PW4000-94 modification & upgrade programmes

The PW4000-94 has had several major upgrade & modification programmes. These are the Phase III programme, the more recent 'ring case' modification, and the withdrawal of a new HPT blade alloy. These improvements have led to a higher level of on-wing performance & reliability.

There have been several major modification and upgrade programmes and airworthiness directives (ADs) for the 94-inch fan Pratt & Whitney (PW) PW4000-94 engine series. The most significant of these has been an AD from the Federal Aviation Administration (FAA), addressing the take-off surge condition in the engine's high pressure compressor (HPC). Another prominent upgrade to the engine has been the Phase III modification.

Phase III programme

The PW4000-94 has two basic configurations: the earlier built Phase I engines, of which 1,100 were produced; and the Phase III modification and upgrade package, which was introduced in 1992 to address higher-than-expected fuel burn, and improve durability and on-wing times. This was aimed particularly at certain MD-11 operations that were having difficulty meeting range and performance targets, although it was subsequently adopted across the wider PW4000-94 fleet.

The physical changes to the engine comprise: new fan blades and fan rub strip; a new design HPC; casing, improved high pressure turbine (HPT) airfoils; gas path seals; a low loss burner, and upgraded low pressure turbine (LPT) materials and airfoils. The objective of this phase III standard was to improve fuel burn by 1.8% on the 747, and 2.8% on the Airbus and MDC applications. Phase III engines also have about 15 degrees higher EGT margins than Phase I engines. About 950 engines were converted to Phase III standard.

This standard also included a wider nacelle for engines powering Airbus and MDC aircraft. Exhaust gas temperature (EGT) margins vary between Phase I and Phase III engines. Phase III engines have brush seals, while the former have knife-edge seals. As an example, the Phase III powerplants of MD-11s have EGT margins about 40°C at 60,000lbs thrust and 29°C at 62,000lbs thrust. In contrast, non-modified engines at 60,000lbs thrust have an EGT margin of around 26°C, which is 14°C less than for the Phase III standard.

"There are still quite a few Phase I engines in operation," says Wayne Pedranti, engineering group program manager at UK-based Total Engine Support (TES). "It is a very costly modification to go from a Phase I to a Phase III. Most operators decided that it was not economically feasible to do so, preferring instead to intermix Phase I and Phase III engines on an airframe. But with that said, about 950 engines were converted."

"Internally, a Phase III standard PW4056 looks exactly like a Phase III PW4060," observes Pedranti. "The only difference involves the data-entry plug electronic engine control settings. To go from one model to another you have to show that your engine can meet the new thrust level. However, there are service bulletins (SBs) to be implemented for some older PW4056s, since these engines may otherwise have internal problems. Moreover, I believe that some operators are required to pay PW for the right to go to the higher thrust level. In fact, many operators use 'multi-thrust' ratings, testing all their engines at the highest PW4060 rating before deciding on which aircraft they will fly. They will fit the corresponding entry plug onto the electronic engine control (EEC) accordingly, to be able to run at that thrust level."

For the 747-400, Boeing offers a Phase III modification with noise reduction inlet. When combined with

The Phase III programme was initially introduced in 1992 to address performance shortfalls of some MD-11 operations. The Phase III modification was subsequently used on the whole PW4000-94 fleet. The main features of the modification were improved fuel burn performance and increased EGT margin. About 950 of 1,100 Phase I engines have been modified.

Part of the Phase III modification programme was the introduction of a new HPT stage 2 blade alloy. This was used to withstand the higher temperatures that Phase III engines run at. The unforseen problems with the new alloy, however, was internal sulphidation and external cracking. This blade material has been withdrawn and the original blade alloy is now used.

FB2C fan blades, the improved noise-reduction liner technology brings noise levels down by 5-8 EPNdB over the original PW4000 delivery configuration. Lead time for hardware is about two months.

2nd-stage HPT blade

The PW4000-94 has also suffered from well-publicised problems with some of the original second-stage (T2) HPT blades that were used in the engine. Two types of blade material were originally used in Phase III engines: PWA1480 and PWA1484. The material PWA1484 caused internal sulphidation of the blades, which then led to external cracks. The engine would have to be removed for a shop visit once these cracks were detected in a borescope inspection.

"PWA1484A is the new alloy for the T2 HPT blades that was used on Phase III engines. This has led to internal sulphidation and stress-corrosion-cracking, especially at the higher temperatures that the Phase III engines are supposed to be able to run at," explains Predranti. "Pratt & Whitney has now released SB72-716 to revert the T2 blade back to the original blade material, PWA1480, because this was used in the Phase I engines which did not have any internal sulphidation problems," says Pedranti. "SB 72-716 re-introduced the PWA1480 material (from which the Phase I blades were made) into the Phase III blade. This SB also modified the Phase I blade by adding a small scarf cut on the root and a new material on the blade tip. This was further enhanced by SB 72-763, which introduced a platinum-aluminide coating on the root. It is also desirable to look for engines that have the second-stage HPT nozzle guide vanes with the improved cooling, which were introduced by SB 72-780."

Pedranti advises that prospective operators of an engine will need to check whether the new SB 72-716, affecting the new second stage (T2) HPT blades, has been applied.

Ring case modification

The FAA's involvement stemmed from a large number of HPC surges at take-off suffered by the PW4000-94 during the 1990s. PW issued more than 100 SBs addressing this and other problems. Many were based on improvements designed for the larger and later variants of the engine.

In 1999, after double surge events on at least two aircraft, the FAA mandated a programme of inspections. PW also redesigned the HPC stator vanes with cutback trailing edges on the vanes at stages eight, 10, 12 and 13 to redistribute the airflow and increase the surge margin. Modified engines continued to experience surges, however, and in late 2000 the FAA prohibited further stator vane modifications and imposed a limit of one modified engine per airframe.

PW subsequently developed a new HPC case design for the engine. This was certified in November 2002 after 200 flight hours of tests on an ex-Air China 747SP acquired specifically to test engines that had failed in service. Based on the equivalent component designed for the PW4000-112, the new 'ring case' design comprises a series of one-piece rings that replace the original HPC case. The original comprised two to four segments around the circumference of the engine's HPC. This is known as the segmented compressor case (SCC), and refers to unmodified engines.

The problem had been the difference in the coefficients of expansion exhibited by the rotating stages and the casing. This resulted in an increased clearance between blade tips and casing shortly after the selection of take-off thrust. The new ring case more closely matches the expansion rate of the disc and provides more rigorous blade tip clearance control.

The new one-piece stator rings require the replacement and modification of both static and rotating HPC hardware. As well as reducing surge risk, the new ring case configuration (RCC) of modified engines improves engine reliability and operability, and should improve the HPC overhaul interval for increased time on-wing and lower operating cost. Additional predicted benefits are a 0.3% improvement in specific fuel consumption and a 3.2 degrees Centigrade improvement in EGT.

The installation of the new cases was mandated in FAA AD 2003-19-15. Pedranti points out that the instructions for performing the RCC modification can be found in the following SBs: 72-755 for Boeing-configured engines; 72-756 for Airbus-configured engines; and 72-757 for McDonnell-Douglas-configured engines. The main reason for this differentiation is to accommodate some external differences which are specific to each engine type. To this end, the applicable SBs must be undertaken at the same time as, or after, the listed RCC

The PW4000-94 series suffered problems with HPC stalls and surges for about 10 years. This was due to wide blade tip-casing clearances in the HPC's latter stages. This has been cured by the 'ring case' modification. With this in place, many operators expect the engine to be capable of removal intervals of 20,000EFH or longer.

modification. Incorporation of the appropriate RCC modification SB therefore constitutes the terminating action for the FAA AD 2003-19-15.

One provision of this AD is compliance date thresholds or deadlines for the number of SCC engines allowed on each aircraft type.

Since June 2006, SCC engines on the 767 must have the HPC inner-case rear hook modified in accordance with SB PW4ENG 72-714 or SB PW4ENG 72-749. Furthermore, only one SCC engine has been allowed on each aircraft.

The inner-case rear hook modification and single-SCC engine limit have applied to the A300, A310 and MD-11 since September 2006, and to the 747-400 since February 2007. After June 2009 only RCC engines will be allowed on all types.

AD 2003-19-15 has also revised the fleet management programme originally imposed by AD 99-17-16. AD 2003-19-15 identifies nine distinct engine configurations and specifies a variety of inspections and tests that engines must undergo prior to their RCC modification.

To reduce the likelihood of surges occurring to unmodified engines, operators were required to carry out a stability test on the HPC at 2,800 EFC after overhaul. In what is known as the 'fuel spike test' or 'Test 21', the engine has to be tested at take-off power in a test cell with the fuel supply cut, re-engaged and then surged back to take-off power. Failing this test forces a removal, in which case the engine is split at the HPC and the modification has to be performed.

Another element to this 'belt-and-braces' approach is to stagger engines on an aircraft, so that there are never two high-time engines on the same aircraft, especially on extended twin-engine operations (ETOPs) A300/A310s and 767s. This is to reduce the chances of a dual-engine surge.

Lufthansa Technik, which is the biggest independent engine overhauler dealing with the PW4000, carried out its first ring case modification in 2004. Robin Schmitz, product and engineering team manager for the engine at Lufthansa Technik, says that by the end of September 2006 the completion rate for the ring case modification on the engine had reached 77%. The active population was 2,169 from a total of 2,477 engines delivered, which means that there were still 477 engines remaining to be modified.

Schmitz expects that all the active engines will be converted by the cut-off date. The estimated cost of the work, including labour, transportation and the test run, is $650,000, and the PW material kit for the ring case costs $300,000.

The modification involves a complete overhaul of the HPC module, with the case being exchanged and the front case modified. The blades of stages 8 to 12 have their tips coated, there is a modification to the turbine vane and blade cooling air valves, and there are two wiring harness modifications and new full authority digital engine control (FADEC) software. Boeing engines also require new quick engine change brackets and tubes.

Schmitz says that the turnaround time for the ring case implementation is 48 calendar days. The work is normally carried out in combination with an overhaul of the complete engine, for which the target time is 60 days.

According to operators, the modified compressor is good for about 30,000EFH or 6,000EFC.

PW says that incorporation of the ring case modification in the PW4000-94 fleet has eliminated the potential for surges. The OEM adds that the confirmed surge rate for the engine has been decreasing steadily since the ring case configuration was released, and over the past year the 12-month rolling rate has reached 0.000 per 1,000EFH. In addition, the PW4000-94's shop visit rate has fallen to 0.076, the lowest in its history.

Other issues

There are several other issues affecting the PW4000-94.

One is an inspection for the spacer between the sixth and seventh HPC stages, as a result of vibrations on these stages. An SB has been issued to deal with this vibration, and it involves the addition of a blade to the fifth stage.

Another modification is an FAA-approved SB issued by Boeing, which provides the data needed to revise PW4056-rated engines to a PW4060 rating, with thrust bump to PW4060C. The SB provides the instructions necessary to revise the thrust management computer and engine indicating and crew alerting system (EICAS) pin selectable wiring.

In other upgrades and modifications, Schmitz says there are some reliability issues with the engine. One is the problem of oil leaking from the bearing, and LHT recommends the implementation of an SB to improve the seals of the forward bearing compartment and the number three bearing compartment.

Another is the HPT stage 2, where Lufthansa Technik recommends the new blade configuration and the new T2 stator vanes for the turbine. The oil leakages and turbine issues have been the principal factors limiting time on-wing.

Cracks are the main problem with the T2 vanes, and Lufthansa Technik has developed a weld repair that means they can still be repaired even if the cracks are beyond the limits specified in the engine manual. AC