The CFM56-5B has powered almost 52% of all A320ceos ordered. The engine has a high EGT margin, making management relatively simple in the majority of cases. Removal intervals and shop visit management are considered, together with probable maintenance costs.

CFM56-5B maintenance management & SV inputs

The CFM56-5B powers the largest share of the A320 current engine option (ceo) family. The first A320s equipped with CFM56-5B engines entered service in 1993, making them 27 years old. There are now fewer than 50 ceo aircraft on firm order, and the A320 new engine option (neo) will be the only types in production by the end of 2020.

The CFM56-5B is well known for its on-wing reliability and long removal intervals. The exhaust gas temperature (EGT) margin is high enough on most variants and thrust ratings for it to remain on-wing up to the life-limited part (LLP) engine flight cycle (EFC) life limits. This, together with typical rates of annual utilisation, means that it is possible for certain engines to only come due their third planned removal and shop visit (SV) after more than 25 years of operation.

Engine performance, reliability and removal intervals have been improved by a series of technical upgrade programmes.

Long removal intervals and the low frequency of maintenance events have led to a prolonged delay in CFM56-5B SV activity across the fleet. The surge in SV activity materialised in 2016-2018. This, and a surge in the SV activity of other narrowbody engines, has led to a shortage of engine shop capacity in recent years.

With engines having been in service for more than 25 years, and large numbers going through, or coming due, their third and fourth SVs, there is also scope to reduce maintenance costs, by using parts manufactured approval (PMA) airfoils and other components, and used serviceable material (USM).

The long-term maintenance costs per engine flight hour (EFH) and per EFC can therefore be examined over a long-term period equating to three planned SVs and most of an engine's operational life. Options for maintenance management during the later years of an engine's operation can also be analysed.

CFM56-5B description

The -5B series of CFM56 engines followed the initial -5A1 series that powered the first A320s in 1987, and continued production up to 2003. The -5A1 and -5A3 powered 390 A320s. Despite the -5A4 and -5A5 also being used to power the first A319s from 1995, the highest thrust rating of the -5A series was 26,500lbs for the -5A3. The -5A, however, lacked thrust growth capability to power the stretched and higher weight A321.

The -5B was developed from the -5A by adding a stage to the low pressure compressor (LPC). The -5B series has a 68.3-inch diameter fan, a four-stage LPC, a nine-stage HPC, a single-stage HPT, and a five-stage LPT. This gave the engine capacity for thrust growth up to 32,000lbs.

The -5B variants can be grouped into thrust ratings. The -5B3 is rated at 32,000lbs, the -5B2 and -5B1 are at lower ratings of 31,000lbs and 30,000lbs for the A321 *(see table, this page)*. The -5B3 is the highest rated variant of the -5B series.

The -5B4 and -5B6 are rated at 27,000lbs and 23,500lbs for the A320 *(see table, this page)*. -The -5B5 is rated at 22,000lbs and the -5B7 rated at 27,000lbs, and together with the -5B6, power the A319 *(see table, this page)*.

The -5B9 and -5B8 are the lowest-rated variants at 23,300lbs and 21,600lbs, which power the A318 *(see table, this page)*.

Overall, there are nine variants rated from 21,600lbs to 32,000lbs. These nine variants are based on the same turbomachinery hardware and parts, with thrust rating being changed through the engine's full authority digital engine control (FADEC) unit. This facility has some use in maintenance management, since high-rated engines operated on the A321, for example, can be de-rated to a lower thrust rating when they have come close to exhausting all of their EGT margin, but still have LLP life remaining. The engines can then gain additional on-wing time when operated at a lower thrust rating on the A320 or A319 if the airline operator has a mixed fleet.

The addition of an LPC stage to the -5B series allowed thrust growth, while the improvement in core engine flow has also

CFM56-5B SERIES VARIANTS & THRUST RATINGS

Engine variant	-5B3	-5B2	-5B1	-5B7	-5B4	-5B6	-5B5	-5B8	-5B9
Thrust lbs	32,000	31,000	30,000	27,000	27,000	23,500	22,000	21,600	23,300
Application	A321	A321	A321	A320	A320	A319	A319	A318	A318
Corner Point (deg C)	30	30	30	45	45	45	45	45	45
Initial EGT margin (deg C)	66	95	105	109	109	145	163	180	145

The CFM56-5B has been specified for almost 4,200 A320ceo family aircraft. There are more than 3,840 aircraft with -5B engines in service. This fleet is dominated by the -5B6/P, -5B5/P, -5B4/P, -5B4/3 PIP, and -5B3/3 PIP variants.

given the engine a high EGT margin. The higher airflow and degree of core engine cooling was also required to compensate for the higher combustion temperatures.

Initial EGT margins are about 66 degrees centigrade for the highest-rated -5B3 and -5B2 variants powering the A321. The mid-rated -5B4 variant at 27,000lbs has an initial EGT margin of up to 110 degrees, while lower-rated engines rated at 22,000-23,500lbs have up to 110-165 degrees centigrade.

Upgrade programmes

The CFM56-5B series has had a series of modification and upgrade programmes. The original standard -5B series engine was introduced in 1993. These are designated with a -5BX suffix, the last digit indicating the thrust rating *(see table, page 34)*.

A total of 49 engines were fitted with a dual annular combustor (DAC) to emit lower nitrogen oxide (NOx) emissions, and designated as -5BX/2P.

The first modification and upgrade was the /P programme, and was launched in 1996. This was an improved standard or airfoils, and was referred to as the 3-D aerodynamic programme. An example is the upgrade of the -5B4 to the -5B4/P.

The upgrade was based on using 3-D airfoils for the HPC, HPT blades, and LPT nozzle. It also used improved cooling in the HPT blades. The overall intention was to increase EGT margin by about 10 degrees centigrade; reduce specific fuel consumption (sfc) by about 3%; and increase the lives of LLPs in the fan/LPC to 30,000EFC, in the HPC and HPT to 20,000EFC, and in the LPT to 25,000EFC. The /P programme was incorporated on the engine production line from 1996, but could also be incorporated into the engine during an SV.

"The HPT blades used in these modification programmes were improved compared to the original -5B engines," says Florian Weinz, senior engineer CFM engines at Lufthansa Technik. "Since their introduction, these new blades are capable of a full removal interval of up to 20,000EFC. The 3-D aero blades are a bit more sensitive and have slightly higher deterioration rates. Despite this, the EGT margins for brand new engines and post-SV are both higher when these blades are fitted. Average EGT margin erosion rates are about 4.0 degrees per 1,000EFC for low thrust engines, and 6-7 degrees per 1,000EFC for higher thrust ratings."

Most original standard engines have been upgraded to /P standard since the modification was introduced. The same applies to DAC or /2P engines. A mixed fleet that includes some /2P engines provides complications for some operators.

The second major modification was the Tech Insertion or Tech 56 programme. This was launched in 2004, provided as a retrofit kit, and became the production line build standard from 2007.

Engines with this standard are identified as having a /3 suffix. An example is the -5B4 variant modified to the -5B4/3.

The modification is intended to increase EGT margin, reduce fuel burn and reduce maintenance costs through improved parts durability. The /3 modification is more expensive than the /P programme when applied to baseline engines.

The modules affected by the /3 upgrade were the HPC, the combustor, the HPT, and the LPT. The main features were the use of second generation 3-D blades and airfoils.

The effects of the programme have been an increase in removal intervals by about 10%, due mainly to improved EGT margin and parts durability. Fuel burn has also been reduced, and NOx emissions are 20-25% lower.

The third main upgrade programme can only be applied to /3 engines. This is known as the performance improvement programme (PIP). It became available in 2011, and only /3 standard engines could be retrofitted with the kit. Most engines built since 2011 have been /3 PIP engines. An example is the -5B4 becoming the -5B4/3 PIP.

Changes to engine hardware mainly

CFM56-5B LIFE LIMITED PARTS

Engine module	Number of parts	Life limits EFC	2020 list price - US$
Fan/LPC	3	30,000	543,000
HPC	6	20,000	1,016,000
HPT	4	20,000	1,088,000
LPT	6	25,000	1,142,000
Complete shipset	19		4,170,000

ACTIVE FLEET OF CFM56-5B-POWERED A320 FAMILY AIRCRAFT

A318		-5B9	-5B8	Total	Production years
Thrust rating - lbs		23,300	21,600		
-5BX					
-5BX/2P					
-5BX/P		4	20	24	2003-2010
-5BX/3		13	2	15	
-5BX/3PIP		4		4	2011-2013
TOTAL		21	22	43	
A319	**-5B7**	**-5B6**	**-5B5**	**TOTAL**	
Thrust rating - lbs	27,000	23,500	22,000		
-5BX					
-5BX/2P		17		17	1997-2004
-5BX/P	58	174	195	427	
-5BX/3	26	76	85	187	2005-2011
-5BX/3PIP	97	12	9	118	2011-2015
TOTAL	181	279	289	749	
A320		**-5B4**	**-5B6**	**TOTAL**	**Production years**
Thrust rating - lbs		27,000	23,500		
-5BX		3		3	1996
-5BX/2P		24		24	1995-2004
-5BX/P		447	30	477	195-2011
-5BX/3		513	98	611	1995-2013
-5BX/3PIP		1,175	99	1,274	2009-2019
Total		2,162	277	2,389	
A321	**-5B3**	**-5B2**	**-5B1**	**TOTAL**	**Production years**
Thrust rating - lbs	32,000	31,000	30,000		
-5BX					
-5BX/2P	8			8	1998-2004
-5BX/P	98	13	27	138	1994-2008
-5BX/3	53	27	3	83	1998-2011
-5BX/3PIP	397	9	2	408	2013-2019
-5BX/3B1	5			5	2008-2009
-5BX/3B1PIP	19			19	2015-2017
Total	580	49	32	661	
Overall total				3,842	

included HPC guide vanes and blades, HPT blades, and two of the LPT stages. The most notable change is that it has 76 HPT blades in a shipset, a change from the 80 blade configuration of previous standards.

There are also a small number of /3 PIP engines that have a thrust bump for hot and high operations.

"The overall benefit of the modification programmes is that they solved certain technical problems and improved the on-wing performance of particular parts and components," says Weinz. "Examples are the improved combustion chamber design, the new variable stator vane (VSV) bushing system, and improved HPT blades. These all contribute to a full first removal interval of 20,000EFC."

Life limited parts

The -5B's life limits for its LLPs affect management of engine maintenance.

The -5B has 19 main LLPs in its four main modules *(see table, page 35)*. These four groups have a 2020 list price of $4.2 million. This compares to a list price of $2.55 million for the same 19 parts in the four modules in 2014 *(see CFM56-5B maintenance management & reserves, Aircraft Commerce, February/March 2014, page 26)*. This is an annual increase in LLP shipset list prices of 6.8%.

There are now three LLPs in the fan and LPC with certified life limits of 30,000EFC, and a list price of $543,200.

The LPT has six parts, and certified lives of 25,000EFC. Their 2020 list price is $1.14 million *(see table, page 35)*.

The core engine has the two modules of the HPC and HPT. These have six and four parts, and have a total list price of $2.1 million *(see table, page 35)*.

CFM56-5B in operation

More than 8,060 A320ceo family aircraft have been built since 1987. The last orders for fewer than 70 aircraft are due for completion before the end of 2020.

The initial CFM56-5A series engine equipped 390 A320s and 144 A319s. The -CFM56-5B series has powered 4,151 aircraft built to date since 1993, and there are 47 aircraft on order with -5B engines.

The -5B series therefore accounts for 51.7% of all A320ceos ordered.

The second main engine type for the A320ceo was the V2500-A5, which was selected for more than 3,220 aircraft and 39.7% of the fleet. The V2500-A1 preceded the -A5 series, and powered 143 aircraft built in the late 1980s.

The -5B series can be split into five main groups: the baseline engines; and baseline /2P engines, /P engines, /3 engines, and /3 PIP engines. The /3 and /3 PIP engines also include a small number of engines with a thrust bump, and are exclusively used by A321s.

The CFM56-5B-powered A320ceo fleet can also be sub-divided between the A318, A319, A320 and A321. The A318 was a minority fleet, with only 43 active aircraft.

The A320 is the largest fleet, with 2,389 active aircraft or on order with -5B engines. The A319 and A321 had similar success, and 751 and 697 of these aircraft are now in service or on order. This totals 3,889 aircraft. There are also another 309 aircraft that have been retired or in storage.

There are almost no aircraft left in operation with baseline engines. There are 49 aircraft with /2P baseline engines. The biggest fleets are equipped with /P, /3, and /3 PIP engines.

Most of the original baseline engines have been upgraded to /P standard. There are 24 A318s, 427 A319s, 477 A320s and 138 A321s with /P engines *(see table, this page)*. There is therefore a total of 1,066 aircraft with /P engines.

There are 896 aircraft equipped with /3 engines, including 15 A318s, 187 A319s,

Later modification standard -5B engines that power the A319 and A320 have high enough EGT margins and hardware durability to remain on-wing for the full LLP limit of 20,000EFC. Such engines may only need two or three shop visits in their operational life.

611 A320s, 83 A321s, and 43 A318s.

The largest sub-fleet are aircraft with /3 PIP engines. Totalling 1,828 units, it includes 4 A318s, 118 A319s, 1,274 A320s and 432 A321s *(see table, page 36)*. The 432 A321s include aircraft with thrust bump capability. Engines powering these aircraft were either /3 engines modified to /3 PIP standard, or factory-built as /3 PIP engines.

These three sub-fleets of aircraft with /P, /3 and /3 PIP engines total 3,790 active aircraft, which are divided between 2,362 A320s, 732 A319s, 653 A321s, and 43 A318s.

Of the 3,790 active aircraft, four main types account for the majority. The first two are -5B5- and -5B6-powered A319s that account for 279 and 289 active aircraft. These two groups account for 15% of the active CFM56-5B-powered A320ceo fleet. Most of the aircraft have /P engines.

The third and largest group is 2,162 -5B4-powered A320s, which is 56.5% of the -5B-equipped A320ceo family fleet. This is a mix of 477 aircraft with /P, 611 aircraft with /3, and 1,274 aircraft with /3 PIP engines.

The fourth largest group comprises 580 A321s equipped with -5B3 engines, equal to 15.2% of the -5B-powered fleet.

These four groups total 3,310 aircraft, and 86.6% of the -5B-equipped A320ceo family global fleet *(see table, page 36)*.

CFM56-5B in service

The A320 family has been steadily improved since its service entry in the late 1980s, especially in terms of maximum take-off weight (MTOW), fuel capacity, and sfc and fuel burn performance. These have all led to increased range. Many airlines now use A320 family members in both short- and medium-haul operations.

The first aircraft served with Air Inter and Air France, and operated typical short-haul sectors such as French domestic routes. These CFM56-5A-powered aircraft operated at average FC times of 1.0FH and up to 1.3FH.

Most -5B-powered aircraft operate longer average routes and FH:FC ratios. The high coreflow and cooler core engine temperatures are just some factors that have kept the rate of engine hardware degradation relatively low compared to previous generation engines. This has allowed aircraft to fly high cycle operations while achieving long removal intervals.

As described, about 15% of the CFM56-5B-powered A320 family fleet is A319s with -5B5 and -5B6 engines. These are operating at 1.60-2.05EFH per EFC.

The largest portion of the total fleet is A320s with -5B4 engines, and many are operating in the 1.85-2.40EFH per EFC range. Another 15% of the fleet are A321s with -5B3 engines operating at 2.05-2.55 EFH per EFC.

These average flight times can mean that aircraft weights are relatively high at take-off. Weinz at Lufthansa Technik estimates that the average take-off thrust de-rate is 15-20% in most cases. “The rate of thrust de-rate is not so critical on the -5B because of the cool core temperatures, unless you are considering the highest-rated 31,000lbs and 32,000lbs engines,” says Alex Marom, director of Bedek MRO heavy maintenance, engines and components, at Israel Aircraft Industries (IAI).

The -5B series for the CFM was specifically designed for the A321’s higher thrust requirements. “The A319 and A320 have been fortunate to benefit from the effects of de-rating,” says Francesco Baccarani, vice president of technical at SGI Aviation. “The A319 and A320 operate at 1.7-1.9FH:FC in most cases, and have the low- and medium-rated engines. These do not experience any particular hardware degradation of EGT margin erosion problems at this operating ratio. The two highest rated variants for the A321 do, however, experience similar rates of degradation to previous generation engines. The typical average EFC time of 1.7EFH is not good for the -5B3 and -5B2 rated at 32,000lbs and 31,000lbs. An average EFC time of 2.5EFH or longer is better for these engines, if it is possible for airlines to achieve this.”

Engine management

The in-service performance of engines will determine their removal interval and their SV workscope, workscope patterns and overall engine management.

Engines powering the A319 and A320 can all generally achieve long removal intervals up to their LLP life limits before exhausting all EGT margin. Engines powering the A321 lose EGT margin at a rate that does not allow them to stay on-wing for as long as LLP lives, and have to be managed around shorter planned removal intervals.

The removal intervals between SVs that engines can achieve, and their resulting SV patterns, will influence the portion of LLP lives that can actually be used before being removed and scrapped, and therefore the reserves paid per EFC for LLP replacement.

If all parts can achieve 100% life utilisation, then the reserves that have to be paid for 2020 list prices for all 18 parts are $169 per EFC. The actual reserves required will have to consider probable life utilisation, and the likely list price at the time replacement comes due.

Because of different intervals and their effects on maintenance management, engines for the A319 and A320 are considered differently to the A321.

A319 & A320 engines

As described, there are 749 A319s in service with -5Bs. Most are 279 aircraft with -5B6s, and 289 aircraft with -5B5s. The majority of both of these two groups are /P engines, and total 427 active aircraft. Fewer than 200 A319s have /3 engines, and only 118 aircraft have PIP engines.

The A320 fleet is more diverse. The largest group or sub-fleet comprises aircraft equipped with -5B4 engines that are of /3 PIP standard. There are 1,175 of these out of the -5B-powered A320ceo fleet. There are a further 99 aircraft with -5B6 engines of the 3/ PIP standard, taking the total number of aircraft with /3 PIP engines to 1,274 out of 2,389 active A320s with -5B engines.

The second smallest group is 611 aircraft with /3 standard engines, and then there are 477 aircraft with /P engines.

Removal & workscope pattern

The initial EGT margins of engines are in the range of 110-165 degrees centigrade for low-rated engines up to 23,500lbs thrust, and 100-110 degrees centigrade for engines rated at 27,000lbs thrust. These are the -5B4, -5B5, -5B6, -5B7, -5B8 and -5B9 variants.

The EGT margin deterioration rate is equal to 17 degrees for the first 2,000EFC on-wing. The remaining margin at this point will therefore be 93-148 degrees for the lower-rated engines, and down to 83-93 degrees for -5B4s rated at 27,000lbs.

The EGT margin deterioration and erosion rate from 2,000EFC is 2.75-3.00 degrees per 1,000EFC. All low- and medium-rated engines should therefore have enough EGT margin to allow a removal interval up to the full life limits of HPC and HPT LLPs of 20,000EFC.

"Most operators have upgraded their engines to /P as a minimum," says Marom. "These engines have been around since 1996. The /3 mod programme came later in 2004 as an upgrade and in 2007 as production standard. The consequence of this is that most of these engines have only been flying for about eight years. We are only now beginning to see large numbers of /3 engines coming into the shops.

"The /3 engines have an improved EGT margin over the /P engines," continues Marom. "Because of this, the /3 engines get close to their LLP life limits of 20,000EFC on their first removal interval. With typical rates of utilisation, this is equal to more than 10 years of operation. This long period explains why there are about 5,700 engines in operation with no SVs so far. This includes engines with thrust ratings of up to 27,000lbs, and engines operated in a temperate environment. Engines operated in a sandy environment will have a high rate of EGT margin and hardware degradation, and so will have a shorter removal interval."

Weinz comments that restored EGT margins following a first SV are about 80% of the brand-new EGT margin. "Moreover, there is no particular difference between the EGT margin erosion rate of the first and subsequent removal intervals," adds Weinz.

CFM56-5B REMOVAL & SV MANAGEMENT - A319/320 ENGINES

Removal	First	Second	Third
EFH:EFC ratio			
Removal interval - EFC	18,000-20,000	10,000-12,000	8,000-10,000
Removal interval - EFH			
Total time - EFC	18,000-20,000	28,000-30,000	36,000-40,000
Module workscope	**Core overhaul**	**Core performance restoration**	**Core overhaul**
New parts	$3.6 million	$2.5-2.6 million	$2.5 million
Parts repairs	$0.7 million	$0.6-0.7 million	$0.8 million
Labour	3,500-4,000MH	3,000-3,500MH	3,500-4,000
LLP replacement	$2.1 million		$2.1 million
Module workscope	**LPT overhaul**	**Fan/LPC overhaul**	
New parts	$ 0.6 million	$0.2 million	
Parts repairs	$ 0.4-0.5 million	$0.35 million	
Labour	700-900MH	500-650	
LLP replacement	$1.14 million	$0.92 million	

1st removal

Baccarani similarly says that engines rated for the A319 and A320 will stay on-wing for up to 44,000EFH and 20,000EFC for their first removal interval. "Most engines get close to their HPC and HPT LLP life limits," says Baccarani. "The main removal cause for these engines for the first SV is LLP expiry and hardware deterioration."

This is confirmed by Air France, which operates the entire A320 family. "Typical first run intervals for engines on the A319 and A320 are up to 20,000EFC, and the LLP limit is the main removal driver," says Michael Grootenboer, senior vice president of engines product at Air France Industries KLM Engineering & Maintenance. He adds that the same is true of the second and third removals, which are also mainly driven by LLP limit. EGT margin loss is not a removal driver.

Weinz adds that Lufthansa generally has a first removal interval of 20,000EFC or 35,000EFH, whichever occurs first. "We find that the main removal causes are core LLP expiry, but also looseness of the VSV bushing, or findings in the combustion chamber after about 35,000EFH," says Weinz.

"The improvement between /P and /3 engines is as much as 2,000 EFC in on-wing life and a removal interval improvement of 1,000-1,500EFC," adds Baccarani. "It is too early at this stage to know what the improvement will be between the /3 and /3 PIP standard. We are only now seeing the first PIP engines coming off-wing for their first SVs, and these are mainly engines operated in hot environments."

Marom says that so far IAI does not have any experience of /3 PIP engines, but it expects them to be similar to the /3 standard engines.

The main consideration at the first removal is the appropriate and required SV workscope. This raises the issue of what restored EGT margin can be achieved after the first SV, since this will affect the subsequent and second potential removal interval. The restored EGT margin will be determined by the level of workscope, and the ratio of new versus repaired and restored parts. A high degree of parts replacement will generally result in a higher restored EGT margin and longer subsequent interval in relation to hardware deterioration.

The main objective will be to balance the possible second removal interval with the remaining LLP life limit. Larger SV workscopes will ideally be required when LLPs have to be replaced, so ideally the workscope on the remaining parts and assemblies in each affected module should match this. At a first removal interval of 18,000-20,000EFC *(see table, page 42)*, the remaining LLP life in the LPT will be just 5,000-7,000EFC. The remaining life LLP in the fan/LPC will be another 5,000EFC at this stage, so 10,000-

Engines powering the A321 are the higher rated -5B3, -5B2 and -5B1 variants. These are sensitive to EGT margin erosion. As a consequence, the majority of A321s are equipped with engines that are the /3 or 3 PIP standard that have higher EGT margin and so longer on-wing life than earlier standard engines.

12,000EFC.

"The first SV will clearly have to be a full overhaul that includes LLP replacement for the HPC and HPT," says Marom. "It will therefore require a high level of airfoil and parts replacement because of the accumulated time on-wing."

A main issue will be what workscope to perform on the LPT. A remaining LLP life of 5,000-7,000EFC will clearly impose the same interval limit on the second SV. For this reason many operators also decide to perform a full overhaul on the LPT at the first SV to allow LLP replacement at the same time, and thus allow a second removal interval of 10,000-12,000EFC as allowed by the LLP life limits of fan/LPC LLPs. This will be at a total time of 28,000-30,000EFC by the second removal *(see table, page 42)*. The second SV workscope will therefore clearly include an overhaul of the fan/LPC.

"The restored EGT margin after a full core overhaul at the first SV will be 70 degrees centigrade for a medium-rated -5B4 powering the A320, and up to 110 degrees centigrade for lower-rated engines such as the -5B6 at 23,500lbs thrust for the A319," says Marom. "This will be sufficient to allow a second removal interval up to 30,000EFC, and so 10,000-12,000EFC."

The length of the first removal interval not only means that HPC and HPT LLPs will have to be replaced, but also that there will be a high degree of replacement of airfoils and other parts. "Although EGT margin loss is not a removal driver, hardware deterioration is an issue after a long interval," says Marom. "Combustion chamber distress is one example. A high level workscope after 20,000EFC will allow two subsequent intervals of 10,000EFC and 10,000EFC."

Baccarani explains that the first SV will have to include the overhaul of three of the four main modules, as described, and that the engines can achieve second intervals of up to 12,000-14,000EFC as a result.

"A harsh operating environment, in high ambient temperatures and sandy conditions, will lead to more hardware deterioration and distress," says Baccarani. "This will be in the major components of the hot section such as the nozzle guide vanes (NGVs), the HPT blades and the combustor.

2nd & 3rd removals

The policy of overhauling the HPC, HPT and LPT modules and replacing LLPs in all three modules at the first SV will allow a second removal after another 10,000-12,000EFC and up to a total time of 28,000-30,000EFC. "This would take it up to the fan/LPC LLP limit, and so force an overhaul on this module," says Marom. "Little or no work needs to be done on the core and LPT at this second SV."

If the general pattern is followed, as described, then the second SV after a total time close to 30,000EFC will clearly include a fan/LPC overhaul to allow replacement of its LLPs. "Most low- and medium-rated engines are getting close to a total time of 30,000EFC by the second SV," says Baccarani. The second set of LLPs in the core and LPT modules will have a total time of 10,000-12,000EFC at this stage, so the HPC and HPT parts will have 8,000-10,000EFC remaining. The HPC and HPT modules will therefore require a performance restoration or a light SV with a high degree of parts repairs. The LPT can be left, which will have 13,000-15,000EFC remaining at this stage. By this

CFM56-5B REMOVAL & SV MANAGEMENT - A321 ENGINES

Removal	First	Second	Third
EFH:EFC ratio			
Removal interval - EFC	8,000-11,000	6,000-8,000	6,000-7,000
Removal interval - EFH			
Total time - EFC	8,000-11,000	14,000-19,000	20,000-25,000
SV workscope	Core performance restoration	Core overhaul	Core performance restoration
New parts	$2.9 million	$3.25 million	$3.25 million
Parts repairs	$0.5 million	$0.7 million	$0.7 million
Labour	3,000-3,500MH	3,500-4,000	3,000-3,500
LLP replacement		$2.1 million	
SV workscope			**LPT overhaul**
New parts			$0.6 million
Parts repairs			$0.4 million
Labour			500-650
LLP replacement			$1.14 million

stage the aircraft has been flying for about 20 years."

The pattern of the first two SVs and the total time also implies the length of the third removal. This is for two reasons.

The first is because the HPC and HPT LLPs are replaced at the first SV. The new installed LLPs with 20,000EFC will have accumulated 10,000-12,000EFC by the second SV, and so limit the third removal to 8,000-10,000EFC, and a total engine time of 36,000-40,000EFC *(see table, this page)*.

At this third SV the two core modules will therefore require a second overhaul and second replacement of LLPs if they are to continue operating for a subsequent fourth interval.

The LPT will have another 3,000-7,000EFC of LLP life remaining. This may be sufficient for an aircraft that will be 22-26 years old at this stage, and will have gone through two heavy airframe check cycles. The LPT with this much LLP life remaining may also have some value on the used market as a time-continued module.

This pattern of removal intervals and SV workscopes *(see table, this page)* can generally be followed by most operators of low- and medium-rated -5B engines powering the A319 and A320 for the first three SVs. This takes the engines up to a total time of 40,000EFC, equal to 22-26 years of operation at typical annual rates of utilisation.

"Airlines with their own engine shops have more flexibility, even though the general pattern is 20,000EFC, 10,0000EFC and 10,000EFC for the first three removal intervals; and the first SV involves overhauls of the HPC, HPT and LPT," explains Baccarani. "Some airlines will perform overhauls on the HPC and HPT, but will leave the LPT and perform an overhaul and full LLP replacement on it at the second SV and a total time of 25,000EFC. The core modules will thus only require a minor SV at this stage after a short second interval."

Another issue to consider is that the age of the engine at the first SV will coincide with possible aircraft retirement. While secondary markets are possible conversion to freighter or use by another passenger airline, only a minority of aircraft actually realise these new roles. A large portion of the fleet is likely to face retirement. This will be partly due to an increasing number of new generation aircraft being delivered to replace A320ceo fleets. A portion of CFM56-5B engines are therefore likely to be purchased for parts salvage at this stage. The expense of installing new LLPs and performing a core overhaul is therefore likely to be seen as uneconomic by many airlines when they come due.

While these potential intervals indicate the SV pattern and general engine management for planned intervals, there is also the issue of unplanned removals. "These account for 10-20% of engines," says Marom. "These can be after short intervals, and may only require small SVs if light repairs are required."

The age of the engines by the time they go through the third and fourth SVs will be 22-24 and close to 30 years. "These SVs present the opportunity to use USM to lower the cost of materials and parts," says Marom. "This will be acceptable for older engines, since the USM and repaired parts will not compromise removal intervals. The availability of USM, however, depends on the supply of teardown engines."

A321 engines

The higher-rated variants that power the A321 have to be managed with shorter removal intervals that affect the pattern of SV workscopes.

Initial EGT margins of the highest-rated -5B3 variants at 32,000lbs thrust are about 66 degrees centigrade, and a little higher at 90-100 degrees for the -5B2 and -5B1 rated at 31,000lbs and 30,000lbs.

The active -5B-powered A321 fleet is about 660 aircraft, and 580 are -5B3 engines. The /3 PIP standard is the most numerous, with 432 aircraft equipped with these engines. Of these, 621 are powered by -5B3 engines, equal to 64% of the A321 fleet.

Another 83 have /3 engines. There are 138 aircraft with /P engines, and most are -5B3 rated.

Given the performance, durability and EGT margin improvements of the /3 and PIP modification programmes, it is not surprising that almost two-thirds of the -5B-powered A321 fleet is equipped with engines of a /3 PIP standard.

Loss of EGT margin and performance is clearly a removal driver in these three variants, and has a bigger influence for the highest rated -5B3. The initial EGT margin loss of about 17 degrees centigrade in the first 2,000EFC on-wing leaves only about 49 degrees, equal to an EGT margin loss rate of 3.5 per 1,000EFC. On this basis, the engine will only be capable of a total on-wing run of about 16,000EFC. The more likely interval will be 14,000-15,000EFC for -5B3 engines.

1st removal

"We are actually seeing high-rated -5Bs coming for their first SV after just 8,000-9,000EFC. So far we only have SV experience with the /P standard engines, and not the higher standard /3 or /3 PIP engines," says Marom. "These engines are especially vulnerable to performance and EGT margin loss in harsh and higher temperature environments. The engine gets a lot of hardware distress and deteriorates very fast. We do expect the /3 and /3 PIP engines to achieve an additional 1,000-2,000EFC on-wing for their first removal intervals. At best this would increase the interval to 10,000-11,000EFC."

Grootenboer explains that the Air France fleet is powered by lower rated B1 engines, and so EGT margin loss is less of a removal driver than higher rated engines.

"Another issue of operating the -5B at 32,000lbs thrust is that the engine's redline EGT limit is often reached," explains Marom.

Baccarani explains that the -5B series was designed to provide the higher thrust requirements of the A321, and that it is a de-rated engine on the A319/320. "This is why the engines on these aircraft perform well, but intervals more typical of older generation aircraft are seen on the A321," says Baccarani.

"The first intervals of -5B3s of /P standard have been 11,000-13,000EFC, when the aircraft is operated at an average FC time of 1.8FH and in a temperate climate and non-sandy environment," continues Baccarani. "In a harsh environment, these engines are only getting half the on-wing intervals. For some engines operated in the Middle East it is good to get intervals of about 6,000EFC.

"If the aircraft operation is changed to longer FC times of 3.0FH, then the engine will still stay on-wing for about 11,000EFC, but will of course be equal to 33,000EFH," adds Baccarani.

2nd interval

A first interval of 8,000-11,000EFC probably means that the first SV performed will be a performance restoration. "This has to be considered against the likely second interval, which can be 8,000-9,000EFC," says Baccanari. "Clearly the two combined intervals cannot exceed the HPC and HPT LLP life limits of 20,000EFC. This means it is only worth considering a full overhaul on the two core modules at the first SV if the interval is as long as 15,000EFC or more."

This long first interval is unlikely, however, and older original standard engines or /P standard engines have only achieved second removal intervals of 5,000-6,000EFC in some cases. The total time by the second removal and SV can therefore be as long as 17,000EFC, but can be as short as 13,000EFC. The longer total time would clearly call for a full overhaul and LLP replacement at the second SV to avoid compromising the subsequent interval, but the shorter total time would provide sufficient remaining LLP life for a third on-wing interval before full overhaul and LLP replacement in the two core modules.

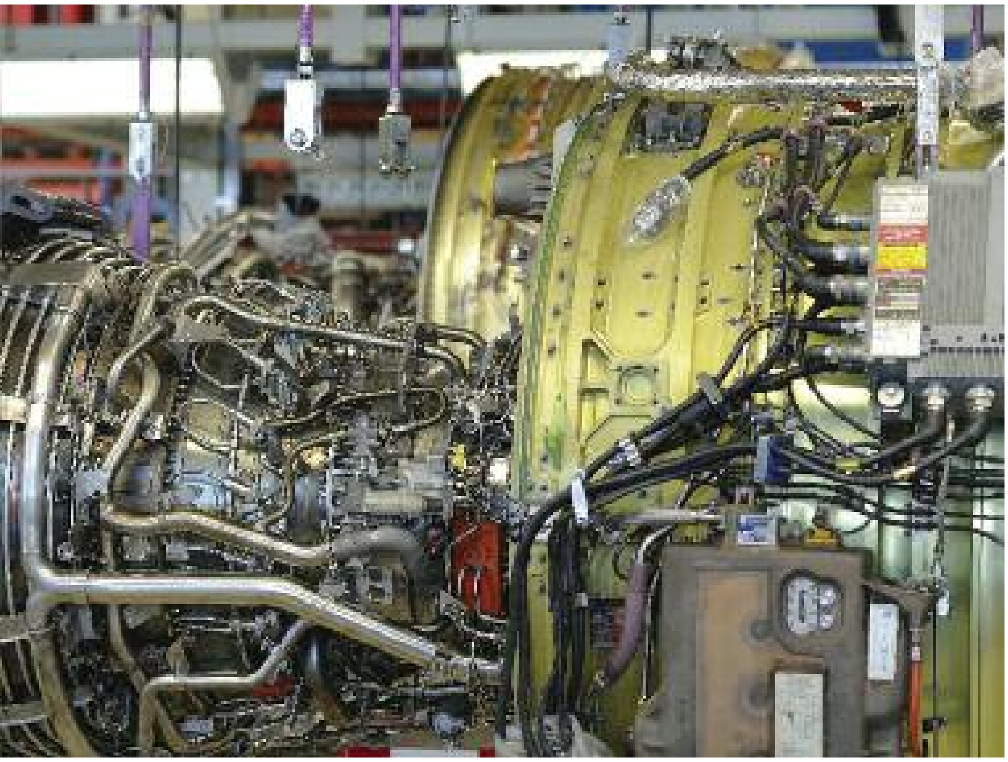
Many older and /P standard engines are achieving first removal intervals of 8,000-11,000EFC *(see table, page 42)*. This leaves sufficient core module LLP life for a second removal interval without being compromised by LLP life. The second interval of these engines is 6,000-8,000EFC in most cases, so a total time of 14,000-19,000EFC will have been accumulated by the second SV. This will require a full core module overhaul and LLP replacement *(see table, page 42)*.

The remaining LLP life of LPT parts will be just 6,000-11,000EFC, while the fan/LPC parts will still have 11,000-21,000EFC remaining. These two modules could therefore be left at this stage, although the LPT would possibly require an inspection, and any findings would result in a workscope.

3rd removal

The third removal interval is likely to be 6,000-7,000EFC, taking total time to 20,000-25,000EFC *(see table, page 42)*, equal to 12-15 years of operation.

At this stage the set of LLPs installed in the core modules at the second SV will have 13,000-14,000EFC of life remaining. The total time at this stage will mean a full workscope on the LPT will be required to allow LLP replacement *(see table, page 42)*.



Without interference from unplanned removals and shop visits, most -5B engines can be managed around removal intervals that closely match LLP lives. The fan and LPC module may only require one overhaul for LLP replacement in the engine's operational life.

The actual time accumulated will determine if there is enough LLP life left for the fan/LPC LLPs to remain for a fourth interval before a full workscope to allow LLP replacement at the fourth SV. This will be at a total time of 22,000-30,000EFC *(see table, page 42)*.

The longer intervals that are possible for /3 standard engines mean a different SV pattern will be required. The first removal interval of 14,000-16,000EFC is possible. Since a second and subsequent interval of about 11,000EFC is also possible, it means that a full workscope on the HPC and HPT core modules and full LLP replacement will be required at the first SV *(see table, page 42)*.

The combined first and second intervals will come conveniently to 25,000EFC, or 1,000-2,000EFC fewer, and so provide an opportunity to replace LPT LLPs at close to their full life limit *(see table, page 42)*. The core modules at this second SV would therefore require a performance restoration. The core module LLPs would have 9,000-10,000EFC of life remaining.

The fan/LPC LLPs at this stage would have 5,000-7,000EFC remaining. A third removal interval of 9,000-10,000EFC may be possible, so a decision would have to be taken at this stage of whether or not to put the fan/LPC through a full overhaul to avoid limiting the subsequent interval due to LLP limits. A fan/LPC overhaul would be required if the total time at the second SV was 23,000-25,000EFC and a third interval of 9,000-10,000EFC was possible *(see table, page 42)*. This would take total time to about 34,000EFC, equal to 21 years of operation at a typical utilisation rate of 1,650EFC per year. Aircraft operating longer cycle times of 2.0-3.0FH will accumulate 1,000-1,350FC per year, so the third SV will come due at 25 years or more.

While there may be a surplus of A319s and A320s when the third planned SV comes due because of a limited secondary market, the A321 is likely to be in high demand as a freighter conversion candidate. There will therefore be a degree of demand for time-continued engines and modules, and salvaged parts and airfoils from dismantled engines.

SV inputs

A portion of engines are maintained via fleet-hour, maintenance cost per hour (MCPH) and other similar agreements. A portion of aircraft are owned or financed with debt arrangements, while others are acquired via operating lessors. Similarly some airlines have chosen alternative methods of engine management and engine maintenance contracts. These can include the actual cost of time (labour) and material used, fixed price, and not-to-exceed contracts.

The approximate costs of the SVs described here are analysed on a time and material basis, and so analyse the cost of the expected labour and material inputs.

The main elements of SV costs are labour, new parts, sub-contract and in-house airfoil and turbomachinery parts repairs, and the repairs of accessories. They also include the cost of LLPs fitted during the SV. There can be a net cost for LLPs, with the sale proceeds of time-continued LLPs removed from the module during the SV. A sale of time-continued LLPs is only likely in a small number of cases. Moreover, time-continued LLPs will be bought on a relatively low pro-rated basis by operators that are interested in acquiring parts for some modules. This will allow them to run for a few thousand EFC as a low-cost way of extracting a few more years of service from an old engine. For this reason any possible sales value of time-continued LLPs are not included in the cost estimates.

The largest cost element of SVs is the cost of new parts and materials. Airfoils and engine parts can generally be repaired for a small percentage of the list price of a new part. That is, the repair cost can be in the order of 25% of list price. While such a saving may be appealing, the use of repaired parts or used serviceable material (USM) will only be satisfactory for relatively short removal intervals following the SV. A high percentage of parts will have to be replaced if long subsequent removal intervals are aimed for. This is particularly the case with airfoils in the HPT.

The list price for shipsets of new parts and materials in each module are high, with the HPT having some of the highest. A full shipset of HPT blades has a cost of about $1.2 million, a shipset of nozzle guide vanes (NGVs) in the HPT about $1.5 million, and a shipset of shrouds about $250,000. The three main sets of parts total about $3.0 million.

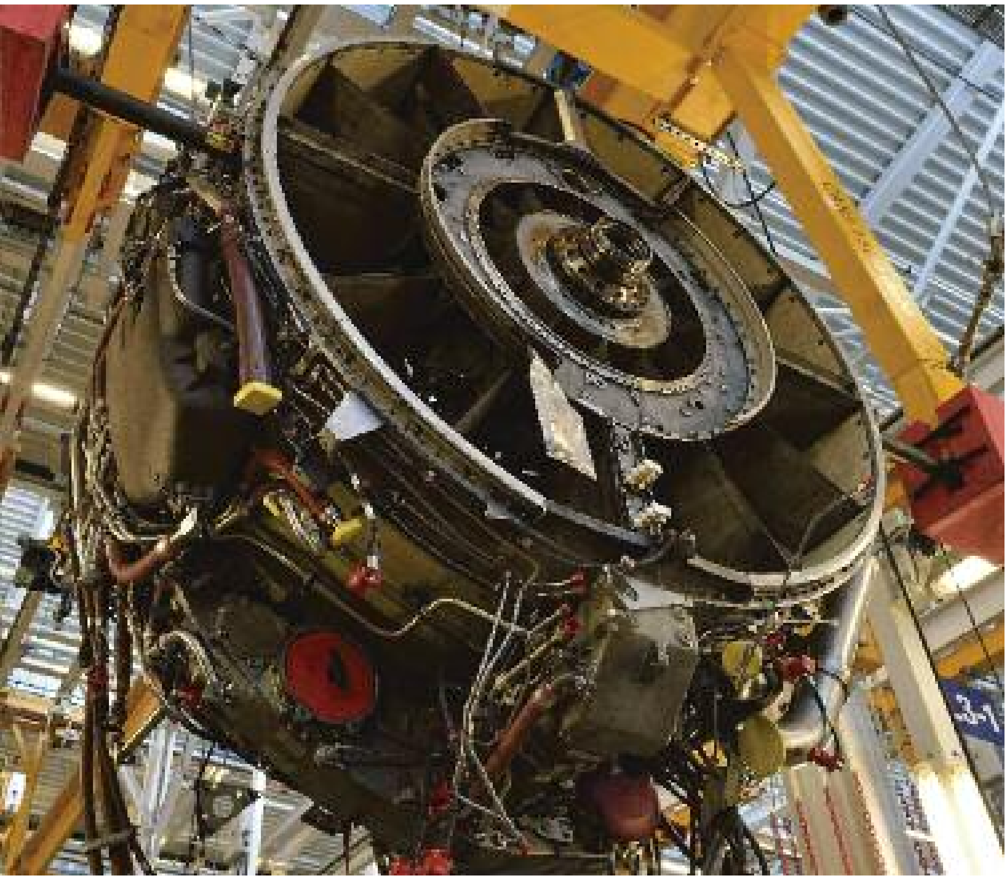
A full shipset of combustion chamber liners and casings has a list price of about $1.2 million.

A shipset of HPC blades and stators has a list price of about $1.0 million.

The fan/LPC and LPT equally have high list prices for complete shipsets of airfoils. A higher portion of these can be repaired compared to parts in HP modules, however. Moreover, many parts can be repaired twice before requiring replacement. Full shipsets of airfoils and parts in the fan/LPC and LPT are $3.2 million and $2.8 million. A repair cost of about 25% clearly provides the possibility of providing large savings in the combined cost of new parts and parts repairs for these two modules.

A319/320 engines

The core overhaul in the case of the A319/320 engines at their first SV, that is now likely to occur 18,000-20,000EFC since new, will require a new shipset of LLPs, as described. This will be $2.1 million.



Airlines that have more flexibility or freedom to determine shop visit workscopes can be in the position where the majority of later standard /P, /3 and /3 PIP engines only require two or three major shop visits in their operational life.

The long interval up to this removal will mean that a high percentage of parts will have to be replaced. "Our experience is that once we can see that material will not last 40,000EFC, two full cycles of 20,000EFC, then it needs to be replaced at the SV after 20,000EFC," says Weinz. "This will include the replacement of all HPT blades and NGVs."

A new shipset of HPT blades, for all 80 blades, is about $1.2 million. The same applies to the 76 HPT blades installed on the /3 PIP engines. HPT blades have soft lives of 20,000EFC or 25,000EFC, and so all will have to be replaced at this stage.

The cost of providing all other new parts is in region of $2.4 million. This represents about two-thirds of parts in the HPC and HPT modules, other than the HPT blades, being replaced.

The cost of repairs for parts not replaced can be expected to be in the region of $400,000. The cost of repairing accessories is about another $300,000. The cost elements of materials and parts repairs will thus total about $4.3 million *(see table, page 42)*. The engine shop labour used will be 3,500-4,000 man-hours (MH) for these two modules.

The same SV will also involve the LPT overhaul. A new shipset of LLPs is $1.14 million at 2020 list prices. List price for all parts in the LPT is about $2.8 million. In contrast, the cost of new parts is expected to be $600,000, while cost of repairs for the majority of parts will be $400,000-500,000, taking the total to $1.0-1.1 million *(see table, page 42)*. Labour consumption will be 700-900MH.

The second SV will incur a core performance restoration, and fan/LPC overhaul.

The core performance restoration will require about 50% of HPT blades to be replaced, while the other 50% can be repaired. The variation in the HPT blade scrap rate will be from 40% for a low thrust engine operating in a temperate climate, but can climb to as much as 60% in a harsh environment.

Cost of new HPT blades will thus be $500,000-600,000. The cost of other parts and materials in the core modules will be less than the first SV, but still be in the region of $2.0 million. The cost of parts repairs will be $300,000-400,000. This will take the total for new parts and repairs to about $3.0 million. Another $300,000 will be incurred for the repair of accessories. Labour used will be 3,000-3,500MH.

The workscope on the fan/LPC will see all LLPs be replaced at a cost of $924,000. A shipset of new parts has a list price of $3.2 million. Only about $200,000 will be required for new parts, and another $300,000 required for the repair of 40-50% of parts in this module. A further $50,000 should be allocated for accessory repairs. Total for parts, materials and parts repairs is therefore $550,000. Labour used is 500-650MH.

The third SV will possibly involve another core overhaul. At 2020 prices this will be $2.1 million for LLPs. At this stage of the engine's operational life it will not be necessary to replace the same percentage of parts as in the first SV. Cost of new parts excluding the HPT, will be about $2.0 million for an engine that could achieve a post-SV interval of at least 10,000EFC. About 40% of HPT blades may need replacing at a cost of about $500,000, while others will require repairs. The cost of all airfoil parts repairs will be about $500,000, and a further $300,000 for accessory repairs, as in the first SV. This will take the cost of all new airfoil parts and repairs to about $3.0 million *(see table, page 42)*. A similar amount of labour will be used as in the first SV.

A321 engines

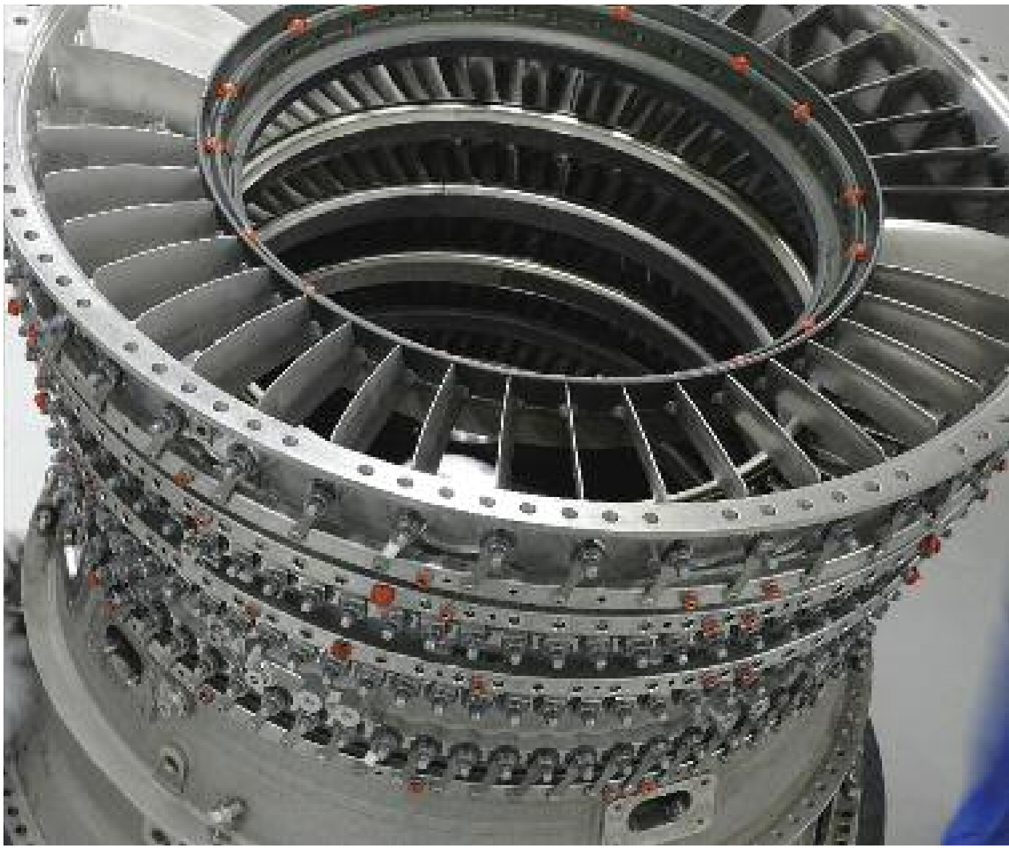
While higher rated engines powering the A321 will not be able to achieve the same removal intervals as on the A319/320, these engines will be able to offset this affect to a degree by lower SV inputs.

The first SV will require a core performance restoration. This will require about two thirds of all non-HPT blade parts to be replaced, and 40-50% of HPT blades to be replaced. The cost for these two elements will be $2.4 million and $0.5 million. A further $0.5 million will be required for parts repairs. This will take the total for new airfoils and airfoil repairs to about $3.4 million *(see table, page 42)*. The cost of accessory repairs will be similar to lower rated engines at $300,000. Labour used will be 3,000-3,500MH. Other modules are left during this SV.

The second SV will be a full overhaul of the same two core modules, as described. This will incur similar costs to the overhaul of the same modules for lower rated engines.

The replacement of the LLP shipset at 2020 list prices is $2.1 million. This will require a similar portion of parts and airfoils being replaced as in the fist SV, and so incur a cost of about $2.4 million at today's prices. A larger portion, about 65%, of HPT blades will have to be replaced, and so incur a cost of about $850,000. The total for new parts will thus be about $3.25 million. Airfoil parts repairs will cost about $400,000, because a smaller portion will be repaired. Another $300,000 will for the repair of accessories. These elements will total about $4.0 million. Labour used will be 3,500-4,000MH.

The third SV will involve a performance restoration of the core



Engines powering the A319 and A320 may only require an overhaul on the HPC and HPT modules for a second time close to the end of their operational life. Many airlines may decide to scrap engines at this stage for parts salvage.

modules, and an overhaul of the LPT. The core restoration will incur similar costs to that of the first SV, although a higher percentage of HPT blades will require replacing at this stage. The cost of new non-HPT blade parts will be similar to the previous core restoration, plus about $0.85 million for HPT blades, taking the total to $3.25 million *(see table, page 42)*. Repairs of airfoils will incur a further $400,000, and another $300,000 will be required for accessory repairs. Labour used will be 3,000-3,500MH.

The costs for the LPT overhaul will be similar to that of the lower-rated engines for the A319/320. This will be $1.14 million for a full shipset of LLPs, plus about $600,000 for new parts and $400,000 for parts repairs.

Other considerations

Besides these main SV events, and their input costs, there are several other issues that have to be considered.

The first of these is that older engines that were of the original standard will have experienced shorter removal intervals, and so have had different SV workscope patterns to /P and /3 engines that are capable of longer removal intervals. Their overall costs per EFH for non-LLP replacement costs will be higher than for the engines that are capable of achieving the removal intervals as modern standard engines as described.

Another issue to consider is unscheduled or unplanned removals. These events may be smaller and lower cost than planned SVs.

If the SV events following an unscheduled removal are similar in workscope and cost to planned visit then they will increase maintenance costs per EFH. If they are major events they will also upset the removal and workscope pattern. The main effect will be to compromise the replacement of LLPs, and cause some parts to be replaced early. Overall it will result in earlier than planned major SV events, and so increase costs per EFH for SV inputs, and costs per EFC for LLP replacement.

A third issue to consider is the availability of time-continued engines on the market. These can be a source of parts that can be repaired, and provide USM for third and fourth SVs, and thus provide savings in relation to cost of parts and materials.

The supply of USM is likely to increase as more aircraft are scrapped as more new generation aircraft are delivered, and a large portion of A320ceo family aircraft do not find markets to keep them operational. The extent to which USM parts might be used would be 25-35% in the HPC and HPT modules.

These engines can also provide time-continued LLPs.

The low-cost parts will suit an operator that has engines at 20 years or older, and is seeking to make savings by building engines to provide a few more years service instead of the optimum number of EFC possible.

This will only be possible if there is a sufficient supply of engines or modules on the market. About 310 A320ceo family aircraft equipped with CFM56-5B engines have been retired or scrapped. Supply of aircraft has been tight over the past year, however, due to the effects of the 737 MAX grounding. This situation is now likely to change because of the worsening Corona virus pandemic. Large numbers of older A320ceo family aircraft could become available as airlines offload older aircraft.

The use of parts manufactured approved (PMA) components and parts has the potential to provide significant savings on parts consumption at SVs. Despite being legal alternatives to the original equipment manufacturer's (OEM's) parts, PMAs are typically priced at 60-75% of the OEM's list prices. Airlines may find it easier to use PMA parts in later SVs.

Providers of OEM parts for the CFM56-5B are HEICO Aerospace, which provides HPC airfoils.

The use of USM can provide similar savings, since USM repaired parts are often sold at 60-70% of the OEM list price for new parts. Consideration has to be given here for the risks of using repaired parts, and the probable on-wing life. The use of USM is more likely to be considered in later SV events. Potential savings are several hundred thousand dollars in each module. This will be an attractive proposition for airlines operating engines that are more than 20 years old, and for an anticipated short interval.

In addition to using PMA parts and USM to lower the cost of SV inputs, engines that are free to be maintained under time and material type contracts can be sent to totally independent engine shops. This is particularly important, considering the surge in the -5B's SV activity over the past few years. These are increasing in number, and include shops such as Aerothrust and Global Engine Maintenance (GEM). These both have shops in the Miami area.

GEM is already experienced with the CFM56-3 and -7B series, and is entering the -5B market. It has capacity for about 60 SVs per year, but can increase this to 84. GEM also has the in-house repair tooling, such as high-speed compressor grinding and a 3-D scanner, to minimise SV turn times. GEM can provide long-term contracts to big airlines. AC