After two years of operational service, the A320neos' PW1100G and the CFM LEAP-1A engine initial in-service performance are examined. In service performance, LLP lives, EGT margins, reliability issues and possible removal intervals are reviewed.

In-service performance of the PW1100G & CFM LEAP-1A

The launch of the three members of the A320 new engine option (neo) family in 2010 provided a second generation of A320 family aircraft. This followed the current engine option (ceo) family, which has been manufactured since 1988. The A320neo family's main feature was the use of two new engine types, the CFM LEAP-1A series and Pratt & Whitney PW1100G series, that were both intended to reduce the aircraft's fuel burn relative to ceo family members by 15%.

There has been some analysis of the fuel burn performance of these aircraft. This started with the A320neo *(see A321neo & narrowbody fuel burn & operating performance, page 26)*, and has been followed by a combined analysis of the A320neo and A321neo and other similar sized types *(see A321neo fuel burn & operating performance, Aircraft Commerce, April/May 2018, page 14)*. While the A320neo family has achieved its main objective of improved fuel burn, a review of the in-service performance of the two main engine types is given here.

A320neo family

The neo has three members: the A319, A320 and A321. The A320neo entered service in 2016, the A321neo entered service in 2017, and the A319neo is due to enter service in 2020. To date, the A320neo family has attracted more than 6,500 firm orders. There are about 740 aircraft in airline service and 20 in storage. Of the 6,507 aircraft, only 36 are the smallest A319neo model. The A320neo accounts for most of the fleet, with 4,155 aircraft, while the A321neo has attracted 2,316 firm orders.

The CFM LEAP-1A family has won orders to equip 2,517 aircraft, equal to 38.7% of the fleet, while the PW1100G has won orders to equip 1,857 aircraft, equal to 28.5%. Engine selection has not yet been specified for 2,133 aircraft, the remaining 32.8% of the fleet.

CFM LEAP-1A fleet

The first aircraft entered operational service in late 2015. This was a LEAP-1A26-powered A320neo operated by Air Asia, which has taken delivery of 27 aircraft to date.

The largest LEAP-1A26-powered A320neo fleets are operated by Azul (25 aircraft), China Eastern (20), China Southern (12), easyJet (23), Frontier (28), Pegasus (24) and SAS (24). LEAP-powered A320neos are achieving annual rates of utilisation of 2,800-3,900 flight hours (FH) and 1,400-2,000 flight cycles (FC). Average ratios are 3,600FH and 1,500FC, so a typical FH:FC ratio in operation is 2.55-2.70:1.

A total of 1,727 A320neos have been specified with the LEAP-1A, and 338 or more are in service. Up to 1,382 aircraft are on order.

The first A321neo entered service in 2017. This was a -1A33-powered aircraft with Alaska Airlines.

There are three sub-fleets of LEAP-1A-powered A321neos: 33 aircraft fitted with -1A32 engines; 18 with -1A33 engines; and two with -1A35 engines.

Fleets of aircraft with these engines are still relatively small. The largest are operated by easyJet (5), Interjet (8), TAP Air Portugal (7), Alaska Airlines (8) and China Southern (5). Up to 53 aircraft are in service. Few fleets have established operations, but annual rates of utilisation are 3,000-3,300FH and 1,700-1,900FC at an average FH:FC ratio of 1.78:1.

There are up to 723 aircraft on order, and more than 2,100 outstanding firm orders for the A320neo family.

PW1100G fleet

The PW1127G-powered A320neo entered service with Chile-based LATAM Airlines, at the same time as the LEAP-1A-powered A320neo. It was shortly followed by aircraft operated by Lufthansa and IndiGo. The largest fleets in service are with IndiGo (75), Go Air (31), All Nippon Airways (9), S7 Airlines (10), Spirit Airlines (12), Volaris (12) and Vueling Airlines (13). There are a total of 247 A320neos in service with PW1100G engines.

The first PW1100G-powered A320neo entered service in 2016. There are two sub-fleets of PW1100G-powered A321neos: 16 aircraft equipped with PW1130G engines, and 83 with PW1133G engines.

A few airlines have established operations since service entry. Average annual rates of utilisation are 3,600-3,800FH and 1,575-1,775FC, and FH:FC ratio is 2.25-2.35:1.

Fewer fleets of PW1100G-powered A321neos have become established. Annual rates of utilisation are similar to A320neos. Some exceptional cases include Hawaiian, which uses the aircraft on medium-haul missions, resulting in an FH:FC ratio of 5.1:1. Its fleet operates at 3,350FH and 650FC per year.

CFM LEAP-1A & PW1100G TECHNICAL SPECIFICATIONS

CFM LEAP-1A

Engine variant	LEAP-1A23	LEAP-1A24	LEAP-1A26	LEAP-1A29	LEAP-1A32	LEAP-1A33	LEAP-1A35
Take-off thrust rating - lbs	24,010	24,010	27,120	32,160	32,160	32,160	32,160
Max continuous thrust - lbs	23,510	20,000	26,680	31,690	31,690	31,690	31,690
Overall pressure ratio	40:1	40:1	40:1	40:1	40:1	40:1	40:1
Core pressure ratio	22:1	22:1	22:1	22:1	22:1	22:1	22:1
Fan dia - Inches	78	78	78	78	78	78	78
Bypass ratio	11:1	11:1	11:1	11:1	11:1	11:1	11:1
Fan stages	1	1	1	1	1	1	1
LPC stages	3	3	3	3	3	3	3
HPC stages	10	10	10	10	10	10	10
HPT stages	2	2	2	2	2	2	2
LPT stages	7	7	7	7	7	7	7
Fan architecture							
No. fan blades	18	18	18	18	18	18	18

PW1100G

Engine variant	PW1122G	PW1124G	PW1127G	PW1129G	PW1130G	PW1133G
Take-off thrust rating - lbs	24,240	24,240	27,075	29,245	33,110	33,110
Max continuous thrust - lbs	24,035	24,035	26,345	26,345	32,780	32,780
Overall pressure ratio	50:1	50:1	50:1	50:1	50:1	50:1
Core pressure ratio						
Fan dia - Inches	81	81	81	81	81	81
Bypass ratio	12.5:1	12.5:1	12.5:1	12.5:1	12.5:1	12.5:1
Fan Stages	1	1	1	1	1	1
LPC stages	3	3	3	3	3	3
HPC stages	8	8	8	8	8	8
HPT stages	2	2	2	2	2	2
LPT stages	3	3	3	3	3	3
Fan architecture						
No. fan blades	20	20	20	20	20	20

CFM LEAP-1A specifications

The LEAP-1A has a conventional two-shaft turbofan configuration, chosen from several possible configurations when the engine was first conceived. Overall, the objective of the configuration was to achieve the highest possible bypass ratio of a conventional two-shaft turbofan, and ultimately provide a fuel burn reduction of 15% over the previous CFM56-5B engine powering the same airframe. The LEAP-1A, and -1B, therefore, optimised the two-shaft configuration so that the core engine could power the largest possible intake fan. While the -1A and -1B share the same design philosophy, they do not have any interchangeable hardware.

The LEAP-1A has seven thrust ratings ranging from 24,010lbs to 32,160lbs, from an engine with an intake fan diameter of 78 inches and which achieves ultra-high bypass ratios of about 11:1. It directly relates to increased propulsive efficiency, and so lower specific fuel consumption (sfc), and lower fuel burn.

This is one of the highest bypass ratios of civil turbofan engines. Other engines with similar bypass ratios include the Rolls-Royce Trent 1000 and PW1000G family. The PW1000G family includes the PW1100G, the alternative engine choice for the A320neo.

The LEAP-1A's bypass ratio of 11:1 compares to the CFM56-5B's ratio of 5.5-5.9:1. The -5B series has a fan diameter of 68.3 inches and is rated at 23,300-30,000lbs.

The LEAP-1A requires its core engine to provide more power to drive a 10-inch wider fan and provide about 2,000lbs more thrust, and achieve the higher bypass ratio. The LEAP-1A's core generates a core pressure ratio of 22:1, and an overall pressure ratio of 40:1. By comparison, the CFM56-5B has a core pressure ratio of 11:1, and an overall pressure ratio of 24.4-33.7:1, depending on thrust rating.

The LEAP-1A's core has nine high pressure compressor (HPC) and seven low pressure turbine (LPT) stages. The CFM56-5B has one fewer stage in each of these modules.

The LEAP-1A also has two high pressure turbine (HPT) stages, compared to the CFM56-5B's single stage. An extra HPT stage is used to extract more energy and so a leaner burn, and achieve overall

A320neo & A321neo operators praise the aircraft for superior fuel burn and payload carrying performance.

higher sfc and lower fuel burn.

The LEAP-1A's core provides more relative power to turn a wider fan. This is illustrated by the ratio of the fan diameter to the various parts of the core engine, such as the HPC and the LPT, which is higher than in earlier-generation engines. The increased number of HPC and LPT stages is used to generate the high pressure ratio necessary to turn the fan. The fan has 18 wide chord blades, compared to 36 blades with mid-span shrouds on the preceding CFM56-5B powering the A320/321ceo, and 22 wide chord blades on the -7B powering the 737NG.

The narrow diameter of the LEAP-1A's core, compared to its fan module, means the core engine is susceptible to bending. The core engine, therefore, needs design features to provide strengthening.

Other design features have been incorporated to optimise the LEAP-1A's configuration. One of these is the use of 3-D woven RTM in the construction of fan blades to save weight while providing strength. Composite materials are also used in the fan case to save weight.

The CFM LEAP-1A has a full shipset of 23 life limited parts (LLPs). These have a 2019 list price of $4.57 million, which will escalate at an annual rate of more than 6%.

These 23 parts are grouped into four main modules with current certified life limits that vary depending on thrust variant, with shorter lives for higher ratings. The fan disk has a current life of 17,200 engine flight cycles (EFC). The other two parts have current lives of 30,000EFC. Target lives for the three parts are 30,000EFC. The life limit of the fan disk, therefore, needs to be extended.

The seven parts in the LPT have target lives of 30,000EFC. Current life limits are varied, with some as short as 5,200EFC, and one already at its target limit. The 11 parts for these two modules have a list price of about $2.3 million.

Target lives for the 12 LLPs in the HPC and HPT are 20,000EFC for low thrust-rated variants, and 17,500EFC for high thrust-rated variants. Current life limits are 15,000EFC for HPC module parts, but lower for some disks in the HPT. The list price for the 12 parts across the two modules is about $2.3 million.

PW1100G specifications

The PW1100G is one of six sub-families of the PW1000G family. The PW1100G sub-family has six thrust ratings to power the A320neo family. These are rated at 24,240-33,110lbs. Four of the other five sub-families are rated at lower thrusts for smaller aircraft.

The PW1000G's configuration is the first civil turbofan engine in its thrust class to have a geared intake fan. This configuration is used on the basis of the conventional two-shaft turbofan reaching the limit of its bypass ratios. It is generally desirable to steadily increase intake fan diameter to increase bypass ratio for the purpose of increasing the mass of air and so reduce the accelerated air velocity through the engine. This increases propulsive efficiency.

A main limiting factor of the conventional two-shaft turbofan configuration is that the LPT at the rear of the engine is mounted on the same shaft as the intake fan at the front of the engine. As fan diameter increases, the speed of the fan in revolutions per minute

The LEAP-1A's EGT margin was increased by about 26 degrees centigrade by incorporation of EEC software.

(RPM), and, therefore, the shaft and LPT, has to be reduced. This is because the lateral speed of the fan blade tips is restricted to less than supersonic levels. This can only be done for longer fan blades by reducing RPM speed.

The conventional two-shaft configuration eventually becomes compromised because the LPT's ability to turn a larger fan is reduced by the limited RPM speed. This means that more stages are needed from a larger LPT to turn the fan. This adds weight, which requires more power from fuel combustion. The ability to increase fan diameter and, therefore, bypass ratio becomes limited.

The PW1000G's geared intake fan configuration circumvents the problem of the LPT's RPMs being limited to the same speed as the intake fan. A gearbox towards the front of the engine, between the fan and the shaft on which the LPT is mounted, means that while the fan will have a relatively low RPM speed of 4,000-5,000 so that blade tip speeds do not exceed supersonic levels, the LPT is free to turn at higher RPMs of 12,000-15,000. The LPT will, therefore, have higher turning power, so it can be relatively smaller than a conventional turbofan. The number of stages and, therefore, blades and vanes in the LPT has an influence on maintenance costs.

The PW1100G sub-family has a fan diameter of 81 inches *(see table, page xx)*, three more inches than the LEAP-1A. The fan has 20 wide chord fan blades. The engine achieves a bypass ratio of 12.5:1. This is not only the highest of all six PW1000G sub-families, but also higher than any other narrowbody engine. It also compares to a bypass ratio of 11.0:1 for the LEAP-1A.

The PW1100G's efficiency is illustrated by its overall pressure ratio of 50:1, which compares to 40:1 for the LEAP-1A. The PW1100G's pressure ratio also compares to the V2500-A5's overall pressure ratio of 35-36:1.

The PW1100G's core engine is relatively small with three LPC stages, eight HPC stages, a dual-stage HPT, and three LPT stages. The size of the LPT in particular compared to the LEAP-1A is a relevant difference.

The PW1100G has a full shipset of 29 LLPs, with a 2019 list price of $4.2 million. List prices escalate at rates in excess of 6% per year. The 29 parts are grouped into four main modules.

There are six parts in the fan/LPC, which include the low pressure (LP) shaft and gearbox. The HPC has 12 parts, the HPT has six, and the LPT five parts that include the LP shaft and diffuser case.

The four groups of parts have current certified life limits that vary with thrust rating. Some parts have current life limits shorter than the target airworthiness limit (AWL).

The PW1122G, PW1124G and PW1127G, rated at 24,240lbs and 27,075lbs, have target lives of 25,000EFC for all parts in the fan/LPC, HPC, and the LPT. Some of the parts in the HPT have target lives of 25,000EFC, but there are three parts with target lives of 12,500EFC.

Modules with restricted life limits are the fan/LPC, HPC and HPT. Some parts will have life limit extensions, but they differ from the planned target lives.

New part numbers (P/Ns) for the same part, with target life limits, will have to be installed. Some of the current parts in the HPC and HPT will be restricted to lives as short as 6,000EFC and 7,700EFC.

The three higher-rated variants are the PW1129G, PW1130G and PW1133G rated at 29,245lbs and 33,110lbs. These three have shipsets of LLPs with the same certified lives for installed P/Ns, and target lives. These are 25,000EFC for all six parts in the fan/LPC, 20,000EFC for all but one part in the HPC, a limit of 25,000EFC for the front hub in the HPC, a mix of 10,000EFC and 20,000EFC in the HPT, and a limit of 25,000EFC for all parts in the LPT.

Current life limits are relatively short for some of the particular P/Ns installed on the engine. The current life limits will be extended during 2019. The parts in the fan/LPC will have been extended to 25,000EFC, except for one at 12,500EFC in early 2019. Many of the parts in the HPC will have been extended to 10,000-20,000EFC by late 2019. Many parts in the HPT will have had their lives extended to 6,500-10,000EFC by late 2019. The mini disk 1 will still have a limit of 3,000EFC. A replacement P/N will have a limit of 10,000EFC.

New P/Ns with target life limits will be available for the HPT in the second half of 2019, and one in the second half of 2020 for the HPC. The 10,000EFC life limit of HPT parts has implications for removals and shop visit (SV) maintenance, since a complete disassembly will be required to replace the LLPs. This compares to annual utilisations of 1,500-2,000EFC.

LEAP-1A in service

The CFM LEAP-1A has been in service since 2016, and there are some initial indications of how well it is operating. The two main issues relating to an engine's in-service performance are fuel burn and maintenance costs. The LEAP-1A's fuel burn performance relative to other closely competing types is fairly well established *(see A321neo & narrowbody fuel burn & operating performance, page 26)*. Maintenance costs are more complex, and are affected by several factors.

TAP Air Portugal has a fleet of three A320neos equipped with LEAP-1A26 and seven A321neos powered by -1A32 engines. It has operated the A320neo since April 2018. These operate alongside its older fleet of 22 A319ceos and 20 A320ceos, powered by the CFM56-5B5, -5B6 and -5B4 that are rated at 22,000lbs, 23,500, and 27,000lbs. It has had the aircraft in its fleet since December 2017. It also operates a small fleet of four A321ceos, which are powered by the CFM56-5B3, rated at 32,000lbs.

The A321neo weight variant selected by TAP is the WV053 version, one of the highest weight variants. This has a maximum take-off weight of 93.5 tonnes (206,132lbs), and a payload of 24.2 tonnes.

TAP comments that the A320neo and A321neo fleets have significantly improved available payload performance. This effect is not only due to increased engine performance over the ceo fleet, but also due to the higher weight variants being used. The weight specifications of the WV053 being used has an enormous impact on the A321neo's available payload on its longest routes.

TAP gives the example of LIS-DME, which is its longest route, which has a great circle distance of 2,118nm. The A320neo has a 1,600Kg (3,520lbs) higher payload than the A320ceo variant it operates on this route, and the A321neo has a 10,600Kg (23,320lbs) higher payload than its A321ceo variants. The A321ceo is so restricted on this route that its available payload is only 56% of the maximum payload. The A320ceo is 5% restricted on the same route, and the A320neo and A321neo have no payload limitations.

TAP gives a similar example of the LIS to Rabil (BVC), on the Cape Verde Islands, route. This has a shorter great circle distance of 1,537nm, but because of obstacle clearances, some aircraft have take-off weight and, therefore, payload restrictions. The A321ceo suffers from a 23% payload restriction on this route, while the A321neo has a 7% payload reduction imposed.

In terms of fuel burn performance, TAP says the A320neo/321neo fleets have a clear 20% lower burn than the corresponding A320ceo and A321ceo fleets. This is a difference between new neo aircraft and aged and mature A320/321ceo aircraft.

The late models of the CFM56, the -5B and -7B, had several major features, in particular high exhaust gas temperature (EGT) margins. As a result, both engines generally had long removal intervals between SVs, which contributed to keeping their maintenance costs low on a per EFH and EFC basis. In many cases, engines were removed for the first time upon reaching the first LLP limit.

The LEAP-1A's EGT margins are an important factor in ultimately determining maintenance costs per EFH and per EFC. Typical EGT margins at service entry are 85-95 degrees centigrade for the -1A24 rated at 24,010lbs. Higher-rated variants clearly have lower margins. The -1A26, rated at 27,120lbs, has a margin of 73-83 degrees, the -1A32 at 32,160lbs has a margin of 54-64 degrees, and the highest-rated -1A33, rated at 32,160lbs, has a margin of 43-53 degrees. This spread of margins between the highest- and lowest-rated engines is about 5-55 degrees less than the CFM56-7B's margins at service-entry.

TAP says that the -1A26 and -1A32 variants had initial EGT margins of 67 and 64 degrees at service entry. This was prior to a EEC software being incorporated on the -1A26, which raised EGT margin to about 93 degrees.

The LEAP-1A variants have initial EGT margin erosion rates of 15 degrees centigrade in the first 1,000EFC, and then mature EGT margin erosion rates of 5 degrees centigrade per 1,000EFC. TAP confirms this with its own experience, stating that initial rates in the first 1,000EFC on-wing are about 18 degrees for the -1A26 following the software

First removal intervals for the PW1127G are expected to be up to 12,500EFC, provided engines are able to overcome any issues affecting reliability.

upgrade, and about 15 degrees for the -1A32.

The implications of this are that the highest rated -1A33 would have a first removal interval of 7,000-8,000EFC, provided there are no other hardware deterioration or reliability issues.

The -1A32 would have a first removal interval of 9,000-11,000EFC on the same basis, the -1A26 would have a first removal interval of 12,000-15,000EFC, and the -1A24 would have a first removal interval of 15,000-17,000EFC. TAP says, however, that it predicts first removals for the LEAP-1A at about 6,000EFC, and about 5,500EFC for the -1A32. These compare to first removal intervals of 11,000-20,000EFC for the -7B series.

It is possible to extend these intervals with a water wash, to recover some EGT margin. This is recommended every 500EFC or 1,000EFC.

The possible SV pattern depends on the LLP limits of the different modules. The HPT had three parts with life limits of 6,900-8,900EFC, and so would limit the first removal interval to 6,900EFC. Two other parts had current life limits of 10,000EFC and 15,00EFC.

All engine variants would have their first removal interval limited to 6,900EFC for the HPT forward outer seal LLP. The plan was to extend the certified life limits of this part by mid-2018 to 17,500EFC for higher-rated variants, and to 20,000EFC for lower-rated variants. The same applies to all other parts in the module. Provided all LLPs could have their lives extended in time, the engines could go through an approximate pattern of removal intervals and SV workscopes.

For the lowest-rated variants, a removal at 16,000EFC would mean that LLPs in the HPC and HPT would have just 4,000EFC remaining, and so would require replacing. LLPs in the two LP modules would have remaining lives of 14,000EFC. Since the second removal interval is likely to be about 11,000EFC, LLPs in the fan/LPC and LPT could, therefore, be left in the engine.

The engine's SV would be workscopes on the HPC, combustor and HPT to restore performance and EGT margin. LLPs would also have to be replaced in the same modules. The fan/LPC and LPT could be left in the engine.

The second SV might be after a second removal interval of 11,000EFC, and a total time of 27,000EFC. These LLPs in the two LP modules would require replacement at this point, forcing their full disassembly. A performance restoration would be required again on the two HP modules.

The third removal interval would be limited to 9,000EFC, due to the installation of LLPs in the HPC and HPT at the first SV. Total time will, therefore, be about 36,000EFC, so the two HP modules would require full disassembly and a full workscope because of LLP replacement.

The lower-rated -1A26 would follow a similar pattern, with each removal interval being 2,000-3,000EFC shorter.

The higher-rated engines would have first removal intervals that are only 7,000-8,000EFC at 33,000lbs thrust, and 9,000-11,000EFC at 32,000lbs thrust. These two variants would, therefore, have two removals allowed by EGT margin before reaching the life limit of 17,500EFC in the two HP modules. The LLPs in these two modules would have to be replaced at this second SV, after a maximum total time of 17,500EFC.

The third SV would require full disassembly and a workscope for the two LP modules because of the 30,000EFC LLP life limits. The HP modules would require a performance restoration.

LEAP-1A technical issues

While these are the planned or expected removal intervals, the LEAP-1A has had some technical issues in its initial period of operation.

The LEAP-1A's overall objective has been to reduce fuel burn by 15%. This has partly been achieved by maximising the possible combustion temperature. Not only does this achieve a lean fuel burn, but it also reduces NOx emissions.

High combustion temperatures are thought to have caused some initial reliability problems. One particular issue has been the loss of EGT margin, due to the loss of coating on the HPT blades. This has occurred at 300-2,800EFC, so after a relatively short time on-wing. The loss of the coating also resulted in an increase in HPT blade tip clearance. There was also an associated degradation of the HPT blade shroud, which is located on the inner wall of the HPT and is used to maintain blade tip clearance to a minimum level and so keep EGT margin erosion rates low. The degradation of the shroud and loss of blade coating led to a sudden loss of EGT margin of about 35 degrees centigrade. TAP says that this issue is currently the main removal driver of LEAP-1A engines, and causes engine removals far earlier than the LLP life limits of 6,00-9,900EFC of certain parts.

A service bulletin (SB) was released by CFM to install re-designed blade shrouds and apply a new coating. This applies to both manufactured blades and repairs to blades during an SV. This included the use of a new coating that has better resistance. This modification has resulted in improved EGT margin.

A number of other modifications has been issued for the LEAP-1A via airworthiness directives (ADs). One is the replacement of the stage two turbine disk, which related to engines with cracks because of incorrect forging at manufacture.

A second AD was issued in late 2018 to replace software on the engine's full authority digital control (FADEC) unit.

PW1100G in service

The PW1100G may have similar first removal intervals to the LEAP-1A. The first removal interval for the lower-rated variant at 27,000lbs thrust is expected to be about 12,500EFC. A similar interval may be achievable for the second removal interval.

If this is actually achieved, then the total time to the second removal will be close to 25,000EFC. This will match the life limits of LLPs. It would thus force a full engine disassembly and overhaul at the second SV, so the first workscope is likely to be a performance restoration.

An interval of about 10,000EFC is likely to be possible for the highest-rated variants at 33,000lbs, the PW1133G. If the second interval is similar then total time at the second SV will be about 20,000EFC. The SV workscope pattern will be similar for the PW1127G, but it is not clear if the engine can achieve these intervals.

PW1100G technical issues

The PW1100G has also been configured to achieve high levels of fuel efficiency. One feature is a high combustion temperature, which is related to some initial reliability issues and general hardware deterioration and early engine removals.

Overall, several reliability issues have affected the PW1100G in its initial period of service.

One issue has been the seal for the engine's number three bearing in the HP shaft, which has affected about 5% of the fleet. The seal in the bearing is wearing out too quickly, after about 300EFH. Several solutions and modifications have been introduced to deal with this problem, such as adding new seals and increasing oil flow.

The PW1100G has also had an issue affecting the combustion chamber. This resulted in 80 engine removals in 2018. This has been addressed by introducing an inspection every 1,000EFH. Later-build engines from 2020 will have a combustor made with thicker material, an improved coating, and improved swirler flow in the combustor. The new combustor will be installed as a replacement in SVs from 2020.

A third major issue affecting the PW1100G has been the deterioration of a knife edge seal in the HPC. The seal has been redesigned to achieve longer life up to 25,000EFC. The new seal will be manufactured from 2019.

A fourth major technical problem has been the failure of third-stage LPT blades. Original blades were produced with a titanium alloy, but replacements will be made with a nickel alloy, which is used to manufacture the stage one and two LPT blades. This alloy will, however, add 20lbs of weight to the engine, so a new stage three disk will have to be introduced.

A fifth problem has been high vibrations of the HP shaft and modules. This has affected a small percentage of aircraft at take-off. Tests are being conducted to find the cause of the issue.

A sixth problem is related to the constant drive auxiliary pump, which sends oil to the bearings during engine shutdown events and while the engine windmills. Debris has been found in the oil, and has been identified as coming from the pump. AC