The engine ship visit process comprises seven phases. Six relate to inspection, disassembly, reassembly and testing; which take 18-24 days. Piece-part repairs vary in length, and not all can be completed if the shop visit is to be completed in the usual time of about 60 days. This will require the exchange of some parts and modules.

The efficiency of the engine shop visit process

The engine shop-visit process is similar for narrowbody and widebody engines, and for most engine types. Besides small workscopes, all engine shop visits will include a hot section inspection or performance restoration, and therefore work on the engine's core modules. Larger workscopes will also include work on low pressure modules. Regardless of whether a shop visit includes work on core modules or the whole engine, the process can be broken down into several distinct phases. The shop-visit process can be improved and made more efficient, and each phase merits detailed scrutiny.

Shop-visit phases

The first phase is relatively simple, and involves the induction of the engine into the shop, and the initial inspection. It uses no more than two days, depending on whether the engine has a quick engine change (QEC) kit and accessories. "This phase may only require a single shift of about eight hours to complete," says Kieran Meier, front line leader PW4000 engine shop at SR Technics.

The pre-induction inspection includes a visual inspection of the engine, in particular the external accessories and line replaceable units (LRUs), and QEC kit. This is why the length of this phase depends on whether the shop has received a bare engine or one with all accessories and the QEC kit still attached. The engine has to be checked for missing items and any external damage or leaks.

In the second phase the engine is disassembled. "The engine is first split into modules, which takes about one day. Then the modules are disassembled into piece parts, which takes about two days," says Craig Richardson, sales, marketing and leasing director at Total Engine Support.

Disassembly of the engine into all the major modules is required if a performance restoration, or a full engine workscope are being performed. The fan, low pressure compressor (LPC) and low pressure turbine (LPT) all need to have a visual and internal inspection where possible, even if the planned workscope is just for the high pressure modules. If there are findings in the low pressure modules as a result of the inspection, some will be included in the workscope.

The disassembly starts with the removal of the QEC, accessories, LRUs and engine mounts. The LPT and fan can be removed first, with the HPT, HPC and combustor being removed last.

"The HPC vanes are some of the last parts to be released from the engine when it is being disassembled," says Stephan Drewes, vice president of engine overhaul at Lufthansa Technik. "They are also some of the first parts that are needed when rebuilding the engine, and so have the shortest available time for repairs to be performed."

Meier says the second phase needs six shifts for engine disassembly, and four shifts for module disassembly. "There is some overlap of the engine being disassembled into modules, and modules being disassembled into parts, so the first modules off the engine can be broken into parts while other modules are being separated," says Meier. "This means the full disassembly does not necessarily take a total of 10 shifts." Most engine shops have two shifts of eight hours each per day, and work five days per week.

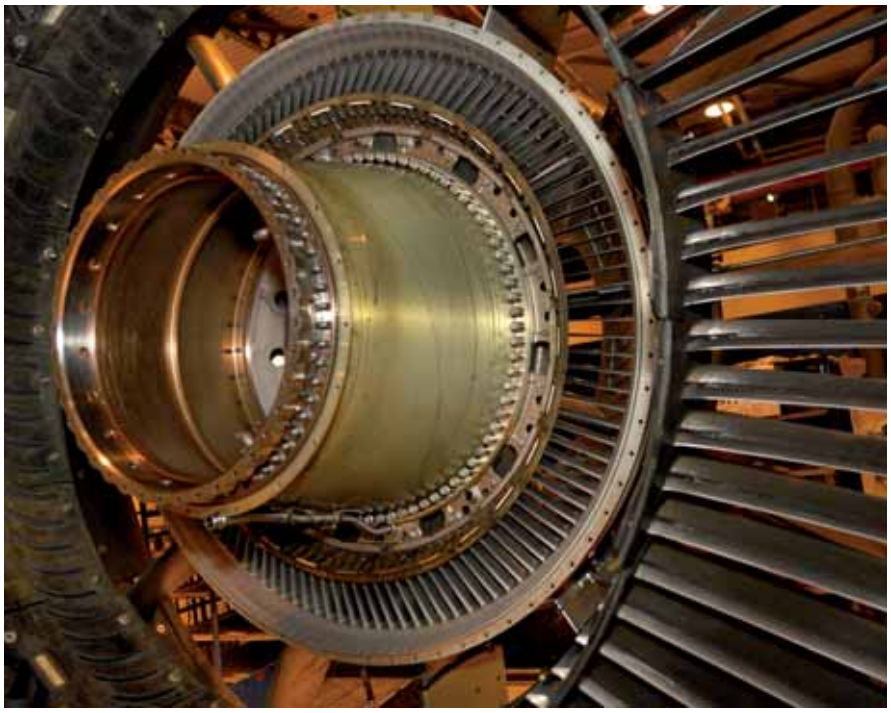
Drewes makes the point that time to complete phases and the shop visit has to be considered in terms of calendar days, rather than working days. "This takes into account some time for weekend breaks, which vary between shops. The time for a shop visit is also affected by the day the engine is inducted into the shop. The last day before the weekend break is a bad day to start an engine shop visit," says Drewes. "The incoming inspection and induction requires the equivalent of about a day, while the engine and module disassembly requires about 11 days."

The next two phases are the longest and the most variable, so they can have the biggest effect on engine shop-visit time and efficiency. "Once modules are disassembled, piece parts have to be inspected. This is the third phase of the shop visit," says Richardson. "Parts are sent in boxes to be cleaned and stripped of coatings prior to inspections. Some parts, which include the life limited parts (LLPs) of discs and shafts, as well as bolts and locking nuts, have non-destructive tests (NDT) performed. Others, which include blades and vanes, are sent straight for repair. Parts inspection should take about five days. This includes some of the NDT testing for some engine parts. This testing time is regarded as belonging to the following phase by some.

"It has to be appreciated that few shops do work on all modules and repairs on all parts in the engine types for which they have capability," continues Richardson. "The HPT blades, for example, require very high-tech repairs, and only a minority of shops and facilities have the capability. Engine shops will therefore always have to send some parts and even modules away to other facilities, which adds time for logistics and transport to the whole process."

Meier points out that the module disassembly and parts inspection phases can also overlap. LLPs, for example, have NDT inspections that can be performed in the engine shop in a relatively short time, and high-tech repairs for blades and vanes, which take longer to complete.

"Parts inspection should take about six shifts," says Meier. "The aim is to have a single piece flow. As soon as one



The re-assembly of modules will overlap with the completion of piece part repairs. The complication is that core modules have to be assembled prior to low pressure modules, and the repair of parts in core modules have some of the longest turn times.

part is inspected, repair starts."

The following phase of module and parts repair is the longest in the shop-visit process. "It is the most sensitive phase, so its management is very important," says Richardson. "There are many parts to consider in this phase, and the time needed to repair each type of part varies significantly, so those with longer repair times affect the length of the shop visit."

Estimates are that this phase can take 21-25 days, although Richardson says that some parts repairs can take up to 35 days, and even longer. Several issues affect the length of this phase. The most important is the need to reinstall all the original parts in the engine that have been removed and repaired. This means that if the engine owner or operator wants all the parts that are installed in the engine to be the same ones that were removed from it, the parts repair phase will take longer.

There is also a problem with parts being sent for repair, and having to be scrapped after failing an inspection or test, when they are almost through the repair process. "This clearly wastes and adds time. Costs can also spiral in this phase, because a lot of parts have to be replaced," says Richardson. "Shop-visit time can increase because of these failures, as parts may have to be sent for designated engineering representative (DER) repairs, which may need to be developed. This can take anything from a few hours to a few weeks."

The following phases are module and engine re-assembly. "These can overlap, since the HPC, combustor and HPT have to be re-assembled first. The fan, LPC and LPT modules can be re-assembled at a later time than the core modules being reassembled," says Drewes.

Richardson says module re-assembly, which includes adding the QEC, LRUs, accessories, and engine mounts on the outside of the engine, takes five to eight days, with the reassembly of modules taking another two to three days.

"Module and engine reassembly should take about 10 and 14 shifts respectively," says Meier, "with an overlap between the two of 8-12 days."

The final phase is the testing of the engine in the test cell, and the final outgoing inspection. This only takes a day, or up to three shifts. Drewes allows two days for engine test, but includes QEC and accessory build-up in this time.

Excluding the parts repair phase, Meier calculates that the total time for the six phases is 18-24 working days. Richardson points out that there is a weekend day to be added to every six working days, so the time in calendar days for the six phases can increase to 21-28 days. This can be as many as 24-30 calendar days if there are two weekend days for every five working days.

Christoph Zederer, senior manager production control at MTU Maintenance Hannover puts the total time for these six phases at 28-30 calendar days, but actual time depends on the type of engine.

"The issue is also blurred," says Drewes, "by the amount of overlap between phases. A lot of module re-assembly can start while parts are still being repaired, so it is hard to say how long each of these phases is. The start of the first module reassembly to the completion of engine re-assembly can be as long as 21 (working) days in the case of a CF6-80C2, but several parts repairs are still being completed during the early part of this 21-day period."

Once the time to complete parts repairs is added to the 18-22 working days for the other six phases, the shop visit can take 50-60 days.

Zederer says total turn times for large regional jet engines are 45-55 calendar days, 50-60 days for narrowbody engines, and 55-65 days for widebody engines.

The main issue affecting total time is whether or not repaired piece parts are exchanged. "A performance restoration on a CFM56-5B with parts exchange has a total time of about 45 days, while the same engine without parts exchange will take 55 days," says Meier. "The turn time for a PW4000 with parts exchange will be 55 days, and will rise to 62 calendar days without any parts exchange."

Richardson says that 65 days is typical for most engine types, and gives 25 spare days on the three-month engine lease term that covers the engine in the shop visit. "This spare period can be used by some airlines to remove and add the QEC and accessories at either end of shipping and receiving a spare engine."

Drewes estimates that the six phases take a total of 35 days, and parts repairs take another 21. "These two overlap, but the total will be 56-60 days for a CF6-80C2. In our experience the PW4000 is slightly longer at 65 days," says Drewes.

The total time clearly depends on the length of the parts-repair phase, which is determined by the operator's policy on parts replacement and other issues.

Bottlenecks

Numerous factors can affect the flow of work and length of an engine shop visit. The main causes of delay and inefficiency relate to parts repairs.

"Inspecting and repairing parts is inherently inefficient, because they are idle during this process. This results in dead time," says Meier.

Zederer also makes the point that the delivery performance of suppliers has a large effect on total turn time. "The MTU Maintenance group therefore aims to perform most piece-part repairs in-house whenever it is economically possible, since it saves transport and logistics time to outside shops while also avoiding potential delivery delays."

The flow of modules through the shop-visit process will also influence total shop-visit time. "A constant flow of

modules so that they are ready at the right time eliminates delays. This is important because delays with individual parts can delay the whole shop-visit," says Drewes. "Core modules are needed first when reassembly starts, so this means the time available for parts from these modules to be repaired is less than those from other modules. It is possible to shorten engine and module disassembly by up to three days, and to shorten their reassembly by the same amount of time if module availability is carefully planned."

A correct flow of modules will be influenced by several important factors: the time to repair parts; whether parts are reinstalled in the same engines they were taken from, or exchanged; and if modules are re-assembled in the same engine they were taken from, or exchanged.

"Module and parts repair phases are the two most variable and sensitive with respect to total time. The core modules of the HPC, HPT and combustor generally have the longest turn times and are the most variable," says Richardson. "The total time on the HPT can be as long as 45 days, including reassembly, because repairs of the middle parts can take 20-35 days, depending on their condition. The LPT also has a long repair time because of the effect on it of high temperatures.

"Installing the same parts back in the original engine is one of the biggest influences on the length of a shop visit," continues Richardson. "Most operators want the same blades and vanes back in the same engine. Mixing parts between engines is possible, but it is difficult because the maintenance condition of HPT blades, for example, has to match that of the rest of the engine."

While some operators are concerned about reinstalling original parts, and its effect on subsequent engine performance, others will accept the practice. John McKirdy, regional sales director Americas at Chromalloy, says that if the shop visit workscope is a complete re-build, then parts can be swapped between engines without much effect on their subsequent performance. "There is usually very little effect of swapping out sets of HPT blades, nozzle guide vanes (NGVs), and HPC blades," says McKirdy, "provided that the sets of parts being swapped between engines have the same coatings, service bulletin (SB) status, part numbers, and part dimensions and clearances. We have parts inventories that allow sets of parts to be exchanged between engines at different stages of a shop visit."

Meier agrees. "Installing repaired parts taken from one engine into another, or exchanging parts between engines, does shorten the total shop-visit time, and generally does not affect subsequent engine performance. Customers still want their own parts installed back in their engines, but parts removed from the first engine in a shop can be reinstalled in the second after they have been repaired."

Most engine shops do not have the capability to perform hi-tech repairs on all piece-parts, so they sub-contract repairs to specialist providers. Sending parts away can add 10 days to the total time for their repair. HPT blades, for example, can have a total repair time of 45 days, including 10 days for transport, packing and logistics. Few engine shops have the capability for HPT blade repairs, so most will be sub-contracted to other shops. This will clearly extend the time for the HPT, as well as the complete shop visit. If parts are not exchanged between engines, the shop visit will be lengthened, unless all parts are scrapped. This is unlikely, however, because of the cost of replacing HPT blades.

"We exchange HPT blades and vanes between engines to reduce turn time, but this requires the engine shop to have a steady flow of engines from the same customer," says Meier. "We have our own internal parts repairs centre, which has signed a contract for a 21-day parts-repair turn time with us. We only send some piece-part repairs to sub-contractors."

Another reason why parts repairs are a cause of inefficiency is because they can

be unpredictable. "Parts can be up to 90% of the way through their repair when there are findings or the parts fail their repair and have to be scrapped," explains Richardson. "They then have to be replaced, all of which wastes and adds time, especially if a part is a long way through a repair when an unexpected or unknown failure occurs. The shop then needs to develop a DER repair, which can take up to three weeks."

Exchanging modules between engines is also an issue. Some modules have long cycle times for disassembly, parts repairs and re-assembly. Some operators accept the practice of modules being swapped between their engines while in the shop. "This sounds OK theoretically, and is not as much of a problem for engine performance as it used to be," says Richardson. "It is difficult in practice, however, because the LLPs in modules from one engine have to match those of the next engine in the shop production line if subsequent on-wing removal intervals are not to be compromised."

Drewes highlights that is inadvisable to mix modules if the operator wants to retain a stable exhaust gas temperature (EGT) margin across a batch of engines.

"Another issue is that not all shops have the capability for all of the modules for all of the engine types they provide services for. Sub-contracting module repairs to other shops adds 8-10 days for transport and logistics," adds Drewes. "Every shop is therefore bound to have these delays built into their total engine turn time. This will probably necessitate the exchange of parts and modules."

The shop-visit process takes longer if module repairs are sub-contracted to other shops. This can increase the turn time by at least 10-20 calendar days.

Piece-part repairs

Each module has piece-part repairs with long turn times. "Laser beam welding and patch repairs of solid fan blades have a long turn time, and can add up to 45 days," says Meier.

The HPC's blades and cases have some of the longest turn times. A normal repair on an HPC case and blades takes 21 days, but if the chord width has to be restored, this can add up to 45 days."

Several repairs in the hot section have long turn times. "Replacement of the aft section of the combustion chamber takes about 25 days," says Drewes.

The HPT has several parts with long turn times. These include weld and braze repairs of HPT blades, which includes applying new coatings. HPT blade repairs have a repair time of 35 days, which increases to 45 days when transport and logistics time is added.

"Replacing an airfoil on an NGV section of two vanes takes 30 days," says Drewes. "It is possible to reduce this time in some cases so that the same parts can be installed back in the same engine."

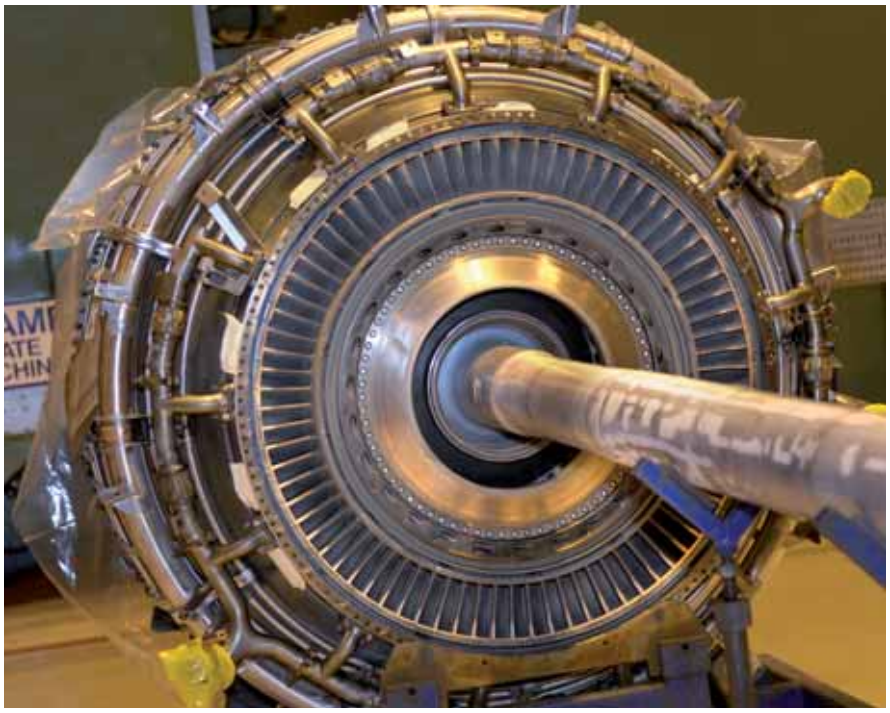
Meier adds that with respect to NGVs, the coatings and gap brazing repairs have a turn time of 45 days.

Repairs to cases and case flanges take a long time. "The flange replacement on a case can take up to 60 days," says Drewes. "This repair is necessary because new cases can cost up to $500,000."

These repair turn times are typical, but individual repairs can take longer and cause further delays. "One example is the repair of the HPT disk on the RB211-535E4," says Joanne Robb, manager material repair at Total Engine Support. "This part has 11 seal fins, and each has to be inspected and welded. There have been times where the repair took 90 days instead of the 35 quoted in the catalogue. An HPC spool can also be problem, as can any spool where discs have to be split for crack detection, repair and rebuild, because NDT inspections are used, which have lead times and also carry the risk of scrap."

The time to complete major repairs can be further increased by findings, the need for DER repairs, and scrappage. "Piece-part repairs risk delay and scrappage, but they have the potential to make large savings versus the cost of new parts," says Robb. "The other option is to exchange parts: removing the material; repairing it outside of the engine shop-visit time limitation; and putting it into customer-owned stock so that it is ready for the next shop visit."

While exchange of piece parts clearly saves time in the parts repair phase, it



It will often be necessary to exchange modules for engine shop visits to be completed within the usual 55-65 day turn time. Exchanging modules requires careful management, since the maintenance status and remaining LLP lives of modules being combined should be similar to avoid compromising subsequent maintenance costs.

also adds to inventory and shop-visit cost. "The turn time for a shop visit can be reduced by as many as 30 calendar days by using adequate exchange material on those parts that have time-consuming repairs. Our experience, however, is that customers focus more on stable or promised on-time delivery, rather than shorter turn times," says Zederer. "On-time delivery is key to maintaining customer satisfaction."

Pre-defining workscopes

Managing engines so that as much maintenance as possible can be planned in advance helps to accurately estimate the shop-visit turn time. The aim is to establish a shop-visit workscope pattern for each engine type based on how it is operated, its rate of performance loss, and its LLP lives.

"An engine's incoming borescope inspection and engine health monitoring data and engine fleet data are all used to help define the workscope," says Meier. This will have data on: EGT margin; vibration of each bearing and rotor; and fuel consumption. The data and other observations should be used to determine the workscope required on each module.

Experience gained of previous shop visits, findings, scrap rates and LLP lives should be used to establish engine shop-visit patterns. The size of the planned or scheduled workscope has little effect on the turn time. "A hot section inspection or performance restoration will take 45-55 days for a large regional jet engine, 50-60 days for a narrowbody engine, and 55-65 days for a widebody engine. The actual turn is related to the workscopes," says Zederer. "Adding the fan, LPC and LPT to the core modules in a complete engine shop visit does not change the turn time, because the work that is critical to the turn time is in the core modules. The HPT and HPC have the longest turn time of all engine modules."

Drewes adds that establishing workscopes can provide accurate estimates of shop visit turn times if only routine maintenance is involved, but the first stage in the engine manual after the engine and modules have been disassembled is to inspect piece parts. There can be findings at this stage, so the planned workscope can escalate.

Unscheduled removals and shop visits are also an issue. "If an engine is removed for an unscheduled visit, for example due to an oil leak, it is advisable to do a pre-strip or pre-disassembly test cell run, to detect vibrations and other parameters that are not monitored on-wing" says Richardson. "Some of these parameters might affect the workscope because they are out of engine manual limits."

Production systems

The traditional system used by many shops was to leave an engine in a stand while it underwent its visual inspection and disassembly into modules and then piece parts. This system meant an engine shop required a lot of space for engine stands on the disassembly and assembly lines.

MTU Maintenance Hannover and Lufthansa Technik have introduced a moving production line system.

MTU Maintenance Hannover developed a 'rolling carpet' system, whereby the disassembly and assembly lines are made of concrete pads, each one of which is a space for an engine. A newly inducted engine is placed on the first pad, and the pads move forward along the production line as they progress through the inspection and disassembly process. When the disassembly process is complete, and all parts are sent to their various inspection and testing areas, the concrete pad becomes free. It moves back to the start of the production line by sliding beneath the other pads. A similar system is used for engine reassembly prior to completion for testing. The whole process is coordinated and timed so that concrete pads move along the production line at set intervals. All other processes must be completed within these intervals so that the shop visit can maintain a carefully planned schedule.

Lufthansa Technik introduced a similar system, but instead of using a rolling carpet system with concrete pads in the floor, it moves engines overhead by using lifting wires and cranes suspended from the shop floor ceiling. Both systems are designed to save shop floor space and reduce total turn time.

Summary

The six shop visit phases that precede and follow the process of piece-part repairs total 18-24 calendar days. If a shop visit is to be completed within a 60 day turn time, there is a limit of up to about 40 days to complete piece-part repairs. Clearly not all repairs can be completed in this time, and this necessitates the use of exchanged parts. Richardson says the priority in most cases is to complete the shop visit within 60 days and exchange parts, rather than rebuild an engine with all original parts and accept a longer turn time. "Parts that have the longest repair turn time will be removed from the engine as fast as possible and sent for repair," says Richardson. "Fan blades, which have long repair times can be removed quickly, but there are inevitably parts which cannot be repaired fast enough to make a 55-65 day total shop visit time. Exchanging parts is complicated by airlines not accepting other airlines' parts, and policies with respect to the number of times parts like HPT blades are repaired." AC