The development of several thousand repairs for different engine parts has brought large savings in engine maintenance costs. Repairs cost a fraction of new parts, and parts can be repaired several times. The types of repairs that exist and their full consequences are studied.

The economics of repairing engine parts

The development of repairs for engine parts has contributed significantly to the reduction of overall engine maintenance costs in terms of $ per engine flight hour (EFH). Manufacturers, specialist repair agencies and airline technical departments have developed hundreds of repairs for each major engine type, leading to a large fall in the number of parts replaced at each shop visit.

Engine maintenance process

Engine maintenance management has had the objective of extending on-wing life and shop visit intervals and achieving lower cost per EFH, which has led to increased engine deterioration. This accelerates after a certain time on-wing, with the result that shop visit workscopes, especially for parts replacement and repair, are increased and raises the cost of the shop visit. The shop visit cost is so severely raised that it is not compensated for by the longer removal interval and so $/EFH increases overall.

Similar amounts of routine labour are used in shop visit workscopes following short or long on-wing intervals. Total shop visit cost after a short interval will be low because few parts require repairs or replacing, but cost per EFH will again be relatively high.

Airlines and engine maintenance providers strive to find a balance between shop visit cost and interval, and where the lowest cost per EFH will be found in relation to shop visit interval. This requires an accurate estimation of shop visit cost for a given workscope following a given on-wing interval. The interval at which lowest cost per EFH is reduced can be increased with further development of parts repairs, since repairs cost a fraction of the price of new parts. The shop visit workscope and cost will also influence the next removal interval and subsequent shop visit workscope and its cost.

The engine shop visit process starts with engine disassembly and inspection of parts. Parts are assessed in terms of needing to be replaced, being repairable or not needing repair. Blades or vanes on the same stage or disk deteriorate at varying rates, so that at removal they are in varying degrees of condition and need of repair or replacement. That is, at the first shop visit a small percentage of blades on the first stage high pressure turbine (HPT) disk will require replacing. Another portion can be repaired and a relatively small portion can be left. At the second shop visit the largest portion of first stage HPT blades will require replacement and at the third shop visit the final portion of original blades will be replaced.

The number of blades replaced at each shop visit will form a distribution curve. The aim of repairs is to shift this curve to the right, so that smaller portions of blades are replaced at first and second shop visits, while the portion of blades that is repaired at first and second shop visits is increased.

Repaired parts tend to result in shorter subsequent on-wing life compared to engines with new parts. The reduction in cost of a shop visit is large in relation to the shorter removal interval, however, and overall costs per EFH are lower. Quality of repairs must be high, however, since poor ones will result in short intervals. The quality of repairs and their effect on the rest of engine performance also has to be considered.

"The two major objectives of parts repair development are to maintain or extend on-wing life and reduce the shop cost at the same time, with the overall objective of reducing airlines' cost of ownership," explains Kim Keenan, senior vice president of commercial engines and aftermarket operations at Pratt & Whitney Engine Services. "This is achieved by developing repairs for parts which have similar performance to new parts."

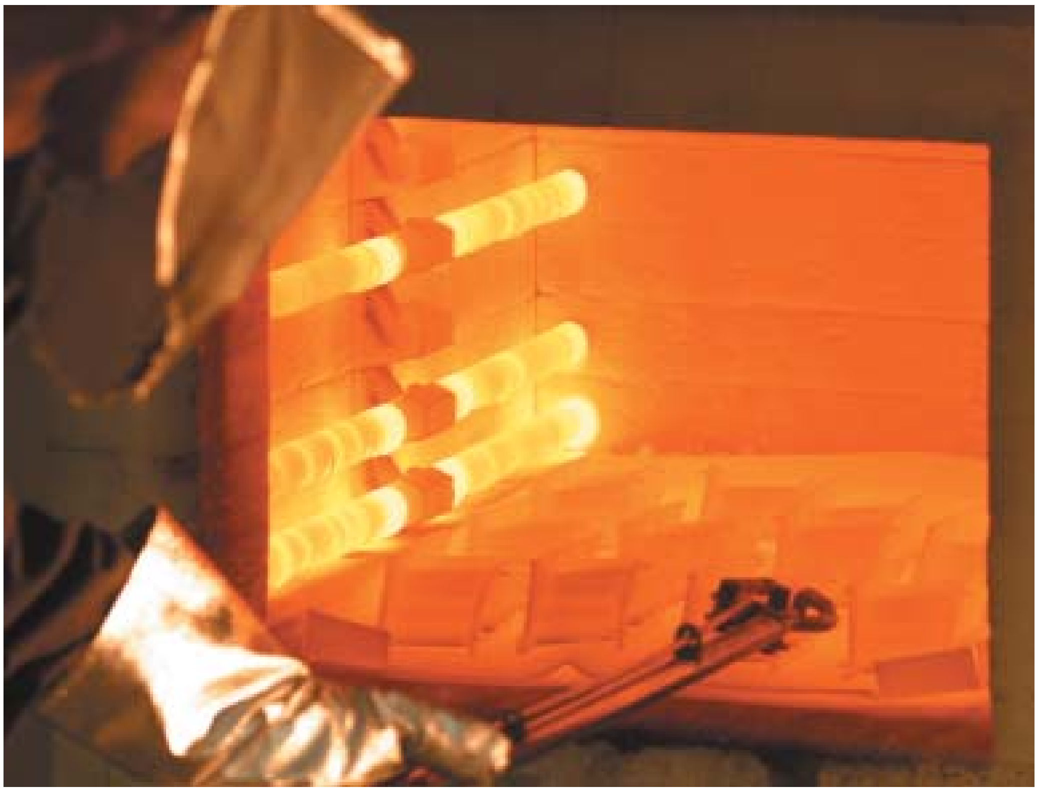
Major repair types

The majority of repairs have been developed for airfoils (blades and vanes) since these have the largest economic impact. "As an engine fleet ages it is possible to analyse major maintenance cost drivers, and what repairs are worth developing to have the biggest impact on cost," says Russ Shelton, general manager of maintenance repair and overhaul marketing at General Electric aircraft engines. "We developed 500 new repairs in 2002 alone, and develop several hundred each year. Examples are repairs to blades, nozzles, compressor blades and combustion chambers."

Airfoils have received the most attention in repair development, although there are also repairs for combustors and engine cases. While repairs are available for life limited parts, life extensions are not permitted.

"The high-cost parts are the drivers in repair development," explains Simon Mermod, engine programme manager at Total Engine Support. "The hot section parts have the fastest deterioration, since they are most affected by burning and oxidising. HPC parts also suffer deterioration, especially in the latter stages which experience high pressures and temperatures. These suffer a high rate of erosion, and the HPC loses performance."

"Repairs are first considered during design, since they are a key factor in engine maintenance costs during the lifetime," explains Jean-Luc Doublet, vice president industrial operations at Snecma Services. "Factors such as the geometry of blades and their cooling holes are considered. The first shop visits for a new engine type now do not occur until up to



The objective of engine parts repairs is to reduce maintenance costs in the long-term. The parts which receive the most repair development are in the engine's hot section. Repairs are now developed so that parts can be repaired twice, making significant cost savings.

five years after entry into service, and so repairs are developed during this time.

"These are more likely to be repairs which allow a restoration of engine performance, since this will be the prime objective of the first shop visit," explains Doublet. "One example is high pressure compressor (HPC) blade tip repairs. The rubbing of the blade tips affects engine efficiency, since EGT margin is eroded. The aim is to recondition the blades and the abradable lining on the inner wall of the compressor case where the blade tips rub. Other examples are the laser welding of blades."

Repairs fit into four categories: repairs to generate cost savings; advanced repairs to extend the life of parts; repairs to improve the performance of engine efficiency; and repairs to prevent the scrapping of parts.

"The cost of a typical engine shop visit will be about 15% for disassembly, reassembly and test, 20-30% for parts repair and 50-60% for new parts and materials," explains Thilo Seitz, manager repair development engine parts at Lufthansa Technik. "The first question that has to be asked is what is the benefit of the repair, and so which of the four categories it fits into. Repairs have to be good enough to ensure a safe and reliable engine operation and therefore get a satisfactory shop visit interval and so $/EFH. About every $1 spent on repairs saves about $5 on new parts. Most parts that are repaired are airfoils, which are the most expensive. Repair costs should also be considered against the cost of used parts on the surplus market and new ones available from parts manufacturer approval (PMA) parts or from the original parts manufacturer."

Lufthansa Technik has developed hundreds of repairs for the engine types it handles. "There have been many service bulletins (SBs) for the V.2500 combustion chamber, which were very costly but made no real reduction in operation cost of the engine. IAE presently does not offer repairs for the high cost items of the combustion chamber like the segments or the fuel nozzle guides. Several SBs had been issued up to now, but no significant reduction in operator cost had been recorded up to now. Still now, a high amount of above mentioned parts must be scrapped after flight exposure. Therefore, we developed our own repairs, which will prevent high scrap cost and unscheduled removals," says Seitz. "Other examples are a repair to the V.2500's fuel nozzle guides; a new one costing about $1,200 and the repair costing less than half this. There are 20 units in each engine, so the repair saves about $12,000 in the shop visit cost. We have also developed 20-30 additional repairs to the shop manual for the CFM56 combustion chamber, and these can improve total EGT margin by up to 19 degrees centigrade compared to what is possible using repairs in the shop manual exclusively."

Another example of Lufthansa Technik's engine repairs is the platform on the PW4000's high pressure turbine (HPT) vane. "This was oxidising, and meant each part had to be replaced at cost of about $8,600," says Seitz. "We developed a welding repair to replace the platform, which cost less than 50% for a new part, saving thousands of dollars per engine."

Other examples of parts repairs include plasma repairs to the tips of blades to restore their length. This is an advance on welding repairs to blade tips, which added material that then had to be ground away again to get exact measurement. Plasma spraying is more accurate, quicker and so cheaper. It also does not require heat treatment, meaning there is no limit to the number of times repairs can be made.

"The parts with the biggest difference between repair and replacement cost are those most worth developing repairs for," says Shelton. "This not only includes airfoils, but also cases and frames and nozzles. These all have specific engineering requirements."

Some repairs can generate large savings. Mermod gives the example of re-blading HPT nozzles in the CFM56. "The blades can be badly oxidised, so they are cut away from the platforms and the sections then refoiled. The cost to do the whole section is $60,000-80,000, which compares to a list price of about $450,000 for a new section. The repair is also made with a new material standard that lasts longer on-wing, which is a bonus."

It is generally accepted that most parts can be repaired twice, and scrapped at the third removal. The cost of the second repair is higher than the first, but repairs still save the purchase of new parts in two out of three shop visits. As an example, a new part may cost $10,000 while first repair costs about $1,500 and second repair costs $3,000. The total cost over three shop visits is therefore $14,500 compared to $30,000 for the replacement of parts at every shop visit.

One consideration is the time for repairs to be developed, and also the third element of using PMA parts as an alternative to repairing parts or using new ones from manufacturers. "Repairs take some time to be developed for new engines, since manufacturers can change parts quite frequently when engines are in their first year of operation. Repairs are not worth developing if the manufacturers are likely to bring out more durable parts," explains Mermod. "PMA parts also take some time to become available, because they are generally available for mature engines."

The cost of repairing parts is 20-60% of the purchasing it new from the manufacturer. Some repairs also incorporate new materials which then result in longer on-wing lives than the original parts were capable of.

Consequent effects of repairs

Repairs cannot be considered in isolation. Although efforts are made to develop a high standard of repairs, repaired parts will not have the same performance as new parts. "It is true that repaired parts, such as the chord width of repaired HPC blades, do not have the same efficiency as new parts," says Doublet.

Shelton explains that poor compressor blade repairs cause a penalty in specific fuel consumption because of eroded chord width. "We developed a repair to restore the original chord width, with the effects of improved on-wing life," says Shelton. "The first objective is to reduce the cost of a shop visit with parts repairs, and this is relatively easy. Expensive repairs can be developed and they improve shop visit interval, but can increase cost per EFH. It is also false economy to develop cheap repairs because they cause short on-wing intervals. Repairs should be developed which avoid unintentional consequences. A disruption to cooling flows in the turbine is one example. Other examples are thick coatings on turbine blades adding to weight and affecting disk life. The effects of repairs on the rest of the engine are hard to predict, however, and parts repair development requires excellent technical know-how" says Shelton.

The performance of repaired parts must be considered in relation to its effect on the rest of the engine further downstream in the gas path. Repaired HPC blades, for example, may not have the same length and chord width as new parts, allowing air to escape around the tip and generating poorer compression. This results in a higher engine speed being needed to generate the same thrust. The effects of this are to increase turbine inlet temperature and reduce EGT margin, shortening on-wing life. It may also increase specific fuel consumption. The following on-wing interval is not as long as it would be with replaced parts, but the first shop visit is expected to restore 70% of the original EGT margin.

The effect of quality of, or need for, repairs therefore has to be considered for other parts further down the gas path. These considerations derive the parameters for parts repair quality and necessitate high quality repairs. That is, a severe reduction in engine performance will result in high costs per EFH, and would make replacement more economic than repair. "The objective should be for quality of repairs to provide a situation at which repaired parts still produce shorter on-wing intervals but overall lower costs per EFH," says Doublet.

Repairs also carry risks. "In addition to on-wing life being reduced, repaired parts can also deteriorate faster than parts in other sections, bringing about earlier than expected removals, or even fail causing unscheduled removals," explains Seitz. "New repairs are developed with an estimate of how long the parts will last on-wing. Lufthansa Technik has achieved on average 20% longer on-wing times than our competitors due to the quality of our parts repairs."

Jim Sheard, director of marketing business development in repair and overhaul at Rolls-Royce explains the paradox of developing a large number of repairs: "The problem with the unpredictable performance of repaired parts is that the more repairs that are developed for parts the harder it is for engine maintenance facilities to maintain an acceptable shop visit interval."

On-wing interval can be improved, however, if the repair reduces the normal rate of deterioration. "The degree of improvement is more marked if the engine is operating in an extreme environment," explains Mermod. "Engines in the Mediterranean lose most of their EGT margin in the first six months after a shop visit and then operate on a very thin margin for several years. The HPT material then eventually breaks up. Building a better quality material means a significant improvement in the material, and so a reduced rate of deterioration. In contrast, engines operating at low thrust ratings and cool environments deteriorate at a much lower rate and can stay on-wing for the whole LLP limit. Overall, repairs that use material upgrades can last longer than the original parts, while repairs using no upgrades will not last as long as new parts."

Economics of parts repair

Mermod explains that there are two aspects to parts repairs. "The first is a saving that repairs make compared to new parts, and the second is the possibility of extended on-wing lives with repairs that use high-specification materials."

The cost of repairs is generally less than half the manufacturer's list price. "The cost of repairs varies between 20% and 60% of list price, and the target is for them to perform as well as new parts," says Keenan. "We have developed more than 3,000 repairs for parts in the PW4000 family since its introduction into service about 20 years ago, and estimate that if we had not done so then the cost of a typical shop visit would be more than 50% higher than is today."

The first issue is the improvement in engine economics because parts repairs depend on how many shop intervals a part will last for following repair. "We have found that applying a thermal barrier to HPT blades increased their life by one shop visit interval. Other parts can get an additional two or three shop visit intervals as a result of repairs. That is, some parts can only be repaired once,

By analysing a hypothetical situation of comparing the shop visit costs of an engine receiving all-new parts and another having its parts repaired, it is estimated an engine receiving new parts would have only a 10% longer on-wing interval but a shop visit cost about three times higher than an engine using repaired parts.

while others can be repaired two or three times," says Shelton.

The distribution of scrapped and repaired parts at each shop visit has to be considered. "For example, some parts have a 5% scrap rate at the first shop visit, a 10% scrap rate at the second shop visit and an 85% scrap rate at the third," says Shelton. This means that after the first shop visit there is a continuous mix of blades that have not been repaired, while at the last shop visit there are repaired blades and replaced blades. "The target is to reduce the scrap rates and increase repair rates at each shop visit."

Doublet gives examples of the cost and economics of repairs. "The segment of a nozzle guide vane (NGV) on a CFM56-3 costs about $1,000 to repair and there are 22 segments in each engine. The price of a new part costs about $15,000, and thus if each segment were prevented from being scrapped by repair at a shop visit, a saving of more than $300,000 would be made." Another example is the re-blading of NGVs, which costs about $5,000 and compares to $15,000 for a new part, again generating large savings.

Seitz gives an example of how the development of a new type of repair can reduce scrap rate and shop visit costs by reducing parts replacement. "There are 28 second stage high pressure turbine shrouds on the inside case of the CF6-80C2's turbine. These shrouds crack, and on average nine of the units have to be scrapped, because according to the manual they are considered not to be repairable. Two of these nine shrouds may have features or damages which will not allow a special repair, but seven will have cracks longer than one inch. The shop manual allowed only cracks less than one inch to be repaired using welding, so we decided to weld the other parts as well with approval from the Federal Aviation Authority. The price of this repair is about $330 compared to $2,150 for a new part. The saving for one repaired part is thus about $1,850, and so if all seven parts can be saved a saving of about $12,500 is possible."

Another of Lufthansa Technik's repairs is the previously described PW HPT vane platform repair. Lufthansa Technik developed this repair by making a developed cast which can be welded to the vane to replace the oxidised platform. A new HPT vane has a list price of about $8,500, while Lufthansa Technik's repair costs about $3,500. "Parts are good for three to four removal intervals, but then have to be scrapped due to wall thickness approaching minimum levels. If a part is burnt, but has only been exposed once or twice to an engine run the repair makes economic sense," explains Seitz. "The repair cost of $3,500 allows an additional two or three runs. If the part has had three or four runs, it can be repaired but has fewer runs available. A new part is more expensive, but then has three or four runs available."

TES's Mermod gives a clear example of how a complete engine can be affected by the difference between new and repaired parts. "We had two engines at the same points in their repair cycles, at the second shop visit, and similar times on-wing when one was removed due to foreign object damage. Otherwise the two engines had similar shop visit workscopes. The damaged engine had new blades and vanes, while the airfoils on the undamaged engine were repaired," explains Mermod. "There was a difference in EGT margin of about 10 degrees centigrade between the two, and this was equivalent to about a 2,000EFH longer on-wing interval for the engine with new parts installed. This gave the opportunity for a comparison of new versus repaired parts, because normally 100% installation of new parts would not be considered. Some airlines operating in a cold climate, would, however, consider installing a high incidence of new parts in order to achieve on-wing runs that go to LLP limits."

Mermod adds that an artificial example of two engines receiving new or repaired parts at the same stage in their repair cycles can be made. This is done using a later CFM56 variant. "The assumptions are that the engines are operated the same way up to their second shop visit. Average FC time is 3FH, and the interval to the identical first shop visit, a performance restoration, is 11,000FC/33,000FH. The subsequent on-wing interval is 8,250FC which is followed by an overhaul. At this stage one engine could have new parts fitted, while the majority of parts would be repaired on the other," says Mermod. "The cost of new materials would be in the region of $3.25 million, while cost of parts repairs and replacement of a minority of parts in the second engine would be about $0.49 million. The remaining shop costs, mainly for labour and materials, would be about $1.05 million for either engine. Although LLPs would need to be replaced at this shop visit, their cost is not considered here.

These parameters take the total shop visit cost to about $4.3 million for the engine with new parts installed, and to $1.54 million for the one with repaired parts."

Mermod explains there would only be about a 10% difference in the subsequent on-wing life of the two engines following this shop visit. "The engine with new parts would achieve about 33,000EFH on-wing, while the one with repaired parts would have a shorter run in the region of 30,000EFH," predicts Mermod. "The shop visit cost amortised over the subsequent on-wing life would thus be about $130/EFH for the engine with new parts installed, while the engine with repaired parts would have a rate of about $51/EFH. This demonstrates a clear difference in cost per EFH, made possible by parts repairs." AC

