs in the LPT. This would take the engine up to a total time of 48,000-50,000EFC. At this stage the engine would have been in active service for 28 years, so it is unlikely that any maintenance will be required.

-7B27/3 engines

As with the -7B26/3, the -7B27/3 will probably have removal intervals about 1,000EFC longer than the -7B27 baseline engine. With EGT margin erosion being a main removal factor for engines rated at 27,000lbs thrust, these would be 11,000-14,000EFC for the first removal interval, and 8,000-12,000EFC for the second and subsequent intervals.

The average intervals would be marginally longer than the -7B27 baseline variant. The -7B27/3 engine could therefore go through the same SV and workscope pattern as the -7B27 baseline. This would be a core performance restoration at the first SV, followed by a full core workscope with LLP replacement and full LPT disassembly and LLP replacement at the second SV, which would come due at a total time of 19,000-20,000EFC *(see table, page 33)*.

This would allow an uninterrupted third interval of 9,000-11,000EFC, to a total time of 28,000-30,000EFC. A removal would be forced by LLP expiry in the fan/LPC. The engine would have been in operation for 16-17 years at this stage.

The fourth interval would be limited to 9,000-10,000EFC, with core module LLP expiry forcing a removal. This would be at a total time of 38,000-40,000EFC, equal to 21-22 years of operation. The actual maintenance performed would depend on operator requirements, the availability of USM and green-time modules.

The fifth interval could be 10,000-12,000EFC, given probable EGT margin. This would take the engine to a total time of 49,000-50,000EFC. No maintenance is likely to be performed at this stage because of scrapping.

Maintenance reserves

The maintenance reserves for Tech Insertion engines are summarised. As in the case of baseline engines, these reserves only include SV inputs and the installation of new LLPs. These are expressed as costs per EFC *(see table, page 33)*.

The reserves for /3 engines are marginally lower per EFC than baseline engines. This is mainly due to the /3 engines being able to achieve longer removal intervals, and in some cases have simpler removal and SV patterns.

As engines progress through life, it becomes less certain if full workscopes and LLP replacement are required, given the likelihood that engines will be retired after they reach 22-23 years of age. Some 737NGs will be sold for freight conversion. The likely high supply of time-continued or green-time engines and modules and USM means that operators of old aircraft will be able to economise on engine maintenance costs.

Evolution /E engines

The shipset of LLPs in the CFM56-7B series comprises three groups: the fan and LPC module with three parts; the core engine module that includes the HPC and HPT, and the LPT. The three parts in the fan/LPC have certified lives of 30,000EFC, the nine parts in the core engine have uniform lives of 20,000EFC, and the six parts in the LPT have uniform lives of 25,000EFC.

The first intervals for most variants and thrust ratings are capable of reaching or even exceeding 20,000EFC. The implications of this are that the core engine LLPs can be fully utilised, making it possible to achieve the lowest possible reserve per EFC for the related LLP components. The second main implication is that, given typical rates of utilisation, the first removal intervals are equal to 11-12 years of operation in the case of engines with low and medium thrust ratings.

The need to replace all LLPs in the core engine modules and the long removal intervals will therefore force a large workscope, including complete disassembly. The work required on the fan/LPC and LPT modules will depend on findings following inspections.

The remaining LLP lives in the fan/LPC and LPT will both affect the subsequent removal interval. The 25,000EFC life limit in the LPT will mean that because of a full-length first removal interval of 20,000EFC, the second interval will be limited to 5,000EFC if there are no LLP changes in the LPT. The same issues mean that the fan/LPC module will be limited to a maximum interval of 10,000EFC.

The high restored EGT margin of engines after the first SV means the second removal intervals can take the total time up to 30,000EFC for most thrust ratings and variants. Overall, the three life groups of 20,000EFC, 25,000EFC and 30,000EFC and the high EGT margins in most variants means there will be compromises between removal intervals and SV workscopes.

As an example, the LPT module would need to have all LLPs replaced at the first SV if the first interval has exceeded 18,000EFC. This is because a maximum second interval of 7,000EFC will only be possible if LLPs in the LPT are not replaced, whereas the restored EGT margin would allow a longer interval of up to 12,000EFC if the LPT parts are replaced. This means the LLPs in the LPT will have to be removed with significant 'stub life' remaining, resulting in high LLP reserves for some modules, although they could be reduced if the removed parts can be sold on the aftermarket. AC