A series of major modification and upgrade programmes for the CFM56-3, 5B & -7B series; and the V2500-A5 were based on replacing original airfoils and associated hardware with 3D Aero airfoils. The main effects were reduced fuel burn and maintenance costs.

Major modifications & upgrades for the CFM56-3, -5B & -7B, and V2500-A5

Various engine upgrade and modification programmes have been introduced as each engine type gains operational experience. The main aim of these upgrades is to improve operational reliability, reduce fuel burn and carbon dioxide and nitrous oxide emissions, increase temperature margins and retain engine performance, and achieve overall lower maintenance costs.

Major upgrade and modification programmes for the CFM56-3, 5B and -7B series; and the V2500-A5 have been introduced over their years of operational service.

CFM56 family

The CFM56 has become the best-selling engine in commercial aviation, and is also the most numerous engine in operation. The three main series of the CFM56 in operation are the -3, -5A/-5B and the -7B, of which several thousand units have been produced. Each fleet has, therefore, accumulated tens of millions of flight hours (FH) and flight cycles (FC) in operational service, with some accumulating hundreds of millions of FH and FC. With extensive experience for each main series, CFM International has been able to make several improvements to its engines and improve their economic performance.

There were 1,988 CFM56-3-powered 737-300/-400/-500s built from 1984 to 1999, almost 4,100 CFM56-5B-powered A320 family aircraft have been built since 1994, and more than 6,800 CFM56-7B-powered 737NGs have been built since built from 1997. Given that an additional 15% of engines over those installed are required to provide spare engine coverage, about 2,300 of the -3 series, 9,400 of the -5B series, and 15,600 of the -7B series engines have been built to date.

The CFM56-3 was the first series to enter service. A lot of the -3's architecture was used in the -5B and -7B series, together with operational experience that allowed improvements to be made to the initial build standards of the -5B and -7B. Most -3s, and the fleet of the earlier -2 series, had been built and entered service before the -5B entered service in 1994. The -3's experience was even greater when the -7B series entered service in 1997.

Despite the -3 series being the first of the three major engine series, the -5B and -7B series had upgrade and modification programmes before the -3 series underwent any major configuration changes to its turbomachinery. The -3 series had its first major upgrade in 1999, with turbomachinery technology retrofitted from the -7B series that had entered service two years before.

The first major upgrade and modification programmes for the CFM56 family were for the -5B series.

CFM56-5B

The CFM56-5B was a derivative of the CFM56-5A, which was the original engine developed for the A320-100. About 390 A320s were equipped with the -5A1 and -5A3 engines, and most were delivered from 1988 to 1991. Another 144 A319s were also fitted with -5A1 and -5A3 engines. The -5A had a highest rating of 26,500lbs thrust, and a three-stage low pressure compressor (LPC), so its core was insufficient to develop enough thrust for the larger A321 that was under development.

The -5B series therefore retained most of the -5A's core, but had a four-stage LPC. The -5B has several thrust ratings, the highest being 33,000lbs for the A321-200. The-5B's core configuration is the four-stage LPC, a nine-stage high pressure compressor (HPC), a single annular combustor (SAC), a single-stage high pressure turbine (HPT) and a four-stage low pressure turbine (LPT). The -5B has a 68.3-inch diameter fan, and a bypass ratio of 5.5: 1 for the highest rated variants at 31,000lbs and 33,000lbs; and rises to 6.0:1 for the lowest rated variants at 21,600lbs. A total of 4,073 A320 family aircraft built from 1993 to 2018 were equipped with CFM56-5B engines.

There are nine variants of the baseline -5B series, all designated with a single digit suffix. The -5B1 is rated at 30,000lbs, the -5B2 is rated at 31,000lbs, and the -5B3 is rated at 33,000lbs. These are all used for the A321. The -5B4 and -5B7 are rated at 27,000lbs for the A320; and the -5B6 and -5B8 for the A319 are rated at 23,000lbs and 21,600lbs. The -5B9 is rated at 23,300lbs for the A318. Not all nine variants were manufactured from 1993 to 1996, however. The -5B1, -5B2, -5B4, -5B5, -5B6, and -5B7 were the six variants manufactured for the A320 and A319 from 1993 to 1996. Production of the -5B3 for the A321, and the -5B8 and -5B9 for the A318 started in 1997 and 2002 respectively. These three variants were never built in the baseline configuration.

A different variant was offered when the -5B first entered service in 1994. This had a dual annular combustor (DAC), and was implemented to reduce nitrous oxide emissions (NOx). Engines with a DAC had a /2P suffix in their designation. Only two airlines specified the engines and production was discontinued. The aircraft equipped with DAC engines were originally specified by European operators Swissair and Sabena. Most are -5B4/2P engines for the A320 and -5B6/2P engines for the A319. The

Upgrade and modification programmes for the CFM56 family have focussed on improving coreflow and EGT margin, reducing fuel burn, extending time on-wing between maintenance shop visits, and reducing maintenance costs.

aircraft were built from 1995 to 2005. The combustor, nozzle and HPT hardware for the DAC engine differed from the SAC engine's, which added maintenance costs to the DAC configuration. Some DAC engines were therefore converted back to SAC engines.

The baseline engine was successful, but had competition from the IAE V2500-A5, and both secured almost equal shares of the market.

The -5B series had a long initial production run from 1993 to 1996. There are only eight A320s with the -5B4 engine left in service.

/P upgrade

The -5B's first upgrade programme came with the /P programme in 1996, and so was an improved build standard. As an example of the -5B4, this variant with the /P modification is designated the -5B4/P. The /P modification could also be incorporated into baseline engines as a retrofit through a maintenance shop visit (SV). Only a small number of baseline engines were upgraded, however.

The /P modification or upgrade is also referred to as the 3D Aero programme. Its main feature was the replacement of 2D blades and vanes with 3D parts. This included re-designed HPC blades, new HPT blades and improved cooling that was incorporated to increase exhaust gas temperature (EGT) margin, and a re-designed stage 1 LPT nozzle. The EGT margin was increased by lowering the EGT of all nine variants by 10 degrees centigrade. One particular advantage of the /P upgrade is that it reduced the difference in fuel burn that the -5B had with the V2500-A5.

The overall effect of the modification is to reduce specific fuel consumption (sfc) by 3%, which would result in a commensurate reduction in fuel burn on the same aircraft being powered by the same engine in equal operating conditions.

A total of 1,246 aircraft were fitted with /P engines. These were built from 1993 to 2012. Not only was the /P the standard engine build from 1996, but it was also retrofitted to engines in an SV. "It is possible to modify some modules in one SV, and modify the others in a subsequent SV," says Simon Mermod, director at Jet Engine Management. "Some modules will have to be upgraded in the same SV because they are complimentary. The engine will clearly not become /P standard until all affected modules have been upgraded."

The cost of the full /P upgrade for all modules was the same list price as the parts for the baseline engine. It would mean some higher costs because some parts would be scrapped early.

"While some modules could be upgraded in separate SVs, the entire module would have to be upgraded, since this involves swapping 2-D airfoils, blades and stators, for 3-D airfoils," comments Mermod. "This meant that a lot of airfoils would have to be scrapped early, so the net cost of the upgrade was close to the full kit price. That is, it would not be a case of replacing unrepairable airfoils with new generation airfoils."

Most airlines took the advantage to incorporate the /P upgrade kit when life-limited parts (LLPs) in the existing engine expired, or at least a major shop visit was required.

There were two other upgrades and modifications that followed the /P programme. The first of these was the acoustic upgrade, which was introduced in 2002 and added a chevron nozzle at the engine's exhaust. This was installed to reduce the engine's noise emissions to a level 10 equivalent perceived noise decibels (EPNdB) below that of Stage III levels.

The modification involved a core engine chevron nozzle, an improved thrust reverser, and inlet linings on the engine nacelle. It gave the engine a margin over Stage IV noise emissions. A small margin was delivered for the highest thrust variant powering the highest weight A321, so wider margins were achieved for lower rated variants.

The modification has been available for production engines since 2004, but to date has mainly been fitted to the highest rated -5B3/P engines that power the A321.

A second major programme that followed the /P upgrade was the life extension of the core engine LLPs. The CFM56-5B can be considered in three of four main modules with respect to LLPs. These are the fan and LPC, the HPC, the HPT, and the LPT. The fan/LPC had target part lives of 30,000 engine flight cycles (EFC), the HPC and HPT had target lives of 20,000EFC, and the LPT had target lives of 25,000EFC. In the case of earlier built engines, the actual certified lives of all discs and shafts were not at the target lives when the engines first entered service. Some parts had initial lives that were less than half the target lives, and could therefore limit and compromise on-wing removal intervals. Short lives of individual parts in modules mean that remaining lives of other parts in the same module could not be utilised.

The LLP life extension programme had the objective of taking all parts to their target life limits.

Tech Insertion

The second major upgrade and modification programme for the CFM56-5B series is the Tech Insertion or Tech 56

A main element of a series of modifications for the CFM56-5B and -7B hasd the use of several generations of 3-D Aero blades in the HPC to improve coreflow, with the effect of reducing EGT margin and fuel burn.

upgrade. Engines with this upgrade have a suffix of /3 in their nomenclature. The upgrade was launched in 2004. It was the production standard from the third quarter of 2007, and was also incorporated into existing engines in maintenance SVs.

The overall objective of Tech 56 was to improve fuel burn and EGT margin, and reduce maintenance costs through increased parts durability and longer removal intervals. The improvements mainly affected the HPC, combustor, HPT and LPT. The core engine and LPT module were those affected.

The main change to the HPC are new design blades with improved aerodynamic efficiency. 'This was basically the use of second generation and better-performing 3-D aero blades," explains Mermod.

The HPT was improved by reducing aerodynamic shock that increased fuel burn and improved blade durability, and the LPT was upgraded through improved cooling that increased longevity.

The programme has the flexibility of allowing only some modules to be upgraded, depending on an operator's requirements. The Tech 56 or Tech Insertion was incorporated into a large number of baseline configuration engines.

The main features of the Tech 56 programme are: an increased removal interval of about 10%; standardised LLP lives in the HPC and HPT modules of 20,000EFC; reduced HPC degradation, which increases EGT margin by 10 degrees centigrade; lower fuel burn; NOx emissions reduced by 20-25%; and an overall reduction in mature maintenance costs of 5-12%. The upgrade, however, did not quite fulfil the projected fuel burn savings.

A total of 951 A320 family aircraft had /3 Tech Insertion engines, with some being modified from their original standard and the remainder being original production engines.

The list price for the entire package was $1.8 million. This does not include the list price of LLPs. Most operators would wait for the life expiry of original LLPs to be replaced with new parts with full life limits.

The /3 Tech Insertion programme does not have to be incorporated in every module. Some modules can have the improvements incorporated, and engines can have the entire modification retrofitted over several maintenance SVs.

"It was only possible to upgrade a baseline -5B engine to a /3 engine, but this was clearly more expensive than upgrading a /P engine," says Mermod.

The /3 modification has been incorporated in engines built from 1994 to 2017. There are also a small number of aircraft that have /3 engines with a thrust bump. These are designated with a /3 B1 suffix.

PIP upgrade

The third major upgrade programme for the -5B series is the performance improvement package (PIP). This included a series of hardware improvements and upgrades to engines that have already had the /3 programme incorporated. Engines with the PIP programme added are designated with a /3 PIP suffix.

The PIP started in 2011. It involves hardware changes to the HPC guide vane diffuser and blades, HPT blades, and two stages of the LPT. These modifications were incorporated in existing engines with the /P and /3 upgrades, and became the build standard for new engines. A total of 1,780 A320 family aircraft have engines with the PIP modifications incorporated. This is the largest group of aircraft, making the /3 PIP engines the most numerous sub-type of the -5B series. These are aircraft built since 2004, and include aircraft delivered in January 2019.

The price of the PIP package is similar to the catalogue lost prices of the equivalent parts in baseline, /P and /3 engines. For example, the cost of the full shipset of blades for pre- and post-modification engines is about $1.1 million. Installing the kit may be overall more expensive, however, because of the need to replace all airfoils in each module. The kit is fully modular, however, so modules can be upgraded individually. It was viewed by some that the most beneficial part of the kit was the HPT, and was best installed at LLP expiry.

There are a small number of PIP engines that also have a thrust bump. These are designated with a /3B1 PIP suffix.

CFM56-7B series

The CFM56-7B engines were developed for the 737NG. With various technologies developed for the -5B series, and the first upgrade programme developed for it, the development of the -7B followed a few years later for introduction into service in 1997.

The -7B adopted a core engine used for the -5B series, with the exception that the -7B had a three-stage LPC and a smaller fan with wide chord fan blades. Because of installation issues on the 737NG, the -7B series needed a smaller fan with a diameter of 61 inches. There are six variants of the -7B series, with thrust ratings of 19,500-27,300lbs for the four main series of the 737NG family. The lowest rated -7B18 engine has a bypass ratio of 5.5:1, while the highest rated -7B27 variant has a bypass ratio of 5.1:1.

The Tech Insertion programme for the CFM56-3 series provided several improvements. The arrival of the upgrade on the market may have been too late, since an increasing number of used engines were coming onto the market.

There are three main groups of engines in the -7B family. The first is the baseline engine, production of which started in 1997 and continued through to the end of 2018.

This build standard incorporated the technology of the /P programme developed in the mid-1990s for the -5B series from the start of -7B production. This included the 3D aero blades, new generation HPT blades for improved cooling, and a re-designed LPT nozzle.

There have been a total of 2,180 aircraft equipped with baseline engines. There is also another small group of 66 aircraft fitted with engines that have /A, /A3, /B1 and /B3 suffixes to their nomenclature.

Tech Insertion

The first major upgrade programme for the -7B series was the Tech Insertion or Tech56 upgrade. This was introduced in 2007, the same time as the same upgrade package for the -5B series. Engines with the upgrade are designated with a /3 suffix.

The package was introduced as standard build configuration for engines from this point, but the relevant hardware could also be retrofitted to existing -7B engines during a maintenance SV. The price of the parts for those included in the /3 upgrade modification are the same as those for the baseline standard engine. The full kit at the time of release has a catalogue list price of $3.5 million.

The material for the /3 upgrade could therefore be introduced to engines as baseline standard parts that require replacing without any additional cost to engine SVs.

The main features of the /3 upgrade are: an enhanced SAC to reduce NOx emissions by 20-30%; re-designed HPC and HPT rotor hardware; the use of 3D-Aero HPC blades; and improved LPT blade and nozzle design. The overall effect of this upgrade is to reduce engine maintenance costs by extended removal interval and reduced hardware deterioration, and a fuel burn reduction of about 1%.

There are more than 1,400 737NGs with engines that have undergone the /3 upgrade programme. These are aircraft built from 1998 to 2018, and so include original build standard engines that have been retrofitted. The /3 configuration was an option from 2007, but baseline configurations have continued to be built.

Evolution upgrade

The second major upgrade for the -7B series is the Evolution modification. Engines with this are designated with an E suffix. An example is a -7B27E variant, rated at 27,300lbs.

The Evolution upgrade was announced in 2009, and the first deliveries were made in mid-2011. The upgrade became the standard production configuration for the engine, and could also be retrofitted to existing engines. Retrofits to previously built engines of different standards were not done.

The Evolution or 'E' has become the most popular variant, with more than 3,067 aircraft equipped with this standard of engine. This includes aircraft manufactured from 1998. There are 100 aircraft with E engines that also have a thrust bump, taking the total to close to 3,200 aircraft out of 6,850 built to date.

The Evolution upgrade included modifications and upgrades to the HPT and LPT, and had the objective of reducing fuel burn by 1% and engine-related maintenance costs by 4%.

Changes to the HPT were to the outlet guide vane (OGV) diffuser to improve aerodynamic efficiency, new blades, and a forward and outer seal. In particular, this included a new design of the HPT blade, which has features to improve durability. The change to the HPT design also reduced the number of blades from 80 to 76.

Changes to the LPT affected the blades, the vanes, the disks and the case. The overall effect was to improve aerodynamics and cooling, and reduce the number of parts in these two modules.

The 'E' upgrade came in four possible configurations. The first was a change to just the OGV diffuser. The second was to the HPT blades, and the third was to the LPT. The fourth incorporates the entire kit to the engine.

Testing revealed that the full kit provides an actual saving in fuel burn of 1.6%. The E upgrade was accompanied by some aerodynamic improvements relating to the engine-airframe installation that led to another 1% reduction in fuel burn.

CFM56-3 series

In 1999, CFMI provided an upgrade modification for the -3 series. This was referred to as the time on-wing (TOW) or advanced upgrade kit, and it took core component and part technology from the -7B series.

The modification involved improvements to the HPC and the HPT, and could be split in two halves. The first is the enhanced performance upgrade, and is a modification to the HPC. The second is the enhanced durability kit, and it affects the HPT.

The enhanced performance kit involves upgrades mainly to the HPC, and incorporates the use of 3D Aero blades and the variable stator vane (VSV) actuator and system. The effect of this is to increase EGT margin by about 15 degrees centigrade, and so extend time on-wing between SV removals. The cost of the enhanced performance kit at release was about $300,000.

The enhanced durability kit has three main elements. The first is the use of new N5 material on the HPT nozzles to improve material degradation. There is also improved cooling in the HPT, and enhanced shrouds at the top of the HPT blades. These all contribute to an improved EGT margin and overall durability. The cost of the parts in the enhanced durability kit was about $480,000 for the blades and about $60,000 for the shrouds in 2003-2005.

The total cost of the full advanced upgrade kit is about $1.4 million, but this was several hundred thousand dollars higher than the catalogue price of the standard parts. The complete shipset of airfoils in each module would have to be changed in a single SV.

The parts are installed during engine SVs, and increase removal intervals by 4,000-8,000EFC through an increase in EGT margin. The benefit is realised for variants rated at 22,000lbs thrust and 23,500lbs thrust. Lower rated engines do not benefit as much from an increased EGT margin, because they are able to achieve long removal intervals.

Some considered the cost to be high, so not all engines were modified. "The TOW upgrade provided more of a benefit to airlines operating in a hot environment, since the cost of the kit would be recouped through increased removal intervals, and so lower maintenance costs per engine flight hour (EFH)," says Mermod. "Many airlines that had engines managed through MCPH contracts provided by the OEMs had the Tech Insertion performed, while others that managed their engines independently did not have the modification."

The cost of the kit would now make it economically prohibitive to upgrade baseline -3 engines. This is especially the case with a large number of time-continued engines and modules available on the market at attractive rates.

V2500-A5

The International Aero Engines (IAE) V2500-A1 was the alternate engine choice for the A320 when it was first launched. The V2500-A1 entered service in 1989, one year after the CFM56-A1, and was rated at 25,000lbs. Like the CFM56-5A1, the V2500-A1 lacked the thrust growth capability required to power the larger and heavier A321. The original -A1 also had technical issues that limited time on-wing and impaired operating performance. These were incorporated into production engines in 1992. Production of the -A1 engines continued into 1994, and 143 aircraft were equipped with them.

The higher rated -A5 series had a marginally wider fan diameter of 63.5 inches, and a larger core engine for increased air mass flow. This included a four-stage LPC, a 10-stage HPC, a two-stage HPT and five-stage LPT. The -A5 therefore has one more LPC stage than the -A1. A two-stage HPT has been used to maximise fuel burn efficiency.

The -A5 series has five main variants: the V2522-A5 and 24-A5 rated at 23,000lbs and 24,000lbs for the A319; 27-A5 rated at 26,500lbs for the A320; and 30-A5 and 33-A5 rated at 31,400lbs and 33,000lbs for the A321. Production of the -A5 series started in 1993 and continued to late 2018. A total of 3,207 A320 family aircraft were equipped with V2500-A5 family engines. In total, all V2500 engines equipped 42% of the A320 current engine option (ceo) family.

V2500-A5 standard

There are three main groups of variants in the V2500-A5 family. The first and most numerous of these is the -A5 standard configuration engines. There were 1,310 A320 family aircraft

The SelectOne modification for the V2500-A5 included a lot of upgrades to the airfoils in the main modules, including the use of 3D Aero airfoils. This increased EGT margin by about 12 degrees, and so lengthened removal intervals by about 20%.

equipped with this engine.

The V2500-A1 had some small modifications and upgrades made to it in its earlier period of operation. In 1999 IAE introduced a 'Phoenix standard' version of the engine. This brought the -A1 up to the hardware standard of the -A5. The -A5's higher coreflow gave it a generous EGT margin, and so allowed for a potentially longer removal interval between SVs before it eroded its EGT margin. The lower rated 22/24-A5 variants have initial margins of 90-115 degrees centigrade, the 27-A5 an initial EGT margin of 70-80 degrees centigrade, and the 30/33-A5 variants an initial EGT margin of 40-60 degrees centigrade. The restored EGT margins reduce by about 15 degrees centigrade after the first SVs. There were 1,310 A319s, A320s and A321s built from 1993 to 2011 that were equipped with -A5 engines.

The -A1's core engine configuration had a low EGT margin, and also had a high rate of EGT margin erosion, so it was limited to short removal intervals. The Phoenix standard modification increased the -A1's overall performance and removal intervals.

SelectOne modification

The SelectOne modification was introduced by IAE in 2007 to improve the engine's operating performance, and on-wing durability.

The SelectOne upgrade included a hardware package that affected the HPT, HPT and LPT. The changes to the HPC were the use of 3D Aero airfoils, whose elliptical leading edge had the effect of increasing coreflow and so reducing core engine temperatures. The HPT had improved materials and cooling in the HPT blades and the use of advanced sealing to increase EGT margin, while the LPT changed the design of stage vanes in the third stage and had the design of its alternating blades and vanes re-staggered.

The overall objectives of the SelectOne programme were to reduce fuel burn by about 1%, increase EGT margin by about 12 degrees centigrade, and extend time on-wing between removals by about 20%. Additional features were a reduction in unscheduled SVs and reduced NOx emissions.

The SelectOne configuration became a build standard option from the second half of 2008, but the hardware could also be retrofitted to standard configuration engines in a maintenance SV. "While it was possible to retrofit, few airlines that were not on an MCPH maintenance management programme took this option," says Mermod. "Some airlines with engines on an MCPH programme had the upgrade performed. The engine would benefit from longer removal intervals, and with the same cost per EFH it would make economic sense to retrofit the kit."

The cost of the SelectOne full kit was about $2.8 million. Some commented that it was not worth installing, unless the LLP shipset in the engine had expired and was being replaced.

A total of 1,221 A320 family aircraft built from 2003 to 2017 were equipped with SelectOne engines. There were also 63 aircraft equipped with E-A5 SelectOne and M-A5 SelectOne engines.

SelectTwo modification

The SelectTwo modification was introduced in 2015. This was a fuel burn improvement upgrade, and was effected via a software upgrade to the engine's full authority digital engine control (FADEC). One main feature was the reduced ground idle rate of the engine to lower fuel consumption during taxi.

The SelectTwo package software upgrade was in the region of $150,000.

SelectTwo became the standard production build for engines in 2015, and these also incorporated the hardware of the SelectOne modification. The package can also be implemented on engines with SelectOne hardware, and can be incorporated with the engine on-wing.

To date, 442 aircraft have been equipped with SelectTwo engines, and there are a further 21 aircraft with E-A5 SelectTwo and M-A5 SelectTwo engines.

Summary

Airlines and engine lessors clearly have to consider all issues when opting for engine upgrade and modification programmes. These include the engine's age and likely remaining life and current market value, its maintenance programme and any related contractual obligations, the engine's maintenance status and part and component configuration, the likely time or opportunity to implement a modification or upgrade, the cost of upgrade package, and the subsequent savings and operational benefits after the modification has been implemented.

The modification programes for the CFM56 and V2500-A5 family can still be applied. These will have declining appeal as the engines continue to age, however, because of the increasing number of time-continued engines on the aftermarket. Upgrades still make economic sense for CFM56-5Bs and -7Bs, and V2500-A5s that are still relatively young. AC