The use of USM in engine maintenance can achieve significant savings for engine shop visits. The pandemic has increased the supply of unutilised engines, and so has potentially increased the supply of engine material. Possible savings from USM are analysed for a range of engine types.

The economic appeal of USM in engine maintenance

Since the cost of parts and materials, particularly airfoils, account for the highest percentage of engine shop visit (SV) costs, the use of repaired parts, known as used serviceable material (USM), instead of new parts has the potential to save several hundred thousand dollars in a single SV. Given the need for airlines to take every initiative to improve cashflow, few can afford to ignore the potential savings from USM.

Engine maintenance

In the summer of 2019, and before the start of the Covid-19 pandemic, activity in the engine maintenance market was extremely high. Moreover, a surge of SV activity for V2500-A5 and CFM56-5B and -7B engines was long overdue and expected to materialise in early 2020.

The sudden onset of the pandemic and the drop in aircraft utilisation and activity led to airlines requiring only a fraction of their fleets for operations. Many airlines chose to retire their oldest aircraft, and park and store the surplus units in their fleets, and swap them with active aircraft to avoid complications with aircraft financing issues and lease commitments.

The drop in traffic and aircraft utilisation overall, and fall in revenues, prompted many airlines to swap engines between aircraft. This means removing engines with only a small amount of remaining maintenance life, and installing engines with more maintenance life, or 'green time', remaining to minimise cash expenditure on engine SVs.

Some younger engine types, operating with the aircraft's original operators, are maintained under a fleet-hour agreement with the engine original equipment manufacturer (OEM). With this type of engine maintenance contract, airlines can conserve cash outflow just by reducing rates of aircraft and engine utilisation, and so delaying engine removals and SVs.

Other forms of engine maintenance contracts typically used both for younger fleets operated by first-tier carriers and older types include fixed price and time-and-material contracts with independent engine shops. Under such contracts, airlines choose when to remove engines and specify the required SV workscope. These are expensive maintenance events, so airlines started delaying engine SVs wherever possible from the spring of 2020.

The large number of unutilised aircraft in each airline's fleet could potentially supply engines with a lot of maintenance life or green time remaining until an SV is required. After March 2020 there was a drop in engine SV activity by as much as 75% compared to the 2019 level.

A second source of green time engines are those that are available via specialist engine lessors and traders. While airlines were unable to plan how many aircraft they would need to put back into service, and when, one issue that was clear was that older aircraft in airline fleets could be retired early. This would provide a third source of green-time engines.

The swapping of engines that require SVs with those with green time available has continued, and is an obvious way for airlines to conserve cash. This technique is still being used, partly because many engine types have long removal intervals; with reduced rates of utilisation, the normal low frequency of removal is reduced further. It is also explained by a large number of aircraft in the fleet being relatively young and their engines not having reached the stage where they need their first shop visit.

A further issue is that during the pandemic, airlines have been obliged to take delivery of new aircraft that they had committed to taking. There are also several hundred 737 MAXs that started to be reactivated in late 2020 following an extended period of grounding. Many older aircraft have therefore had to be retired since early 2020, thereby unexpectedly increasing the supply of time-continued or green-time engines.

Aircraft have continued to operate, however, and more are being reactivated as passenger numbers and traffic volumes recover at different rates around the world. The total number of narrowbodies in operation with passenger carriers at the end of June 2021 was 13,230, compared to 15,247 in January 2020 before the pandemic began, and 6,460 narrowbodies in operation at the end of May 2020 when fleet activity was at its lowest.

In the case of widebodies, there were 3,169 active passenger aircraft at the end of June 2021, compared to 4,536 active in January 2020, and just 2,039 in May 2020.

Case for USM

The number of aircraft being operated is gradually increasing in some parts of the world as travel restrictions are eased. Some markets are at or near full recovery. The number of green-time engines and modules available that can be swapped with those that have been removed will clearly decline. At some point there will be an increase in the number of engines going into shops for maintenance visits and workscopes of at least hot section or performance restorations. While airlines still need to conserve cash as some of their fleets remain grounded, and the future remains uncertain, the use of USM in engine maintenance is a clear way to generate savings in each SV.

USM is an economic option for airlines because a percentage of airfoils and high-cost parts in each stage or section of the engine will be out of SV manual limits, and so will have to be scrapped following inspection. These parts can be replaced with new parts from the OEM at high current list prices (CLP). Examples of CLPs are about $102,000 for a V2500-A5 fan blade, $16,000 and $19,500 for stage 1 and 2 (high pressure turbine) HPT blades, $40,000 for clappered old technology PW4000-94 fan blades, $35,000 for a HPT stage 1 NGV and $58,000-60,000 for a low pressure turbine (LPT) stage 1 NGV on the CF6-80C2, and $4,000-5,000 for latter stage high pressure compressor (HPC) blades in the CFM56 family.

The alternative to replacing scrapped parts with new is to use USM parts. These are recovered parts that have been inspected and found to be within repair limits, so they can be repaired and reinstalled in the engine. "There are three categories of USM," says Devin. "These are 'serviceable', where parts have had little or no work done on them and are within manual limits; 'repaired' parts, which have accumulated a few thousand engine flight cycles (EFC) and had a simple or light repair; and 'overhauled' parts, which are required for a higher power requirement and have had a higher level of repair."

There is a small number of stages in the CFM56-5B and -7B series where parts have 'soft lives' or life limits of 20,000EFC or 25,000EFC for their removal. These have a CLP of about $17,500 each, so the a full shipset costs about $1.4 million. "HPT blades also have an EFC limit to be repairable," adds Jamie Devin, vice president of business development, at Global Engine Maintenance. "They can be repaired if they have accumulated 13,000EFC on-wing. Similar issues apply to the nozzle guide vanes (NGVs) in the HPT, and the stage 1 area of the LPT." These two factors can make it harder to acquire these particular airfoils as USM.

"There are still airlines willing to use repaired HPT blades and vanes that have been repaired with a relatively short life remaining," says Glenford Marston, chief executive, at AeroNorway. "HPT blades with just 7,000-9,000EFC left to their soft life are still bought to be installed in engines."

The saving generated from the use of USM therefore comes from the difference in the OEM's CLP and the purchase price of the USM parts from a specialist provider. This cost difference per part is then factored by the number of parts in the airfoil stage that are scrapped and replaced.

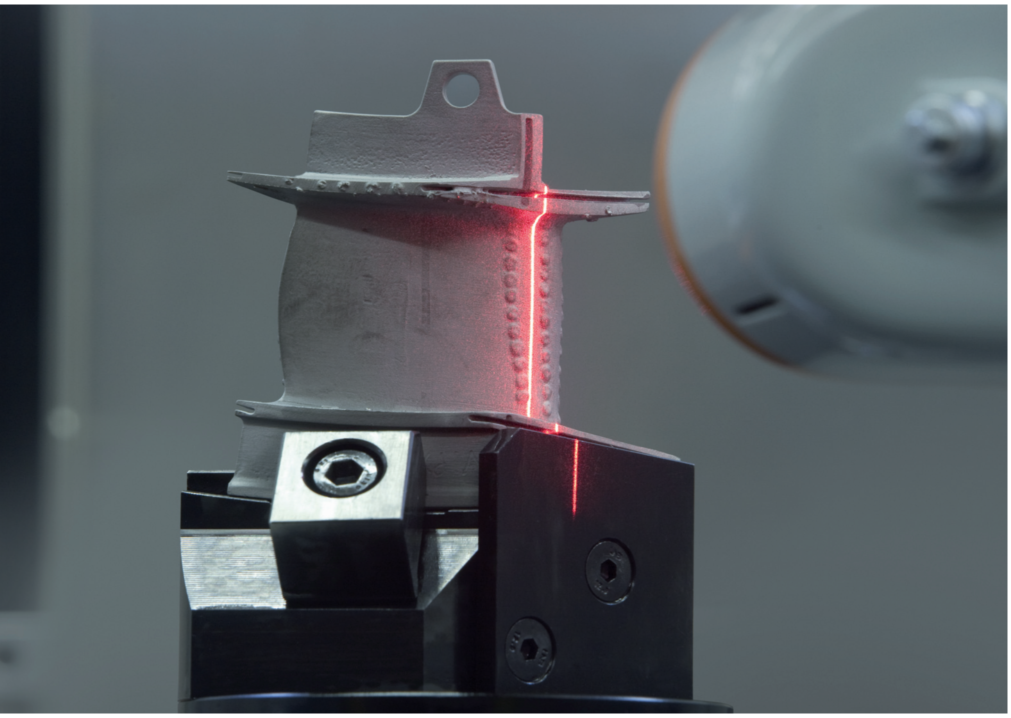
USM acquisition

There are three main methods of acquiring USM parts for installation into the engine. "The main source is the engine teardown specialists, such as Aerfin, AAR, TMS Aero, GA Telesis and CFM Materials," says Neil Russell, chief operating officer at AeroNorway. "The teardown specialists send removed parts to the specialist parts repair shops, such as Chromalloy. These can then be sold by the teardown specialists. AeroNorway acquires the parts for the airline, either on a speculative purchasing basis or as a tailored requirement."

TrueAero is one teardown specialist. "We have experience with the PW2000, PW4000, CF6-80C2, V2500 and the CFM56 family," says Jacqueline Fernadez, senior vice president of materials at TrueAero. "We buy engines for the purpose of teardown, extract the parts and repair those that are within limits."

Airlines can always acquire USM thyselves, although this is less common. USM will be installed in each stage alongside repaired parts. Parts that can be repaired are rarely installed back in the same engine. Russell explains this is because it takes 30-40 days, or longer, to repair HPT blades and NGVs.

"The time it takes to repair certain blades and vanes can be longer than the



Airlines will use USM in engine shop visits wherever possible, since USM is seen as having the same standard as new parts provided by the OEM.

cost of performing the SV, because the shop may only want to use particular airfoil repair shops," says Devin. "These can be busy and so have delays, and they may also be a long distance away and in other countries, which will result in additional time due to transport and customs-related issues. Therefore what often happens is that the engine shop removes the entire set of blades in each stage, and sends them to a specialist provider. There may be 60 blades in a particular stage, 18 of which may be scrapped and the other 42 repaired. The parts repair shop will provide the engine shop with a shipset of 60 airfoils for installation in the same engine stage, but they will actually be parts from other engines. The parts repair provider will charge the repair fee for the 42 repairable blades, and charge a USM sale price fee for the other 18. The specialist repair shop will then keep the 42 repairable blades it has received from the repair shop. This exchange mechanism reduces the time the engine shop has to wait for the airfoils, so it can complete the engine SV in a shorter time, without waiting longer for the original set of airfoils to be repaired."

In addition to the price difference between new OEM parts and the purchase price of USM parts, and the number of parts in each stage that have to be replaced, there is also the issue of which stages in a particular engine type frequently have medium or high scrap rates of parts, since this provides significant cost savings when using USM. Fan blades have low scrap rates in all engine types. The same generally applies to most HPC blades and vanes in all engine types.

The airfoils that most airlines and engine shops can focus on to generate significant savings through the use of USM are those in the hot section. These will be the combustors, NGVs, HPT blades, LPT inlet guide vanes (IGVs), and first and possibly second stage LPT blades.

"Many airlines want us to guarantee a particular fill rate of scrapped parts that are replaced with USM," says Marston. "These fill rates can be as high as 95-97%, and such a level can reduce the cost of an SV by hundreds of thousands of dollars. The actual fill rate achieved depends on what parts are available. AeroNorway sets up agreements with parts vendors to recycle material with us that we have removed from engines. All airlines have a preference for USM, and even engines that are going through their first SV will try USM because the parts are generally viewed as having the same standard as new parts."

Aircraft & engine types

While the economic basis for using USM appears straightforward, a main issue is the supply of feedstock engines to provide airfoils and other high value parts that can be repaired. These feedstock engines are those with low remaining maintenance life, so they only become available in large enough numbers when a fleet has reached maturity, or at least a significant percentage of a fleet has been retired or scrapped. A small number of engines can become available for teardown following an airline bankruptcy or if an airframe has to be written off.

A large portion of a fleet reaching retirement age provides a significant number of engines for teardown and dismantling. At this stage the market value of engines with zero or low maintenance life will reduce, and increase the availability of USM parts on the market. The availability of used engines and USM is clearly zero or severely limited in younger fleets.

An example of an appropriate engine type for supplying USM is the CFM56-3, powering the 737 Classic fleet. The number of retired long-term stored aircraft exceeds the number of aircraft left in operation. As time progresses, more aircraft retire and so continue the supply of teardown engines. This is one factor that contributes to keeping the maintenance costs of older aircraft types low.

The main aircraft types that have been retired and stored in large enough numbers to provide a supply of teardown engines include the 1980s widebodies, the earlier generation CRJ regional jets, the Embraer E-170/-175 E-Jets, the 757-200/-300, the 737 Classic, the earlier-build 737NGs, and the earlier-build A320 family members.

Aircraft normally retire at a steady rate, with 3-5% of the number built being retired each year from an age of about 20 years. Some will be converted to freighter, varying from zero for some types, to a high percentage of certain types, like the MD-11 and A310-200, that are particularly suited to a freighter role. This will prolong the market for engine USM.

The Covid-19 pandemic has resulted in a large number of aircraft, for several aircraft types, being retired early. "This has definitely increased the supply of used and low maintenance time engines on the market. There is a large number of distressed aircraft assets, especially in the case of older types," says Lee Carey, vice president of asset management at EirTrade Aviation. "This has resulted in some airlines selling engines, or terminating leases early. Asset values have of course softened as a result. All of this ultimately has reduced the overall cost for a specialist to acquire engines in the right sort of condition, tear them down, extract all the relevant parts, and then send the better parts for repair.

"The supply of used CFM56-5Bs/-7Bs and V2500-A5s will continue as more 737 MAXs are reactivated and delivered, and more A320neos are delivered, resulting in more 737NGs and A320ceos being retired. This will result in an oversupply of aircraft for some time," continues Carey.

The market value of engines with zero or only a small amount of maintenance life remaining will be higher than older generation engines, but the high supply of engines will have depressed values. "The value of a run-out CFM56-7B was about $2 million pre-Covid," says Devin. "The

Some compressor airfoils have low list prices, while more complex 3-D and variable compressor airfoils have list prices nine or 10 times higher. The use of USM in these cases can generate significant savings.

value of these has dropped to $1.0-1.25 million since."

The limited engine SV activity across the market will actually contribute to a high supply of engines and material, since engines are being retired and disassembled, while few active engines are being put through an SV and are therefore not consuming repaired parts. "The limited level of engine SV activity is because green time on engines is still being used up by airlines," Continues Carey. "We expect engine SV activity to start increasing in the latter part of 2021, and it could increase steeply during 2022. It may take another 24-36 months, however, for there to be a big increase in demand for narrowbody engines."

EirTrade has an airframe disassembly and dismantling facility in Knock, Ireland and is in the process of opening its own engine teardown shop in Dublin, Ireland, but up to now has sub-contracted this activity to other specialists, most of which are located in the US. "We have been tearing down a record number of engines as a result of the pandemic, and we expect to see an increase in the portion of time-continued life-limited parts (LLPs) and USM being used in engine SVs," says Carey. "Our own engine teardown shop will focus on the CFM56-3, -5A, -5B, and -5C families."

The actual supply of USM for the main types, such as the V2500-A5 and CFM56-5B/-7B depends on the green left in individual engines. "There are more likely to be part-out engines that are the baseline versions of these types," says Russell. "We are seeing some CFM56-5Bs and -7Bs that have had the first Tech Insertion modifications getting torn down because of their low remaining maintenance life."

Potential savings

The basis for realising savings from using USM in engine SVs is the difference per airfoil between the purchase price of USM and the OEM's CLP for a new part, multiplied by the number of parts that are scrapped and can be replaced with USM parts. "The list prices of engine airfoils are well known and established, so it is the purchase price of USM airfoils that has the main influence on the possible savings," says Carey. "In the current market, the cost of USM is about 60% for stage 1 LPT blades and 20% for stage 4 LPT blades. Stage 1 HPT blades are higher at 70%, while HPT NGVs can be bought for about 30% of CLP. These percentages of CLP for USM clearly vary with market supply and demand, as well as the probability of the equivalent part in the engine scrapping out. A lot of engines are being disassembled and parted out, but engine SV activity is also low, which is currently reducing consumption.

"The use of USM airfoils has to be considered against subsequent engine performance," adds Carey. "There is little change in performance for HPC airfoils. Repaired HPT parts can have poor durability, depending on the accumulated time of the repaired part."

Taking just one stage of an engine as an example, the stage 1 IGV in the LPT of the CFM56-5B/-7B has 22 parts, and typically about five or six parts are scrapped in the shipset. Each part has a CLP of about $29,000, while a USM part can be bought for about $19,000. A saving of about $10,000 per part and $50,000-60,000 for the six parts in this shipset of this single stage can be made through the use of USM.

CF6-80C2 & PW4000-94

The 1980s generation widebodies include the 747-400, many variants of the 767 family, the A300-600 and A310, and MD-11. Most were powered by the CF6-80C2 series and PW4000-94 series engines.

Both engine types were split between earlier-built engines with PMC controls, and later-built engines with full authority digital engine (FADEC) controls. CF6-80C2 engines are designated with an F suffix as -80C2F.

Most of these five main types with CF6-80C2 or PW4000-94 engines have been retired.

The 767-300ER remains in operation in relatively large numbers. In the case of -80C2F-equipped aircraft, there are 438 767s, mainly -300ERs, in active service. This is 79% of all -80C2F-powered 767s built.

Of these 438 aircraft, 272 are in freighter configuration, being a mix of factory-built and converted aircraft. The freighter aircraft should provide a continued level of demand for engine USM.

In addition to 767s, there are 148 747-400s, 52 A300-600s, and 69 MD-11s still in active service that are powered by the CF6-80C2F engines.

In comparison, 226 of these aircraft have been retired or stored. The supply of CF6-80C2F material has been enhanced by the number of 747-400s that have been either retired or stored since the start of the pandemic. Since early 2020, 59 747-400s, 84 767s, and five MD-11s have been placed into storage or retired. This is equal to 419 installed CF6-80C2F engines potentially coming available on the market.

The CF6-80C2 has a two-stage HPT and five-stage LPT. The stage 1 NGV and HPT blades have 23 and 80 parts in the shipsets, with CLPs of about $39,000 and $18,500. Scrap rates will be 15-20% and 50% respectively, so four or five NGV airfoils and about 40 blades may be scrapped and replaced with USM. These would have purchase prices of 60% of CLP, and so cost $24,000 for the NGV and $12,000 for the blades. The saving generated by replacing these 45 airfoils would be about $75,000 and $260,000 respectively.

Similarly, the CF6-80C2 has a second stage HPT with CLPs for the NGVs and blades at about $18,000 and $10,500.

While these are cheaper than stage 1 parts, the second stage in the HPT has 24 NGV airfoils and 74 blades. A saving similar to what is possible in the first stage could be realised for the second stage.

The first two of the five LPT stages have a total of 242 blades and 29 NGV airfoils. These four stages have a total CLP of more than $2.4 million. A scrap rate of 20-40% for all four stages and a price of 50-70% of CLP for the USM can generate a saving of $200,000-300,000.

757 & PW2000

The 757-200 has also proved to be popular as a freighter, with 224 aircraft with RB211-535E4 engines and 98 with PW2037/40 engines in service. This compares with 575 RB211-powered and 415 PW2000-powered 757-200s that were built.

A large number of 757-200s were in operation with US majors, and some of these fleets had already been retired before the pandemic. The onset of the pandemic accelerated this retirement. There have been 106 RB211-535E4-equipped and 47 PW2000-equipped 757-200s placed into storage or retired since early 2020.

The pandemic also led to the grounding of all 757-300s.

There has therefore been a large increase in the number of RB211-535E4 and PW2037/40 engines on the market that can supply airfoils and USM for remaining operators.

In addition to the large number of 757-200s that have been converted to freighters, there are still more than 100 aircraft with PW2037/40 engines in service as passenger aircraft. The continued popularity of the 757, which includes some military applications, provides an opportunity for engine USM parts and material.

The PW2000 has a two-stage HPT configuration with 48 blades in the first and 64 in the second stage; the two NGV stages are one potential use of USM and therefore have the scope for significant savings in SV costs.

The first stage NGV comprises 36 parts, each with a list price of about $16,300, and so a shipset cost of $590,000. The first stage of the HPT includes 48 blades, each with a list price of $16,500 and so a shipset list price of $790,000.

The cost of USM is about $10,500 and $11,600 per airfoil, and so a saving of $7,000 and $5,000 per airfoil is possible. Depending on the scrap rate, the saving for these two stages could be $40,000-50,000 and $95,000-110,000.

The second stage NGV has 20 parts at a list price of about $37,000 and a shipset cost of $735,000. There are 64 blades in the second stage, each costing $12,300; the shipset list price is about $800,000.

The PW2000 LPT is five stages. As with all engines the first stage, and its accompanying inlet vane, is the most vulnerable because of the high gas temperatures as they leave the HPT. Blades and vanes in the first two stages of the LPT can therefore generate an opportunity to generate a significant saving. The first and second LPT stages have 135 and 138 blades, and the corresponding two vane stages have 38 and 42 airfoils. The combined list price of these four sets of airfoils is close to $1.9 million.

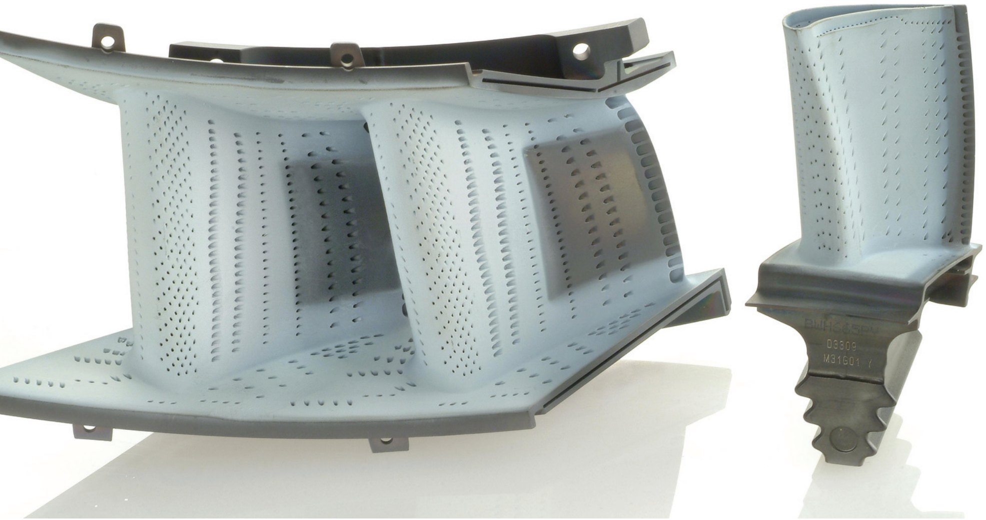
737 Classic & CFM56-3

There were almost 2,000 737 Classics built and equipped with CFM56-3 series engines. Of the three variants of the -3 series, the most numerous was the -3C1 engine, which equipped more than 1,060 aircraft.

Of the original production run of -3C1-powered aircraft, 404 are still in active service. Another 369 aircraft have been retired, and 115 are in storage. Of these, 134 have been retired or placed into storage since the spring of 2020.

The CFM56-3 series has an HPC with nine stages; there are up to 82 blades in the latter stages. The accompanying stators have 82 and 84 in the first two stages, and this reduces to 10 in each of the last three stages. The total number of airfoils in the HPC is 904. Each blade and vane has a list

The NGVs and stage 1 HPT blades probably provide the largest possible savings in engine maintenance via the use of USM. One issue that can limit the potential is the soft life limits of some of these airfoils in certain engine types.



price of $500-5,000, with some being static and others having variable angle capability. The total shipset cost of HPC airfoils is more than $900,000.

These airfoils are not subject to high temperatures, but are the first to be subject to foreign object damage. “The scrap rates in the HPC can be similar to those in the HPT,” says Marston. This can be in the region of 30% for an average throughout the whole HPC module, and so would be equal to about $270,000 of new parts at list price. USM for the HPC in the -3 series can be acquired for about 40% of list price. On this basis, a saving of up to about $160,000 can be realised through the use of USM.

The engine’s combustor is comprised of three main parts; the outer and inner liner, and the casing. These three pieces have a shipset price of about $1.2 million. The two liner segments are often repairable, but the casing may need replacing. The alternative to the list price of $800,000 would be a repaired part that is available at a cost of 65% of CLP, and so a saving of about $280,000 if USM is used.

Scrap rates of HPT blades, shrouds and NGVs can average about 50%. The list price of these three main parts in the module is more than $2.8 million. “The issue of using USM for HPT blades is, however, more difficult than all other airfoils in the case of the CFM56 family,” explains Devin. “First, many HPT stage 1 blade P/Ns have soft lives of 20,000EFC that cannot be exceeded. Second, there is a limit on the number of times these blades are permitted to be repaired. There are some cases, however, when blades are removed after an interval of 12,000-13,000EFC, and these can be repaired and then sold as USM.”

The availability of USM HPT blades will clearly determine the possible saving. “The cost of USM HPT blades can typically be 70% list price,” says Carey. On this basis, the saving per HPT blade can be about $4,000. If half the 36 blades have to be replaced, and half of these are replaced with USM, then the saving for this stage will be about $35,000.

A 50% scrap rate for the NGVs and shrouds will affect about $1.8 million of parts at list price. The purchase of USM for the replaced NGVs at 30% and 70% for the shrouds will generate a saving of about $600,000.

The total savings that could potentially be generated in the complete core engine could therefore be about $1.1 million.

CFM56-5B & -7B series

The CFM56-5B and -7B are similar in configuration and build standard. The HP modules on the -7B are identical to the -5B.

Both engines have LLPs in the fan/LPC and LPT with lives of 30,000EFC and 25,000EFC. This contrasts to lives of 20,000EFC for the core engine. The difference in LLP lives between HP and LP modules means that a workscope is usually performed on the HP modules at most or all SVs, while LP modules have workscopes less frequently. High thrust variants of both main types have shorter removal intervals than engines with lower thrust ratings.

There are also three main build or airfoil configuration standards of the -5B and -7B.

The first main group of -5B is designated with a /P suffix. There were 1,253 A320 current engine option (ceo) family aircraft built. The /P was not the original build standard of the baseline -5B. Many of these engines were upgraded to the /P, which was an improvement package introduced to new-build and already built engines in 1996.

The second improvement programme was the Tech Insertion upgrade, which was introduced in 2004. This could be applied to existing engines, and was designated as the -5BE. The oldest aircraft with Tech Insertion engines are thus 17 years old.

The implications are that aircraft equipped with -5B/P engines are more likely to be retired, returned to lessors or placed into long-term storage than aircraft with -5BE engines. At the end of June 2021, there were 758 active A320ceo aircraft with -5B/P engines. There were another 327 in storage and 159 had been retired. Therefore, about 60% of the total fleet was in active service.

Of the aircraft in storage, 297 have been parked since the start of the pandemic, and 95 of these were placed into storage during 2021. In addition, 57 of the 159 retired aircraft were retired during 2020 and 2021. In addition, there are large numbers of A320 new engine option (neo) aircraft due to be delivered, which is likely to lead to further A320ceo retirements and lease returns.

There is therefore good scope for acquiring used CFM56-5Bs and acquiring parts for repair to sell as USM.

Similar to the -5B engine, the -7B series also has three main modification standards. The fist is the baseline -7B engine, which equips 2,266 aircraft. These aircraft and engines were built from 1997. The second main build standard was the Tech Insertion upgrade or standard, and was introduced in 2007. These engines are designated as -7B/3 engines. The oldest are therefore 14 years old. Of the 2,266 aircraft with -7B engines, at the end of June 2021 1,518 were in active service, while 529 were in storage, and another 203 had been retired. Therefore 67% of all aircraft built were in service. The number of aircraft in storage and retired includes 494 aircraft that were placed into storage and 38 aircraft that were retired since the start of the pandemic. These are likely to be sources of USM over the coming months and years. Also, as with the A320, there are many A320neos and 737 MAXs on order that are scheduled for delivery and are likely to prevent many stored aircraft being reactivated, as well as displace aircraft that are in active service.

As with the CFM56-3 series, there is potential for operators and engine shops to use USM in the core modules of -5B and -7B engines.

The HPC has nine stages, and a total of 614 rotating blades plus 332 stators. The blades have list prices between $500 and $2,450, while the stators in the fifth to ninth stages are variable angle, so have list prices in excess of $5,000. "Scrap rates of HPC blades can typically be 30%, while scrap rates for stators will be lower at about 10% in many cases," says Devin.

Carey estimates USM parts for these stages can be acquired for about 40% of list price. On this basis the potential saving from using USM throughout the HPC module is about $131,000.

The combustor case is more likely to be scrapped than either of the two liners. Its list price of $835,000 can be avoided with a USM part that may cost about $550,000, and so generate a saving of $285,000.

The three main parts of the HPT are the 21 parts in the NGV, 80 blades and 42 shrouds. "These have scrap rates that average 10%, 50% and 20%. While these rates will clearly depend on the time on-wing up to the SV, this interval is variable between thrust-rated variants," says Devin.

It is possible to acquire USM at 30% of list price in the case of the NGVs, but the cost is likely to be higher at 70% of list price in the case of HPT blades and shrouds. Overall, a saving of $200,000 or more is possible in the HPT.

"The scrap rate in the LPT is clearly highest in the first two stages of four in the module," says Devin. "The LPT inlet guide vanes, or nozzles, is the first stage after the HPT blade, followed by the first stage LPT rotor blades. These two stages have typical scrap rates of 25% and 20%. The scrap rate for the second inlet guide vane and the second stage blades is typically 35%."

The first two LPT nozzle stages have 24 and 18 blades, and unit list prices are $29,000 and $20,500. Their rotor sections have 162 and 50 blades, with list prices of $2,400 and $2,750. Overall, the potential saving in the LPT is about $265,000 if USM is used wherever possible in the first two stages. "Scrap rates for blades in the third and fourth stages are just 10% and 5%, and stators rarely require replacing," explains Devin. The potential savings from using USM in these last two stages are therefore small.

The total saving that USM can provide for all three main modules in the core engine could be about $915,000.

V2500-A5

The V2500-A5 was used to power more than 3,200 A320ceo family aircraft. As with the CFM56-5B and -7B, there were three main build standards. The baseline engine was the original build standard. This equipped 1,431 aircraft. At the end of June 2021 there were 744 aircraft in operation, 52% of the total. There were also 470 aircraft in storage, of which 428 had been placed into storage since the start of the pandemic. Another 203 were retired, including 56 aircraft retired since early 2020. More than 480 aircraft with baseline engines had been retired, returned off-lease, or stored since spring 2020.

The second build standard was called the SelectOne. It was introduced in 2007, and 1,305 aircraft were equipped with this engine. At the end of June 2021, 1,027 of these aircraft were in active service. Another 271 were in storage, and 257 of these had been parked since the spring of 2020. Five had been retired.

The baseline and SelectOne-equipped fleets had relatively large numbers of aircraft stored and retired, and so provide a potentially ample supply of teardown and USM candidate engines.

The most likely opportunities for supplying USM are the HPT module, which has two stages. The first stage NGV has 40 blades, and the first stage HPT has 64 blades. The unit list price of these two airfoils is $19,500 and $16,000. "Typical scrap rates are 25% of the NGVs and 30% for the blades," says Bill Polyi, president and chief executive officer at Magellan Aviation Group.

The second HPT stage has 17 airfoils in the NGV and 72 blades. The list prices of these airfoils is $40,400 and $11,800. "These have similar scrap rates to the first HPT stage," continues Polyi.

The fan module is another module where USM can provide some savings. The fan has 22 blades, each with a list price of $102,000. "A typical scrap rate is about 10%," says Polyi. "Therefore two or three fan blades can be expected to require replacing." A USM cost of about 40% can therefore save about $60,000 per replaced blade, meaning a saving of about $120,000 or $180,000 for the fan blade shipset." AC