**The JT9D is one of the most widely used civil turbofans. Its continuing importance makes an examination of its maintenance requirements and costs per flight hour a compelling issue.**

# JT9D maintenance costs examination

The JT9D powerplant will be in operation for up to another two decades, serving a broad market. There are about 2,700 JT9Ds still in service which generate about 1,100 shop visits per year.

The diversity of the JT9D and its increasing numbers in the secondary and leasing markets makes a study of its maintenance requirements and costs per engine flight hour (EFH) an important issue.

## Economics

Costs per EFH are basically influenced by the frequency of shop visits (SVR – the shop visit rate is expressed as the number of visits per 1000 EFH), the workscope of each shop visit, shop visit pattern and the manhours and materials used in each shop visit. That is, the cost of shop visits is amortised over the EFH interval between visits. An additional cost is the provisioning of engines while the shop visits are being performed.

Costs per EFH therefore have to be studied by analysing SVRs, workscopes and workscope patterns and the material consumption of shop visit workscopes.

## Application

There are basically three generations of JT9D. The first is the basic -7 series which includes the -7A, -7F and -7J. These all power the 747-100 and -200.

The second generation consists of the -7Q, -59A and -70A which power the highest gross weight 747-200s, A300s and DC-10-40s.

The third generation is the -7R4 series which power the 747-300s and early 767s, A300-600s and A310s.

The basic differences between these generations is thrust rating and technology.

## Fleet reliability

The broad application of JT9D variants results in a wide range of average flight cycle times and a commensurate variation of SVRs and time on-wing between removals. There are 2,700 active engine in the global fleet. These generate just under 1,100 annual shop visits.

The first generation -7A, -7F and -7J 747-100 and -200 engines have an average cycle time close to five hours. There is a large deviation from the average even within this group since 747s are used in Japan on short domestic routes yet also operated by carriers such as Virgin Atlantic on seven to nine hour sectors. This group of engines has a total SVR of 0.198 (one visit every 5,050 EFH). There are just under 1,400 first generation engines in use. These account for about 500 annual shop visits.

The second generation -7Q, -59A and -70A engines also fly a wide variance of cycle times. The -59As on A300s have an average cycle time of two hours while the DC-10-40s powered by the -59A and operated by Japan Airlines (JAL) have a slightly longer cycle time of 2.5 hours. The -59A on the A300 has an average SVR of 0.344 (one visit every 2,900 EFH) and an on-wing time of 5,800 EFH on the DC-10. The -59A on the A300 and DC-10-40 generate less than 100 shop visits annually. The -70A on Northwest's DC-10-40s and 747-200s has a similar time between shop visits to the -59A. The -70A and -7Q are operated in large numbers and produce about 200 shop visits per year.

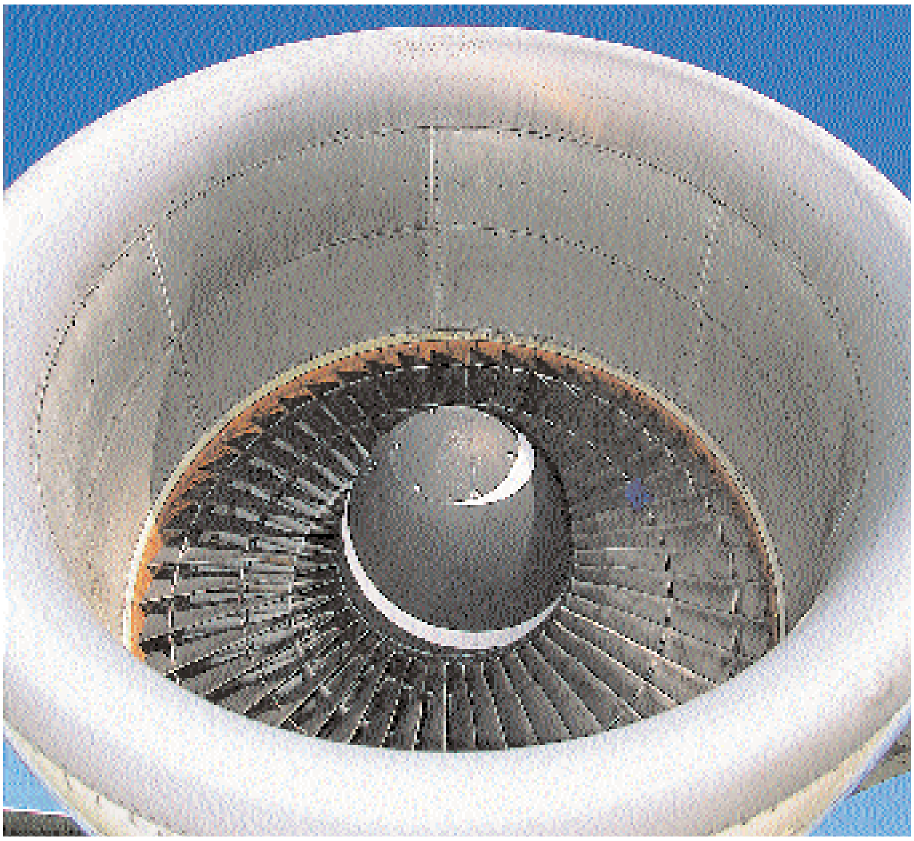
The variance in SVRs and cycle times on the -7R4 powered aircraft is just as wide as first and second generation engines. The -7R4G2 (747-300) has an average cycle time of 5.5 hours and is used by Sabena, Swissair, Singapore Airlines, South African Airways and JAL. Its SVR of 0.136 is the lowest of all JT9Ds and is equal to 7,400 flight hours. The flight cycle time for the twin engine -7R4 is 2.5 hours and has a SVR of 0.217 (4,600 EFH).

There are operators such as Saudia which uses the -7R4 on the A300-600. Saudia has an average cycle time of just 1.67 hours. Saudia's hot operating environment means the SVR is relatively high at 0.326, or 3,067 hours between shop visits. There are about 150 -7R4G2 shop visits per year for the 747-300 and another 170 for -7R4s on twin-engine aircraft.

## Shop visit pattern

Generally the pattern of shop visit workscopes will depend on the rate of deterioration in the different modules and on the requirement to replace life limited parts (LLPs).

The average shop visit interval across the fleet is 5,000 EFH and cycle time is 5.0 hours. The shop visit interval is also 1,000 cycles. The variance in cycle times and shop visit intervals means



*JT9D cycle times vary considerably. Engines have a high parts scrap rate and maintenance costs are about $300 per EFH for short cycle engines and $200 per EFH for long cycle engines*

generalisations cannot be made about shop visit workscopes.

The life of LLPs in the JT9D depends on the area of the engine and which generation they belong to. The majority have lives of 15,000 or 20,000 cycles. A smaller number of LLPs have lives between 8,000 and 13,000 cycles. An average cycle time of 5.0 hours means most LLPs have to be replaced every 75,000 or 100,000 flight hours. Under normal operators' rates of utilisation this is equal to 20 and 25 years of flying with long-haul aircraft. In this respect many LLPs are never likely to be replaced in some engines during their working life.

There are situations however when engines that, for example, have accumulated 13,000 cycles are in the shop and one LLP requires replacing. In this case it is likely that all LLPs with a 15,000 cycle life would be replaced at this time.

A large number of JT9Ds have come on to the market in the past year. Willis Lease Finance has bought 12 747s from United for parting out and AAR has bought BA's 15 747-100s. The oversupply of engines means it is cheaper in many cases to buy a time-continued engine than put one through a shop visit whatever its workscope requirement. Engines which operate on five hour or longer flight cycles will reach an age of 20 years or more before LLP replacement comes due. In this case LLP replacement is not an issue in maintenance costs.

Shorter cycle times of two hours will result in LLP replacement at 30,000 to 40,000 EFH, or every six to eight shop visits and seven to ten years. LLP replacement then does become an issue, but the long period between replacement still means the costs are amortised over a large number of flight hours.

## Workscopes

Maintenance costs per EFH are driven mainly by SVR and the workscope of each shop visit. Hot sections require the most frequent shop visits, called 'light visits'. Other sections are repaired less often at the same time as a hot section repair. This constitutes a 'heavy visit' and can sometimes include the replacement of LLPs. The ratio between light and heavy shop visits and will then have a further impact on costs per EFH.

The JT9D with an average flight cycle time of 5.0 EFH generally conforms to a light–heavy–light shop visit pattern. The on-wing time and shop visit patterns are influenced by the workscope of each shop visit. For example more extensive repair or reconditioning work on the engine's compressor usually results in longer on-wing times. Longer on-wing times can also be achieved through greater replacement rather than repair of parts and blades. However, this policy does not necessarily result in lower costs per EFH.

"Time on-wing is most sensitive to performance retention in the hot section in the case of the JT9D," explains Lars Edstrom, powerplant engineer at Volvo Aero Engine Services. "The -7R4G2 on the 747-300 lasts well because it operates long cycles and has good exhaust gas temperature (EGT) retention. In some cases the engine can get up to 12,000 EFH on wing between removals and so would end up having a heavy–heavy shop visit pattern. In some cases the -7R4G2 can achieve up to 15,000 EFH or 16,000 EFH between shop visits.

"The -7R4G2s in the Sabena fleet average five to eight hours per cycle on the 747-300, which is longer than the 747-300 fleet average," says Phillip Posoz, JT9D shop visit manager at Sabena Technics. "This is a sharp contrast to the -7R4E1s powering our A310s. These have a much shorter average cycles."

"Each module has its own workscope and so a shop visit workscope varies because each module requires work at different times," says Posoz. By our definition a light workscope is a repair as required and usually involves a hot section inspection. A heavy workscope involves a full overhaul and at minimum is a performance restoration shop visit. LLP replacement will make the visit heavier. Several module repairs also constitute a heavy shop visit.

"We start with a full overhaul and then follow this with a light shop visit, which is then followed by another overhaul. Occasionally it is possible to get a light–light–heavy workscope pattern, but extensive replacement of parts is required in the heavy shop visit to get durability in the engine," explains Posoz. "The life of LLPs is also determined by engine thrust rating which has some effect on shop visit pattern. The -7R4G2 rated at 56,000lbs has an average LLP life of 15,000 cycles, while the lower thrust -7R4E1 rated at 48,000lbs to 54,000lbs has an average LLP life of 20,000 cycles."

The JT9D is basically an engine where the hot section requires refurbishment about twice as frequently as the low pressure turbine and compressor sections. Although only a generalisation, the 'average' shop visit pattern is to have a hot section inspection or light overhaul about 5,000 EFH after an overhaul and then a full overhaul after another 5,000 EFH.

"Engines operated on short cycles of about 3.5 EFH normally achieve 5,500 EFH to 6,000 EFH on-wing between removals and conform to a light–heavy–light shop visit pattern," explains Edstrom. "The on-wing time after overhaul is about 7,500 EFH, followed by a hot section inspection and light repair and then another 4,500 EFH is achieved until the next overhaul.

"Longer cycle time engines can get 10,000 EFH or more before removal on the first run after an overhaul. The -7J might then have enough EGT margin left to be able to get away with a hot section inspection and some other repairs," says Edstrom. "This would still be a light–heavy–light pattern, despite the long on-wing time after the overhaul.

"The -7Q would probably have less EGT margin and so repair to the high pressure compressor might be required as well. The workscope pattern on the -7Q would then be more like an alternation between heavy workscopes and heavy shop visits of a smaller workscope. For example, materials would be repaired on the first shop visit in several modules and replaced in the second visit. The low pressure turbine would also be worked on in the second visit and not the first," says Edstrom.

"Very long on-wing times of 15,000 EFH or more can be achieved with extensive workscopes," says Edstrom. "These workscopes include repairs on all sections, the installation of new turbine and compressor blades, and for example, the refurbishment of bearing seals to avoid leaks on high time engines."

Long times between visits does not always produce lower costs per flight. An engine shop has to consider the operation and strike a balance between on-wing time and the level of parts replacement and workscope. One clear advantage of a low SVR is a large saving in spare engine investment or provisioning.

## Shop visit costs

Generally the manhours and materials consumed for similar shop visits are similar for all JT9D variants. "Light shop visits can consume between 1,500 and 3,000 manhours while heavy visits take 4,500 to 7,000 manhours," says Posoz.

"The number of manhours consumed by repairs differs a lot," says Edstrom. "The complete refurbishment of a young engine will take less than 5,000 manhours while the refurbishment of an older engine, which can involve repair of the casings, can take more than 6,000 manhours."

Posoz puts the material cost for a light visit between $300,000 and $500,000 and between $1.0 million and $1.5 million for a heavy visit. Using high labour rates in the region of $80 to $100 per manhour total shop visit cost is between $450,000 and $800,000 for a light visit and $1.5 million and $2.5 million for a heavy visit. About 75% of the cost is for the consumption of material.

"Material costs are higher for second generation and third generation JT9Ds," says Edstrom. "The cost of LLPs is $1.67 million for a full set of second generation parts which have a life of 15,000 cycles, except the first and second turbine stages which have lives of 11,000 and 13,000 cycles. The third generation LLPs are similar, at about $1.67 million, and have lives of between 15,000 and 20,000 cycles.

The majority of material costs are basically attributed to turbine materials. The first and second stage turbine blades and second stage turbine vanes alone cost almost $1 million.

It is possible to repair these parts a limited number of times. The first stage turbine blades can only be repaired once, while the second stage blades and turbine vanes can be legally repaired twice, but their condition means that sometimes they can only be repaired once.

This makes it hard to estimate material costs. The higher the proportion of parts that are repaired rather than replaced, the shorter the next on-wing time. The shop visit cost might be lower but the hours between removals are less. This makes it hard to generalise about workscopes, shop visit costs and what strategy results in the lowest cost per EFH.

"If hot section inspections are performed every shop visit at an average rate of 5,000 EFH then some turbine parts are scrapped every 10,000 EFH, that is every second shop visit after being repaired once. The common situation is that every second visit first stage turbine blades are replaced and second stage turbine blades are repaired. Every third visit second stage turbine blades are replaced. Even if all the blades conform to this pattern of repair and replacement the workscopes vary considerably rather than just following the light–heavy–light pattern. The issue is complicated by the fact that 60-90% of first stage turbine blades might be scrapped on the first shop visit after a long on-wing run, depending on the engine's modification status. It is not possible to generalise, but

### SUMMARY OF JT9D MAINTENANCE CHARGES

| | -7R4E | JT9D-7J | JT9D-7Q | -7R4G2 |
|---|---|---|---|---|
| **first visit** | | | | |
| Time on-wing since overhaul (EFH) | 6,500 | 10,000 | 10,000 | 12,000 |
| Average cycle time (EFH) | 3.5 | 7.0 | 8.0 | 9.0 |
| Cycles on-wing since overhaul | 1,857 | 1,429 | 1,250 | 1,333 |
| Workscope | L | L & repairs | LH | H |
| Manhours | 3,000 | 3,500 | 4,500 | 6,000 |
| Materials ($) | 800,000 | 850,000 | 1,000,000 | 1,600,000 |
| Total cost ($) | 1,040,000 | 1,130,000 | 1,360,000 | 2,080,000 |
| **second visit** | | | | |
| Time on-wing since overhaul (EFH) | 4,500 | 4,500 | 4,500 | 12,000 |
| Average cycle time (EFH) | 3.5 | 7.0 | 8.0 | 9,0 |
| Cycles on-wing since overhaul | 1,286 | 643 | 563 | 1,333 |
| Workscope | H | H | H | H |
| Manhours | 6,000 | 6,000 | 6,000 | 6,000 |
| Materials ($) | 1,600,000 | 1,650,000 | 1,750,000 | 1,900,000 |
| Total cost ($) | 2,080,000 | 2,130,000 | 2,230,000 | 2,380,000 |
| Workscope pattern | L-H-L | LH-H-LH | LH-H-LH | H-H |
| Total EFH | 11,000 | 14,500 | 14,500 | 24,000 |
| Total cycles | 3,143 | 2,071 | 1,813 | 2,667 |
| Total cost ($) | 3,120,000 | 3,260,000 | 3,590,000 | 4,460,000 |
| Cost per EFH ($) | 284 | 184 | 190 | 186 |
| LLP lives (cycles) | 15,000 | 15,000 | 15,000 | 15,000 |
| LLP lives (EFH) | 52,500 | 105,000 | 120,000 | 135,000 |
| LLP cost($) | 1,670,000 | 1,670,000 | 1,670,000 | 1,670,000 |
| LLP cost ($/EFH) | 32 | 16 | 14 | 12 |
| Total maintenance cost ($/EFH) | 315 | 241 | 262 | 198 |

***Workscopes: L=light, H=heavy, LH=lighter heavy***

the longer the on-wing time the higher the scrap rate and material cost.

The high pressure compressor blades cost $200,000 to replace. High pressure turbine blades cost $2000-$3000 each to replace. The first generation engine blades are cheaper because they do not have the coatings the later engines have.

"Quite a lot of parts are replaced on the first few low pressure turbine stages on every heavy visit," says Edstrom."Not much is done to the low pressure compressor except for cleaning and inspecting. Fan blades only have to be scrapped for chord length erosion on high time engines."

Generally the JT9D has a high scrap rate of expensive materials in many parts of the engine.

## Costs per EFH

We have described several average cycle times, average on-wing times and workscope patterns to which JT9Ds can conform.

A short cycle engine would have a flight cycle time of 3.5 EFH and a light visit 6,500 EFH after an overhaul followed by another overhaul after 4,500 EFH. In this case the engine has a simple light–heavy–light shop visit pattern. The short cycle time leads to the highest cost per EFH.

This compares to a -7J on a seven hour flight cycle with an alternation of lighter heavy shop visits and heavy shop visits which achieves 10,000 EFH on-wing after overhaul and then another 4,500 EFH after the first visit.

It is possible that a -7Q or other variant might operate an eight hour average cycle and achieve the same number of hours on-wing between removals. However because of a lower EGT margin the next shop visit after overhaul would be heavier.

A -7R4G2 with long on-wing times between removals and heavy workscopes have the lowest cost per EFH.

Manhours and materials consumed in each of these cases are summarised in the table *(see page 33)*.

The cost of LLP replacement per EFH is shown assuming that a full set is replaced on average every 15,000 cycles. In the case of the -7J and -7Q operating long cycles the LLP cost is theoretical since LLP replacement could come at a time when it is cheaper for an airline to buy a younger time-continued engine than overhaul the one they have.

Costs per EFH are in the region of $300 per EFH for engines used on short cycles, declining as average cycle length increases. A -7R4G2 should achieve costs per EFH just under $200, excluding LLPs.

## Spare provisioning

The final element is the provisioning cost for spare engines. Some operators still elect to maintain their own inventories. The number required will depend on their level of coverage for engine removals and fleet size.

Other methods of spare provisioning are to pool engines with other airlines or have short term leases from several engine lessors.

Short-term leases are charged at a daily rate and maintenance reserves for the hours used. The airline will also have to incur the cost of engine removal.

The lease term will have to cover the period of the shop visit plus extra time to schedule the engine change at a convenient time. Shop visit time might be 60 days on average but the spare engine will have to be leased for up to another 30 days so that the aircraft can come into the hangar for an A-check when the engine change can take place.

Daily lease rates for the JT9D are constantly changing and have dropped in the past year as a large number of JT9Ds have come onto the market and still more are due.

In times when market values of time-continued engines fall, as in the current climate, it can be more economical to buy engines rather than have run-out engines overhauled.

Daily lease rates vary between $1,800 and $2,500 depending on variant. A 90 day lease will then result in a cost of $162,000-$225,000. Maintenance reserves will again depend on the variant in question, but lessors will add a contingency margin. These rates could then start at $250 per EFH for younger variants on long cycles to $350 per EFH for older generation short cycle engines.

Maintenance reserves will depend on aircraft utilisation but a rate of 300 EFH per month will generate a cost of $225,000 for long cycle engines and $315,000 for short cycle ones.

Total cost of provisioning for each engine shop visit will then total $425,000 for a long cycle engine to $515,000 for a short cycle one. These costs are amortised over the average time on-wing between shop visits which varies from about 6,000 EFH for older engines up to 12,000 EFH for the youngest engines operating long flight cycles.

Provisioning cost per EFH works out at $86 per EFH for short cycle engines and about $35 per EFH for younger powerplants. AC