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CFM56-3, RB211-535, PW2000, PW4000-94 & CF6-80C2 aftermarket | RM techniques for post Covid-19
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The parking of large numbers of 1980s and early 1990s aircraft has increased the supply of engines used for the 737 Classic, 757-200, 767-300ER & 747-400 freighters. The effect on engine lease rates and market values, and their market prospects are all discussed.

Aftermarket activity for older generation engines

The result of airline capacity reductions in response to the Covid-19 crisis has been the parking and storage of 12,600 jetliners. The effect of this has been to increase the supply of used and time-continued or 'green time' engines on the market. Some estimates are that as many as 2,000-2,500 of these aircraft will never return to service if the industry's recovery is as slow as expected. How has this situation affected the used engine market?

Aircraft & engine types

There are more than 20 main aircraft types so more than 25 main engine types are affected by the crisis. The types that are most affected, and have the most influence on the engine aftermarket are current and previous generation aircraft.

There are two main groups of aircraft and engine types to consider. The first is older 1980s generation aircraft, many of which are converted to freighters. The most important types in this group are the 737 Classics, the 757-200, 767-300ER and 747-400. The market for the engine types powering these aircraft is much affected by the supply of engines with remaining maintenance life. These aircraft and their respective engines are considered here.

The second group is younger generation narrowbody aircraft types: the 737NG, A320 current engine option (ceo) family and A320 new engine option (neo) family. The 737 MAX, although officially in service, has not been directly affected by the crisis because it was already grounded and all aircraft were put into storage. Moreover, they will be returned to passenger service in the shortest time possible. The second group includes younger generation widebodies from the 777 and A330 families.

The two older generation narrowbodies most affected are the 737 Classic -300 and -400 series, and the 757-200/-300. About 215 737-300s and -400s have been parked, more than half the remaining active fleet. This has affected the availability of CFM56-3 engines.

Also, more than 275 757-200s and -300s have been parked over the same period, and fewer than 70 aircraft are left in passenger service. This has clearly increased the supply of RB211-535 and PW2000 engines on the used market.

The widebodies most affected by the pandemic are 1980s and early 1990s aircraft. The types parked in the largest numbers and fleet percentages are the 767-300ER, the A330-200/-300, 777-200/-200ER, 747-400 and A380.

The 767-300ER and 747-400 are two of five aircraft types that share the same basic PW4000-94 and CF6-80C2 engines along with the A300-600, A310-200/-300, and the MD-11. The latter three had already been retired and parked in large numbers before 2020, thereby releasing many PW4000-94 and CF6-80C2 engines on to the aftermarket.

Many passenger-configured 747-400s had already been retired and parked before 2020, but the Covid-19 crisis saw 90% of the remaining 147 aircraft in the fleet parked from March to May 2020. Also, 68% of the remaining fleet of 410 passenger-configured 767s were parked.

It is clear from airlines that virtually all of these 747-400s and most 767-300ERs will not return to passenger service. The parking of so many aircraft has released a large number of CF6-80C2 and PW4000-94, as well as RB211-524G/H, engines onto the market.

Used engine markets

There are several markets that owners or prospective owners of used engines can investigate. In a normal market there are two categories of engines: those that are still in relatively high demand and being operated in an active fleet, and whose remaining maintenance life is equivalent to several years of operation; or engines with only a limited amount of maintenance and operational life remaining, and fewer potential market opportunities to exploit.

Remaining maintenance life that is equal to several years of operational life is determined by several factors. The first of these is remaining life limited part (LLP) lives. Most of the main engine types discussed have LLP lives of 12,000-20,000 engine flight cycles (EFC) in the high pressure compressor (HPC) and high pressure turbine (HPT). LLPs in the fan and low pressure compressor (LPC) and low pressure turbine (LPT) have longer lives. In many cases the full life limits are 20,000-25,000EFC, although some higher-thrust rated variants of an engine type are lower at 15,000EFC or similar.

Other main factors determining remaining maintenance life, when the engine is operated at typical engine flight hour (EFH) to engine flight cycle ratios (EFC) and in particular operating conditions, are the engine's remaining exhaust gas temperature (EGT) margins and the likely or probable EGT margin erosion rate. Another major factor is the condition of the engine's airfoil hardware, especially in the HPT and combustor.

Probable maintenance life to the next shop visit (SV), the SV workscope pattern that the engine usually follows, and the probable workscope that will be required

The COVID-19 pandemic has led to 215 passenger 737 Classics being parked and retired in 2020, releasing large numbers of CFM56-3s onto the market. The market value of 'green time' engines are estimated to be up to about $1.25 million.

at the next SV combine as the factors that determine an engine's maintenance status.

Several years of 'maintenance life' on an engine is equal to at least three or four years of operation. Engines used on short-haul operations operate at relatively short EFC times and EFH:EFC ratios, so the factor relating to years of maintenance life will be the rate of EGT margin loss per 1,000EFC, and the remaining EGT margin and LLP lives. Most short-haul aircraft accumulate 2,000-2,500 FCs per year, so engines will need at least 6,000-8,000EFC remaining, and the commensurate exhaust gas temperature (EGT) margin, to have three to four years of maintenance life.

Most engines operated on long-haul missions will have average EFC times of 7.0-9.0EFH. Engines accumulate 4,500-5,000EFH per year, and so 500-750EFC per year in most cases. Engine deterioration here is driven more by hardware degradation and erosion and EFH time, and less by accumulated EFC and EGT margin erosion. Full SV intervals are typically 15,000-20,000EFH, equal to 1,500-3,000EFC. Remaining LLP life will therefore be less of an issue for engines that power widebodies and long-haul aircraft.

Engines with this level of maintenance condition and life will have three or four main markets available to them.

The first has always been supplying airlines with spare engines via short- and medium-term lease contracts that allow airlines to avoid investing in engine inventory. This is particularly attractive to airlines operating older aircraft types as passenger aircraft for a short period, or as converted freighters where airlines are sensitive to the capital cost of aircraft.

Engines with this level of maintenance life remaining can also be used by traders, specialist brokers and lessors for sale and leaseback transactions. Airlines planning to phase out fleets can use such mechanisms to release the capital in engines and pay lease rentals for a few remaining years of operation. This leaves the engine broker, trader or lessor with an engine that can be torn down for parts.

The other two main markets for engines with appreciable remaining maintenance life are selling whole engines or engine modules with some remaining maintenance life or 'green time'. Airlines can use such engines and modules as an economic alternative to putting engines through expensive maintenance SVs, usually when operating aircraft for the last few years of service, and where the market value of green-time modules or engines produces a lower cost per EFH and EFC than a full SV. Engine and module values therefore have to be depressed for this to be economic.

"The way that the market values engines with these maintenance conditions and potential markets is first the supply of engines versus the demand for them," says Chris Grey, principal at AerAuster. "There are a range of other factors. These are issues, such as whether the engine is on its first or second SV interval, and the time remaining to its next SV. This is determined by remaining LLP life, hardware status, EGT margin, and the cost of the next SV. There is also the issue of the likely residual value as the alternative of a part-out engine."

Engines with insufficient maintenance life remaining to be attractive to airlines for any of these options are those with up to three years' remaining life. These make the best candidates for teardown and disassembly into parts and components. Some can be sold direct, while others will first have to be repaired, and then sold as used serviceable material (USM).

The exception may be an airline that is operating old aircraft, usually as freighters, for the last two years or less of operation and is seeking a cheaper alternative to putting an engine through an SV. This is one last possible use.

Engines like this are valued on the basis of the inventory of all parts in the engine; the value is the sum of the market value of all the parts, plus the pro-rated value of the remaining LLP life. The value of LLPs is the LLP shipset cost adjusted for the percentage of full life remaining. So a shipset of LLPs at $6 million, with just 15% of life remaining will be valued at $0.9 million. This is adjusted by a pro-rate factor, which is determined by the level of market demand. This is 50% for an older type like the CFM56-3, but 90-100% for a more popular type like the CFM56-7B or V2500-A5.

"The pro-rate factor for LLPs in a widebody and long-haul engine is generally smaller than on a narrowbody engine," explains Grey. "This is mainly because the LLPs have less of an influence on remaining life, and their replacement can also be avoided in many cases."

CFM56-3

The CFM56-3 is still active, with a few shops still providing SV capability, and GE and Safran both still providing technical support and new parts.

There were 1,988 commercial variants of the 737-300/-400/-500 family aircraft built in 1984-1999. Of these, more than 1,300 had been retired, stored, parked or written off by the end of 2019. This left almost 680 aircraft in service at the start of 2020, split between 301 freighter, combi and quick change (QC) aircraft, and 378 passenger variants.

A large portion of the original fleet, totalling about 280 737 Classics, has been converted to freighter, the feedstock being available at low market values. The plentiful supply of 737-300s and -400s meant values had dropped to $2.0-3.5 million, significantly reducing the total build cost of a 737 Classic freighter.

The old age of 737-300s and -400s had reduced freight operators' interests in acquiring them for conversion, since 737NGs were available in large enough numbers and at low enough values to

The availability of 737 Classics has led to a drop in market values, reducing the total build cost of freighters to record low levels. There was resurgence in 737-300/-400 conversion activity in late 2019 and early 2020.

make them attractive conversion candidates. This situation was reversed, however, by the grounding of the 737 MAX in February 2019, since all airlines operating passenger-configured 737NGs needed their capacity, and had to delay retirement or lease returns.

This situation re-ignited interest in the 737-300 and -400 for freighter conversion by cargo operators. Values of -300s and -400s that came available, with engines with maintenance life remaining, climbed up to $5 million, and some were even advertised at more than $5.5 million. The 737 MAX grounding meant that some Classics were being retained for passenger operations.

The Covid-19 pandemic reversed the situation again, with more than 230 of the 680 operational aircraft being parked during the first five months of 2020. This includes more than 215 of the 378 passenger-configured aircraft, and another 16 aircraft.

The 737-300 and -400 are still sought after for freighter conversions. Of the aircraft still in service and parked during 2020, 105 aircraft are 737-500s. Most of these are equipped with -3C1 engines, the most popular CFM56-3 variant.

The 737-500 is not popular with freight carriers as a conversion candidate, but its appeal is the supply of engines to the aftermarket. Most of these are -3C1s.

The remaining 152 parked 737-300s and -400s are potential freighter conversion candidates, so the prospect of most of these aircraft returning to passenger service is virtually nil. There has been an increase in demand for freight capacity since the Covid-19 pandemic started, but the time taken to acquire and modify aircraft means only a limited number could be converted before the pandemic is over.

There are also 69 active 737-300 passenger aircraft, 43 with -3C1 engines; and 42 active -400s, 38 with -3C1 engines. The retirement of all remaining passenger-configured 737 Classics is likely to be accelerated. There are therefore up to 268 active and parked 737-300s and -400s equipped with -3C1 engines. This large supply has implications for market values.

Aero Norway provides maintenance capability for the CFM56-3, -5B and -7B series. "We have reduced our engine shop activity from eight or nine SVs per month to six or seven because of the pandemic," says Glenford Marston, chief executive officer at Aero Norway. "The actual activity in recent months has been about five SVs per month, and -5B and -7B activity has dropped off because so many A320ceos and 737NGs have been parked and stored. We fortunately kept our CFM56-3 maintenance capability. The freight airlines are very busy operating 737 Classics. There is actually a big void in the supply of -3 engines, because there are several -3s coming into the shop for maintenance, and it is perhaps surprising there are fewer green time -3s available.

"We have seen few engines parted out, and I think people are waiting to see how the industry reacts. I expect it to re-size, but this will depend on the type and level of recovery," adds Marston. "For example, many specialist traders and brokers are not yet buying engines because they are expecting the values of most types to drop, and to make big savings. We are looking to buy engines, and expect values to drop further."

Marston points out that many operators, lessors and brokers have yet to release their assets on to the market, but that they may be forced to in the future.

In relation to engine values, Marston says that before the Covid-19 outbreak there was a shortage of -3 engines on the market. This is partly explained by the resurgence in interest in the 737 Classics for freighter conversions, as well as a longer-than-expected operation of passenger aircraft following the 737 MAX grounding.

The value of most -3 engines was based primarily on remaining LLP life and the pro-rate factor, which had gone up before the pandemic because of the shortage of engines. Buying a -3 on the market to perform maintenance on it and put it into service had become too expensive. "Values have become reasonable again following the pandemic, and some engines have been sold because owners need the cash. The lack of engines with remaining maintenance life has forced customers to perform engine SVs," says Marston. "No one pays more than 50-60% for the pro-rate adjustment factor for an engine that is a teardown or part-out candidate. That is an engine with little or no remaining maintenance life left, but whose parts could be repaired to supply USM. This would be used to reduce the cost of SVs."

A shipset of -3 LLPs has a list price of $3.5 million, so an engine with up to 30% of LLP lives remaining would have an adjusted value of $1.2 million. However, with the pro-rate factor applied, the engine's market value would be $0.6 million. Engines with less time remaining would have a value as low as $200,000.

"An engine in 'green time' condition, with 4,000-6,000EFC of maintenance life remaining, might have a current market value of $850,000 to $1.25 million. An engine fresh from an SV would be higher at $1.2-1.65 million," says Marston.

The pandemic and the need to save all possible costs has seen an increase in the number of airlines interested in acquiring green-time engines and modules. "There was a ready market for this," says Marston. "Many airlines are performing light SVs and repairs where possible, and this will provide 4,000-5,000EFC. We are not getting airlines performing convenient SVs, which can often be performed during extended base checks and on engines with just a few thousand EFC left. Another change is that there is a lot more interest in the use of USM in SVs."

This can save several hundred thousands of dollars per SV, but is only possible when engines are available at low teardown values. The supply of -3 engines was tight, but this has now improved to an extent. With owners still hesitant to release their assets, the supply of teardown engines remains limited.

RB211-535 & PW2000

The RB211-535 and PW2037/40 are used only on the 757-200/-300. There were 984 757-200s and 55 -300s built. Most -200s and all -300s were built in passenger configuration.

The 757-200 was in particular used in large numbers by American Airlines, Delta and United. The RB211-535 powered more than half the fleet.

At the start of 2020 just over 600 757-200s were in operation in passenger and combi configuration, and all 55 passenger -300s were still in operation. More than 300 757-200s in passenger configuration had been parked, retired or written off before mid-2019.

There were also 314 757-200 freighters in service at the start of 2020, with 42 older freighters retired or put in storage. Three freighters have been parked since the Covid-19 outbreak, leaving 311 in service.

These 311 freighters are divided between 212 aircraft with RB211 engines, and 99 powered by PW2037/40 engines. The 311 aircraft are a mix of 229 factory-built aircraft, most of which are used by FedEx and UPS, and 82 converted aircraft.

Precision Conversions expects at least 17 more conversions from the relatively small number of parked and stored aircraft that are now available. Most parked aircraft have yet to be sold. Larger numbers may be sold later in 2020, after various government stimulus and support packages stop, and airlines have a clearer indication of what aircraft they will need to put back into service. Aircraft without any financial commitments will be the first to be sold.

The total number of additional conversions may be about 25, and will take place over the next two years or so.

The global lockdown and drop in passenger traffic has seen a large portion of the passenger fleet parked or retired in a period of just two months. This includes 124 RB211-powered aircraft with the largest fleets from American (34 aircraft), Icelandair (12), Jet2.com (9), Tui (8) and United Airlines (39).

There were also 105 PW2000-powered aircraft parked or stored during this period, including 81 from Delta Airlines and 11 from United Airlines.

As these aircraft have been retired, they and their engines have become available on the market. This includes 24 1990s- and early 2000s-built airframes and 58 RB211-535E4 engines from American, all of which are regarded as good quality conversion candidates. There will also be large numbers from other parked fleets.

These parked aircraft are a major source of engines for the freighter fleet that is still in operation, and is likely to continue growing as more aircraft are converted. The large number of parked aircraft means there are potentially a larger number of aircraft and time-continued engines left on the market.

The 757-200's popularity as a freighter means that the LLP and SV costs on both its engine types are high. At usual rates of utilisation and the usual removal intervals between SVs, the resulting engine maintenance reserves per EFH and per EFC have generally been acceptable to passenger operators.

Freight carriers with lower rates of aircraft utilisation and revenues can only

There have been about 230 passenger-configured 757-200s with both main engine types parked and retired since early 2020. This includes large batches from single operators. Demand for the 757-200 freighter remains strong, but engine availability and the high costs of engine shop visits continues to present challenges.

justify full SV costs if the engine will subsequently be used for a long period.

The PW2000 is rated at 37,000lbs or 40,000lbs on the 757-200, and so designated the PW2037 and PW2040. The PW2000 had a reduced temperature configuration (RTC) modification, resulting in longer removal intervals.

The RTC-modified PW2037/40 engines are capable of removal intervals of 5,500-7,000EFC at an EFH:EFC ratio of 2.0:1, provided the engines are not restricted by remaining LLP lives. Life limits in the PW2000's LLPs are 15,000EFC and 20,000EFC.

The intervals will be shorter when operating at a shorter average EFC time. Many freight operators are flying at FC times of 2.5-3.0FH. Engine removals are therefore up to 14,000-20,000EFH in the case of RTC engines.

Non-RTC engines have shorter intervals of 3,400-4,000EFC, equal to 8,500-12,000EFH.

RB211-535 engines generally have slightly longer removal intervals, and reach 7,500-8,000EFC in many cases. This will be equal to 19,000-24,000EFH for aircraft operating at 2.5-3.0EFH per EFC. LLP life limits are determined by the engine's operating profile. Parts with the shortest lives are in the HPC and HPT and they can be as short as 12,600EFC. Parts with the longest lives are in the LPT, and are up to 27,000EFC.

What should generally be considered is that because of low-density payloads, freighters are likely to have a higher degree of engine take-off de-rate than passenger aircraft, and so could achieve the longer removals intervals on average.

These engines are capable of removal intervals equal to several years of operation. Most 757-200 freighter operators are achieving annual rates of utilisation of up to 2,000FH and 800FC.

In the case of RTC-modified PW2000 engines, an interval of 5,500-7,000EFC and 14,000-20,000EFH is equal to 7-11 years of operation. Similarly, the 7,500-8,000EFC and 19,000-24,000EFH removal interval of RB211-535E4 engines will be equal to 9-13 years of operation.

Full SVs can therefore only be justified if the aircraft are already being operated as freighters, or will be acquired and converted to freighters, and can be expected to operate for at least this many years, given their age and accumulated FH and FC. The same applies to a new shipset of LLPs.

SV costs for the PW2000 are $4.0-4.5 million for a performance restoration and $5.5-6.0 million for an overhaul. RB211-535E4 engines will typically have a Level 3 SV costing $5.4-6.0 million, or a heavier Level 4 SV at $5.8-6.5 million.

A new shipset of LLPs for the PW2000 has a list price of $6.5 million, while a shipset for the RB211-535E4 is $6.0 million. Clearly the cost of buying new LLPs cannot be justified given the usual rates of aircraft utilisation and the number of likely remaining years in service.

Freight carriers operating 757-200s will therefore do everything they can to acquire engines with green time and remaining maintenance life, as well as sourcing used material for use in SVs. It may be economic for airlines to acquire modules with little remaining maintenance life, but with the equivalent of several years of LLP life.

Engines and modules with at least sufficient remaining LLP life for the forecast period of operation need to have 8,000-10,000EFC for aircraft intended to operate for 10-12 years, if they are to completely avoid engine SVs. This will clearly not be possible for all engines in the fleet over such an extended period.

The main issue therefore facing 757-200 freighter operators is what supply there is of PW2000 and RB211-535 engines in the market with the right amount of green time or maintenance life remaining.

Airlines have to weigh the costs of the two options of acquiring engines with low maintenance life and a value equal for a teardown engine and performing an SV, or acquiring an engine with green time remaining. Acquiring an engine that requires both LLP replacement and an SV is too expensive to be a consideration.

RB211-535E4 engines with up to 3,000EFC maintenance life remaining could be valued at a rate of $1,000 per EFC. That is, an engine with 3,000EFC left would have a market value of $3.0 million *(see Factors affecting the supply of PW2000 & RB211-535 engines in the aftermarket, Aircraft Commerce, June/July 2019, page 4)*.

RB211-535E4 engines with a longer maintenance life will have a higher value, and can sell for $6 million or more. These values would, however, come close to the total cost of acquiring part-out and teardown engines plus the cost of an SV.

Despite the large number of aircraft parked at short notice in the first half of 2020, many engines are expected to have little remaining maintenance life.

A third option, which may work out more cheaply on a per EFC basis, is to temporarily take advantage of low short-term lease rates of $40,000-60,000 per month, plus maintenance reserves. Maintenance reserves are charged per EFH for SVs, and per EFC for LLPs, so the lease rate for rental is equal to $600-900 per EFC. Clearly only lower lease rentals make economic sense.

Airlines may be forced to accept an uneconomic option during the aircraft's whole operational life. The current demand for acquiring green-time engines to avoid SV maintenance will inevitably lead to a shortage of engines, and so push a large number through SVs in future.

It could prove prudent for freight operators to buy and warehouse engines if they have the cash available.

747 & 767 fleets

Most 767 variants were equipped with CF6-80C2 and PW4000-94 engines. The 767 was one of five 1980s widebody families powered by these two main engine types. The other four were the A300-600, A310, MD-11 and 747-400. Most aircraft in the fleets of these four types were retired before 2020. These retirements provided a large number of engines on the used market that has made it possible for many airlines to avoid the high cost of putting engines through SVs by acquiring green-time engines.

At the start of 2020 there were still 124 MD-11 freighters in service. These were operated mainly in large fleets with FedEx and UPS, plus smaller fleets with Lufthansa Cargo and Western Global. In the first few months of the pandemic, 19 MD-11Fs were parked or retired.

At the start of 2020 a large number of 747-400s were in operation as passenger, combi and freighter aircraft. This included 77 CF6-80C2F-powered and 39 PW4000-94-powered aircraft.

Most of these were parked or stored shortly after the Covid-19 outbreak, leaving just three CF6-powered combis in service with KLM, and three PW4000-powered passenger aircraft with Wamos Air and Air China.

There were 65 CF6-equipped 747-400s parked, and a further nine retired, in late 2019 and the first half of 2020. These came from fleets operated by KLM, Lufthansa, Qantas, China Airlines, Qantas and Thai International. Taking into account spare engine inventories held by these airlines, these 74 aircraft could potentially put at least 300 CF6-80C2F engines onto the market. However, there are almost no markets for used 747-400s, and passenger-to-freighter conversions have ceased.

There were also 19 PW4000-powered parked and a further 17 aircraft retired in late 2019 and early 2020 by Air India, Corsair, Delta Airlines, El Al, Korean Air and Max Air. These aircraft will bring up to 160 PW4000-94s onto the market.

The 767 is the largest fleet of the five 1980s generation widebodies. At the start of 2020 there were almost 450 767s in passenger service, plus 346 freighters. There are five main engine types: Pratt & Whitney's JT9D-7R4 and PW4000-94; and General Electric's CF6-80A, CF6-80C2 and CF6-80C2F. The PW4000-94 and CF6-80C2F have full authority digital engine control (FADEC) units.

Most 767 passenger aircraft in operation at the start of 2020 are powered by the PW4000-94 (149), CF6-80C2 (47) and CF6-80C2 (243).

Most 767 freighters (285 units) are -300ER series. Nine are equipped with PW4000-94 and 246 with CF6-80C2F engines. There are also 30 freighters with CF6-80C2 engines; those with power management control (PMC) throttle controls.

The CF6-80C2F is clearly the most important engine type in terms of securing a supply of engines to support future freighter operations. The 767-300ER is one of the most popular types for conversion programmes, and forecasts are for many more to be modified.

The CF6-80C2F has clearly been preferred by freight operators when choosing engine variants, because PW4000-powered converted aircraft were originally unable to get certified at the highest maximum landing weight (MLW). When aircraft are modified to freighter their MLW is increased to 326,000lbs. This provides a difference of 17,000lbs between the MLW and the maximum zero fuel weight (MZFW); the highest possible MZFW is 309,000lbs.

The converted PW4000-94-powered aircraft could not initially have its MLW upgraded to 326,000lbs during freighter conversion, so the PW4000-powered aircraft suffered a payload restriction compared to the CF6-80C2-equipped aircraft. The CF6-80C2 therefore became the engine of choice. The PW4000-equipped aircraft has since had its MLW upgraded to 326,000lbs during freighter

The conversion of 747-400 passenger aircraft to freighters has ceased. All exisiting freighters have continued to operate at high rates of utilisation. The retirement of large numbers of passenger-configured 747-400s has released PW4000-94s and CF6-80C2s onto the market, depressing their values.

conversion, so it can have almost the same payload as aircraft with CF6 engines. The PW4000-equipped 767-300ER fleet could therefore see a larger number of aircraft being converted, especially as the number of suitable CF6-powered examples declines.

At least 30 converted 767-300ERs are operated by Prime Air on behalf of Amazon. More aircraft are being converted, all with CF6-80C2F engines.

There are up to 100 parked 767-300ERs with CF6-80C2F engines that could provide conversion platforms. There are also, however, more than 110 parked 767-300ERs with PW4000-94 engines, plus 30 that are still in active service. With the MLW weight penalty on PW4000-powered aircraft overcome, this fleet could provide suitable conversion candidates.

There are just over 200 A300-600, A310 and 767-200ER freighters in service, of which 90 are operated by UPS and FedEx. The remaining 110 are all ageing, and the converted 767-300ER is the best replacement candidate, having the closest structural and volumetric payload.

The conversion of 747-400s to freighters has ceased, but the 767-300ER conversion market should remain strong for several more years. The main market for PW4000-94 and CF6-80C2 engines from parked and retired aircraft will therefore be to continue supporting 747-400 freighters in service, and to support an increasing number of 767-300ER converted freighters.

PW4000-94

"The demand for PW4000-94 engines to support freighter fleets, the 747-400 in particular, is doing well," explains Bill Polyi, president and chief executive officer at Magellan Aviation Group. "There is strong demand from airlines to lease every available engine with a decent amount of maintenance life. Airlines are clearly doing everything they can in the current climate to avoid SV costs of several million dollars. They are not even buying green-time engines with maintenance life remaining. Instead they are taking out short-term leases."

This is likely to only be a short-term market bounce, since the lack of long-haul and intercontinental flying operations has severely reduced the amount of belly space available. Freight operators are therefore busy serving short-term demand and high-yield freight for a period that may only last for another six to nine months.

"The main demand for PW4000-94s is for PW4056s to support 747-400s, and to a lesser extent PW4060s to support 767 freighters," says Polyi. "There is a temporary shortage of PW4060s for 767s."

There is a large number of serviceable aircraft with PW4000-94s that have plenty of maintenance life left, and these will be the first to return to service when international travel starts to recover. This will still leave a large number of aircraft with little airframe maintenance life left. They can therefore be used as a source of engines that can be acquired by lessors and leased to carriers.

Polyi estimates market values for PW4000-94s with green-time maintenance condition of 1,500-3,000EFC to the next SV at $1.5-3.0 million. "The base rent for PW4000-94 has now come down to $20,000 per month, and a full lease rental with maintenance reserves included is $65,000-70,000 per month at typical rates of utilisation," says Polyi. "The availability of engines is high because of the large number of aircraft that were parked this year. In the meantime, the market value of teardown engines has fallen to $200,000-500,000. There are only five to 10 major parts in the engine worth salvaging from the point of view of repairing and selling them as USM."

CF6-80C2

The main demand for whole CF6-80C2 engines, modules and serviceable materials is for 747-400 and 767-300ER freighters. As the 767-300ER freighter fleet is dominated by the CF6-80C2, there is a larger number of aircraft to be potentially supported compared to the PW4000-94. Most passenger-configured 747-400s and 767-300ERs are inactive.

"We have seen consistent demand for parts and materials to support SVs," says Stratton Borchers, president at TrueAero. "There has, however, been an increase in the number of whole engines that are serviceable, with maintenance life remaining; and teardown engines to provide parts for repair.

"The long-term effect of the crisis is not year clear, and it may take several years to see the full impact," continues Borchers. "One major factor affecting the availability of engines and the activity of airline operations is the US Government CARES act to support US airlines, which is due to end in September. If this is not extended or traffic is not sufficiently recovered by then a large number of the parked aircraft will become available."

It is already known that a large number of CF6-powered 747-400s has been parked and will not go back into operation, making their engines available on the market. The situation with the parked 767-300ER fleet is not as clear. Some aircraft could go back into service if there is a relatively strong recovery.

"Lease rates for CF6-80C2s have come under pressure during the crisis," says Borchers. "Rates have probably fallen by 15% to begin with, but the actual rate commanded by a lessee will depend on their credit rating.

The CF6-80C2 and -80C2F are in a strong position, since they power about 50% of 747-400 freighters, but more

Demand for 767-300ER freighter conversions is strong. The majority of more than 300 aircraft is powered by CF6-80C2 and -80C2F engines. This has increased the difference in market value between 'green time' PW4000-94s and CF6-80C2s.

than 90% of 767-300ER freighters. "The freighter market is clearly less impacted, and while people are sourcing engines for freight operations, those with engines are not yet in a rush to sell them," continues Borchers. "Few trades are happening, and it seems many sellers are sitting on the fence because of the Covid-19 crisis."

Airlines will be doing everything to avoid the high cost of SVs and LLP replacements. A shipset of CF6-80C2 LLPs has a list price of $8 million. Parts in the HPT module have uniform lives of 15,000EFC, while all other LLPs have lives of 20,000EFC.

Most 747-400s and 767-300ERs will have operated at long average EFC times, which increases the likelihood that many engines on parked aircraft are close to using the full life of their original LLPs, or will have used some of their second set of LLPs. Engines in the latter group will have green time remaining, and so be in demand.

Most CF6-powered 747-400s have accumulated a total time of more than 15,000FC but have not exceeded 20,000FC. This will indicate accumulated time on their engines, although engine-swapping must be taken into account.

A large number of parked passenger-configured 767-300ERs have an accumulated total time of 10,000-29,000FC. Retired 767-300s, with CF6-80C2F engines, have reached total times of 23,500-44,600FC. This indicates that most engines will have their second set of LLPs, and some are likely to be on their third set.

Finally, there are 137 parked 767-300ERs and -400ERs, all with -80C2F engines. These aircraft have total accumulated times of 10,000-44,000FC. United Airlines' 767-400ERs in particular all have low total times of 11,000-15,400FC. The quality of these aircraft and their engines of course raises the issue of how likely it is that these aircraft will go back into service or become available on the market.

"Some CF6-80C2s have been torn down for parts to be repaired and used in SVs," say Konrad Walter, managing partner at TMSaero and Dean Morgan, president of ASI Group. "Engines from aircraft that were taken out of service in 2019 or earlier should not be overlooked. There were kits to convert the QEC on an engine from an A or D configuration (to power an A300-600 or A310, or an MD-11) to a B configuration (to power a Boeing aircraft). These kits plus labour could cost $1 million or more depending on many factors. In fact, this service bulletin (SB) is no longer recommended or supported by GE.

"The simpler and cheaper alternative is for A and D engines, for example, to be broken down to acquire parts to be used in the SVs of B engines," continue Walter, and Mark Tipton, vice president of engine services at ASI Group. "The challenge is finding suitable surplus engines that provide serviceable modules and 767 QEC material. The 747-400 engines can support the module requirements. Parts and materials can be used for the SVs of 767-300ER engines."

Despite the cost, there are some good quality D engines from MD-11 freighters. "We have hired TMSaero to convert some D engines for use on 767-300ER freighters," says Morgan. "There is also significant interest in A engines. For example, the core of A engines can be mated with the low pressure modules and QECs of B engines to make complete powerplants. This is a relatively easy conversion, and cheaper than converting the QEC kit. This mating of A and B modules is done on the basis that there is little or no market remaining for the A300-600 and A310. The cost of buying a donor B engine for the fan and QEC modules and mating it with the core of an A engine is about $0.75 million."

There is also another consideration. Many operators will need higher thrust variants of CF6-80C2 engines: the -80C2B6 and -80C2B7 variants rated at 60,030lbs for the 767-300ER. This compares to the -B1 or A1 or A8 engines rated at 57,160lbs for the 747-400ER, or rated at 57,860lbs for the A300-600 and A310-300. A thrust upgrade can be applied to a lower-rated engine, provided it has the correct internal hardware, but this will incur an extra cost.

Walter thinks the values of green-time CF6-80C2s are too high, considering the market. "We have not bought any in the current market, but we have been offered -80C2A engines with less than 2,000EFC remaining for $2 million. Another engine with 4,000EFC left had an asking price of $4 million. Values are staying high," says Walter. "Before Covid-19, the value of parted-out -80C2s ranged from $650,000 to $1.1 million. Some buyers are still paying these prices. The QEC kit and all other externals would cost another $400,000-600,000."

There is a long-term market supporting the CF6-80C2 for the 767-300ER. There are, however, bidders outbidding specialist engine buyers, and this is pushing values up too high. This will start to change, however. There are also airlines buying direct themselves, and freight carriers are asking TMSaero to build engines from modules or acquire engines direct. Freight airlines tend to look for engines with 1,500-3,000EFC of maintenance life. This will give them up to six or seven years of operation.

"The values of CF6-80C2s have been changing almost daily recently, generally downwards," says Walter. "While values of serviceable engines are at $1,000 per EFC of remaining maintenance life, they average about $2.5 million. The values of -80C2s should not change much because it is a popular freighter engine." AC