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An aero engine's life cycle can be divided into three main stages: the financial, management and trading phases. Careful and far-sighted management is necessary to balance maintenance cost against operational risks whilst maintaining maximum asset value as the engine progresses through these different periods.

Managing engines wisely

Everything is rosy during the 'honeymoon period', the first years of an aero engine's life cycle and main part of the initial financial phase. The power plant has been freshly delivered from the OEM and mated with its original operator who will generally be able to enjoy its daily faithful, revenue-creating service without worrying much about prolonged and expensive maintenance. Premature engine removals for component deterioration should be covered by the OEM as part of its product warranty, and even foreign object damage (FOD) events might fall under a separate insurance policy. Typically, the OEM will also make guarantees for fuel consumption, piece-part life and reliability, especially on new-generation equipment, and possibly even commit to cost per flight hour and/or flight cycle. Apart from ensuring compliance with the regulatory requirements and keeping a moderate level of technical oversight (to make sure the required maintenance and operational processes are safely and adequately working), the operator has no more engine management responsibility.

But this sweet, uncomplicated life typically comes to an end after approximately seven years; although this does depend on the type of aircraft and its utilisation. At this point the engine is taken off wing for its first scheduled maintenance shop visit. The OEM's warranty begins to expire in individual areas, and its financial support starts to dwindle. The engine becomes 'adolescent', as David Garrison, MD engine and component maintenance at Delta TechOps in Atlanta, US, puts it. For him, the operator has to take on more responsibility for the power plant's maintenance planning in this second part of the financial phase. Garrison states: "During this phase one will be actively managing the unscheduled engine causes and determining the engine's true capabilities based on the current design and the owner's [airline or lessor] operating parameters. During this phase one is also analysing the best life-limited part (LLP) management philosophy."

Power-by-the-hour

A power-by-the-hour (PBH) or total support agreement with the OEM or an MRO provider is one option for the operator. This would allow continued flying without assuming the responsibility of balancing maintenance costs against operational risks and determining the maintenance planning. Normally, the engines stay in the service of the initial operator as there is only limited aircraft remarketing taking place at this point in time. The operator can pay the OEM/MRO an individually arranged, flight hour-based rate for their technical support services and concentrate on its main business of providing air transport. For example, Delta TechOps's PBH contracts usually include fleet removal forecasting, service bulletin modification and inspection recommendations, on-wing engine condition monitoring, and the development of a maintenance programme, according to Garrison.

During the initial 'honeymoon' period of an engine's life cycle, its maintenance is largely determined by the OEM's product warranty policy and guarantees, and the operator/owner does not need to manage an engine plan.

However, even apparently comprehensive packages do not necessarily cover all eventualities that might concern an aircraft operator or owner. "One comment about total support is that all too often it is not really total support," remarks Karl Gibson, operations director of TES Aviation, an aero engine management company based in the UK. He highlights that total support and PBH agreements always carry exclusions and might not cover certain work; FOD removal as an example. These extra-contractual maintenance events have then to be accomplished on the basis of their individual (man hour) time and material cost requirements. In that case the operator incurs both the cost of the regular PBH/total support payments, whether any regular maintenance work has actually been done or not, as well as the individual time and material-based payments for the additional work. Hence Gibson argues that, in order to forecast the entire MRO expenditure for an engine over a given period of time, the operator has to make an analysis of likely time and materials cost in the first place, irrespective of whether the company then decides to sign a PBH/total support contract or not.

This does not mean that a PBH/total support agreement won't still be the best option. "We look at what is best for our customer's requirements and do studies across a number of maintenance cost per flight hour agreements," explains Steve Froggatt, engineering manager at TES Aviation. "We won't always go for time and material if the power-by-the-hour contract makes more sense. It all depends on the engine, operator, any specifically harsh operating area or condition."

For Abdol Moabery, CEO and president of GA Telesis, an aircraft asset management firm, component supplier and maintenance provider in Fort Lauderdale, Florida, the issue comes down to whether the operator wants to make regular payments to a PBH/total support provider for the maintenance in advance or pay for the individual events as they come along. "The provider of that [PBH/total support] service is accumulating cash for a 10 or 15-year programme. Some airlines view that cash as important to their business [now]. So they don't want to pay up front and would rather just do it as time goes by."

Whatever decision is eventually made, it is of fundamental importance to get a clear understanding of the full maintenance cost that is likely to be encountered throughout the proposed service period for the engine. Although these expenditures can vary substantially between different operators and equipment, they can nevertheless be predicted with great precision over long periods of time. Analysing an engine's remaining life cycle in light of its operational requirements and the financial objectives of its owner, if it is a leased engine, is the first step for any technical management team before determining the future maintenance plan.

Management phase

This becomes increasingly important as the engine progresses from the financial phase into the management phase. By then the powerplant is between 12 and 15 years old, may have transitioned from one operator to the next, its PBH/total support contract may be expiring, and it will need to come off-wing for its second, third or fourth shop visit. All product warranty and guarantees have finally expired, and the maintenance plan is no longer governed by the OEM's product and repair developments. There will be a range of alternative PMA parts and DER repairs available on the market, which will give the operator/owner some choice to tailor the future maintenance plan to its individual needs. "The management phase is where most change is going to take place within an engine and its value," states Froggatt. "The management decisions one makes at that particular point, for a number of shop visits, is going to dictate the residual value when one gets towards the trading phase [when the engine will eventually be disassembled to serve as a parts source]. As the lessor, one is looking more into the asset value,

Trading phase: when the value of the individual parts and components exceed the book value of a complete engine, it is teardown time and the asset will serve as a spare part source.

> *"The risks of operating PMA parts are vast. The risks are calculated over a fleet of engines. So in the case of an airline with a vast fleet, one can look at that risk and decide it is worth doing. But the small operator may look at it and say, 'for the cost savings that I save, it's not worth it'.*
> **— Abdol Moabery, CEO and president, GA Telesis**

because one is looking at the end and what one wants to do with the asset. The operator, specifically, is looking at the cost per hour, because that's what it is all about to turn a profit."

The main factors in the assessment of an engine's remaining life cycle, which will indicate how long the engine may be able to stay on-wing until the next shop visit, are aircraft utilisation, the status of the LLPs and their remaining flight hours/cycles, the maintenance history, and the airworthiness directive (AD) status. If the analysis is performed from an operator's perspective who has leased the engine, the length of the proposed service period is another major determinant. External engine management consultants are typically engaged in contracts over three or five years. Engine trend monitoring data at different power settings (usually idle, take-off and cruise) will provide a clear picture of the power plant's current performance and what deterioration can be expected in terms of both extent and rate. Establishing the fuel flow and exhaust gas temperature (EGT) parameters will allow the management team to outline an initial overhaul strategy, according to Moabery. "As turbine blades get older, the wear starts to cause EGT margin degradation, and the engine will very quickly move from a strong performing engine to one that operates with no EGT margin."

Once all these parameters have been determined, it becomes possible to predict which maintenance tasks will be necessary in the future, what this will cost, what options the operator will have to control its spending, and how this might be affected by additional, unscheduled maintenance. "We run those engines forward on our system which allows us to forecast all the events. We would work-scope each engine individually as a paper exercise and identify what the costs were against the critical elements within that work scope, what the material costs would be based on the material standard that is in there [the engine]," explains Gibson. "We would include all the unscheduled events that could potentially happen, lease costs, everything ... and we would give them effectively what the cost per hour of their operation would be."

If it is a leased engine, the interests between the operator and owner are likely to diverge as indicated above. The airline might only be contractually obliged to release the engine with a certain life left on it at the end of the lease agreement. This would allow the company to minimise the workscope accordingly to reduce its costs during the lease period. On the other hand, however, the lessor will be looking at the cost of operation over the entire ownership period, which might go long beyond the original operator's lease agreement. The lessor will want to enhance the workscope as much as possible in order to maintain a high asset value. This would make it more attractive and marketable to other operators who might lease the engine in the future. The two parties have then to find some common ground to keep the cost per hour of the engine at a level that is acceptable for both. If the lessor demands a technical standard that is significantly higher than what is necessary to the operator, one solution could be that the lessor makes a contribution to the maintenance cost.

The use of PMA parts and DER repairs, instead of the standard OEM material and processes, is clearly one, if not the, most important and powerful means to reduce engine maintenance costs. However, while their use has been widely established throughout Western Europe and North America, this is not necessarily the case in all other regions. PMA parts

The use of PMA parts and DER repairs instead of the standard OEM material and processes is one of the central questions when an engine enters the management phase and the future value strategy is determined.

can become an obstacle when trying to find a lessee for an overhauled engine, for example, in China and India — two future growth markets.

But even within the boundaries of jurisdiction of the FAA and EASA, the cheaper alternative repair materials and processes might not always pay off either. In light of the increased operational risk of using PMA parts and DER repairs, the potential cost savings might be considered much less tempting for an airline with, for example, 10 aircraft than a carrier with a fleet of 100 aircraft. "The risks of operating PMA parts are vast," believes Moabery. "The risks are calculated over a fleet of engines. So in the case of an airline with a large fleet, one can look at that risk and decide it is worth doing. But the small operator may look at it and say, 'for the cost savings that I save, it's not worth it'. If I have a major engine failure or a catastrophic event, then all of those savings are wiped out by one event."

Trading phase

At approximately 20 years of age, the engine enters into the trading phase, the final part of its life cycle. By this time, the value of the entire aircraft is mainly driven by the engine value. Ironically, however, the book value of the power plant in itself is coming down so far at this point that it no longer warrants the cost for an overhaul. The engine's technical standard and performance has been surpassed by its younger counterparts in the fleet, and possibly even by new-generation equipment that has emerged in the meantime. Furthermore, there will be an increased number of other engines of the same type and similar age on the market, which have been phased out by other operators and have consequently brought down engine lease rates and spare part prices. Not only does it then become cheaper for the operator to swop an engine against a leased one rather than to repair or overhaul it, indeed there comes the point where the value of the individual parts and components exceed the book value of the complete engine. It is teardown time at this point and the engine will serve as a source for spare parts.

The dynamics of the trading phase are subject to the economic conditions at the time. In periods of growth, when queues before airline check-in desks and OEM sales offices are long, the service lives of older aircraft are stretched too, and consequently lease prices for older engines with some residual 'green-time' are stable. 'Green-time' is the available period during which an older engine can remain in service until its last maintenance records expire and it will be torn down. Conversely, when the industry goes into a downturn and airlines are cutting capacity, the older, less efficient aircraft are the first ones to stay on the ground. "A good example right now is the CFM56-3 model [for 737 Classics], where there are so many spare engines available in the market that an operator may decide to run off 'green-time' on a leased engine as opposed to putting in $2-3m to repair the original engine," reports Moabery.

While the deferral of maintenance and using-up of surplus engines will help to drive older equipment permanently out of the market, it would be a short-sighted waste of material and finances to take advantage of aircraft capacity cuts in the current economic climate and apply the practice to younger equipment too. Garrison warns: "In the airline industry, economic cycles are a way of life and have a significant impact on an airline's budget sensitivities. The airline industry is a cash hungry business and during an economic downturn, airlines work hard to preserve cash. This stance can make engine management very difficult, because you will need to invest in your fleet during the shop visit to make sure that you build in the goodness to obtain your engine run time and reliability plan. Airline customers who do not maintain the investment discipline during the economic downturns can expect their cost per hour and total cost to increase in future years."