The majority of rotable and repairable components are maintained on an on-condition and condition-monitored basis, while some are still hard time components. There are five categories of rotables and repairables which have to be considered when identifying & allocating costs.

Rotables maintenance management

The adoption of a maintenance steering group (MSG) 3 system has changed the management of the maintenance for many rotable and repairable components. They are now 'on-condition' or 'condition-monitored', rather than hard-timed, which has altered the predictability of component maintenance and made its management more complex. It is now therefore harder to estimate their related maintenance and repair costs.

Component types

Components are sub-divided into rotables, repairables and expendables. Rotables and repairables can both be repaired and overhauled, but rotables have serial numbers and repairables do not. Expendables, consumables and materials are once-used and cheap items that are used at all levels of maintenance.

Rotables and repairables are therefore of most interest. Aircraft are considered in relation to air transport association (ATA) chapters, for example: chapter 21, air conditioning; chapter 24, electrical power; chapter 26, fire protection; chapter 27, flight controls; chapter 28, fuel system; chapter 29, hydraulic power; chapter 35, oxygen; and chapter 36, pneumatics.

The components in each chapter are considered in terms of their physical location on the aircraft, safety implications in the event of their failure, and how they are to be maintained. Three maintenance methods are used: hard time, condition-monitored and on-condition.

Hard-time maintenance was applied to the majority of components on older aircraft using maintenance programmes devised prior to MSG3. "MSG3 involves a top-down approach, where components and systems working satisfactorily do not need any preventive maintenance, and only need maintenance when they either deteriorate to a certain level or fail," explains Phil Seymour, managing director at the IBA Group.

Components that can be treated like this are ones with redundancy or that can be tested or inspected at specified intervals. Components with redundancy are referred to as condition-monitored, and include items such as the servos that move flight control surfaces. Since there are two servos with the same function, one can fail without jeopardising safety.

Components that are are inspected or tested regularly to detect deterioration or failure are referred to as on-condition. For, example, the thickness of a brake disc pack is crucial to its ability to provide sufficient braking power. The thickness is monitored by calipers or a thickness indication pin, and the brake is removed for repair when the thickness is still more than a minimum specified limit.

Hard-time components are those that are repaired or discarded at regular intervals, and are included as part of the items in maintenance checks. Examples of hard-time components are safety-related items, such as life jackets and gas bottles that inflate emergency evacuation slides.

"With MSG3 maintenance, an increasing number of components that were hard-time in older-generation aircraft have become either condition-monitored or on-condition," explains Seymour. "The inspections in a maintenance planning document (MPD) for an aircraft have specified intervals, and are coded to denote the type of task required. For example, DS means that an item must be discarded, and RS that it should be restored by a repair or overhaul. The cost of replacing or repairing items is relatively easy to assess and, together with the intervals in the MPD, it is relatively straightforward to determine the cost per flight hour (FH), or other interval, of repairing and replacing these hard-time components.

"The LU and SV codes, which denote that an item should be lubricated or serviced, are also used for hard-time tasks, but only concern the expenditure of materials, and not the cost of rotables or repairables," continues Seymour. "Other codes are OP for an operational check, IN for an inspection, and FC for a functional check. These are tests and inspections for condition-monitored or on-condition items, and may or may not result in maintenance being required. This makes it harder to predict the cost of maintenance for these components, than when they were treated as hard-time items. Nevertheless, the increased number of items that are on-condition and condition-monitored has led to a reduction in overall maintenance costs, because maintenance on components and systems is less frequent."

Hard time components

Besides safety equipment, there are still several other major types of component with hard-time intervals. One example is the landing gear, which on most aircraft has a calendar limit for removal and overhaul of eight to 10 years. Other examples are the flap tracks on some aircraft.

The replacement or repair of hard-time components is timed to coincide with checks, such as small line or A checks with short downtimes, or base checks with longer downtimes. In either case, the total turn time for removing, transporting, repairing, testing and reinstalling a component must be considered. Sometimes this will be within

On-Condition and condition-monitored rotables and repairables can be sub-divided into as many as four categories. These include line replaceable units, components that are inspected and tested during airframe checks, components that are allowed to fail at random during operation, and heavy components.

the length or downtime of the check, and so referred to as a 'closed-loop' item. In other cases, such as a landing gear overhaul, it will be longer than the check downtime, and so referred to as an 'open-loop' or exchange item.

Both closed- and open-loop items can be repaired in the maintenance facility's backshops, although a repair shop in close proximity to the hangar is not necessary in the case of open-loop or exchange items. Few maintenance providers have the facilities required to repair all types of closed-loop items, so third-party repair facilities are needed for some closed- and open-loop items.

Besides planning when to remove these items and where they will be repaired, ease of access to, and removal of, these items must also be considered. Modern-generation aircraft have been designed to be maintenance-friendly, so that components are more accessible and can be removed and reinstalled in a shorter time than on older aircraft.

Condition monitored

Few components on modern aircraft are hard-time and most are now on-condition or condition-monitored. They are also easily removed and installed, and are either closed- or open-loop. An example of ease of removal is a heat exchanger on a 747, which is located in the engine pylon, and can be removed and replaced in about three hours. The same task on a 727 can take a whole day.

Servo units for moving flying surfaces, and air cycle machines, are other relatively large components that can be removed and replaced in a few hours.

With the majority of components being on-condition or condition-monitored, and easily removed and installed, their repair no longer has to be aligned with base checks that have a long downtime, or that open up the aircraft structure to allow component removal.

Some condition-monitored items can be removed when they have failed. In the case of a servo for moving flight control surfaces, failure is usually detected when hydraulic fluid leaks out, rather than because the flying surface is not moving, as other servos will still move the flight control surface. An increasing number of on-condition and condition-monitored items also send failure or fault codes to the on-board maintenance computer on the flightdeck. Although this does not specifically state what has failed, it provides codes that allow the fault to be identified or isolated.

On-condition and condition-monitored components therefore fall into two categories: those that are allowed to fail at random; and those that are inspected and tested during maintenance checks, and may then require non-routine maintenance. Many part numbers fall into both categories.

Reliability data

Airlines must record details, including the time, of a component's installation on an aircraft in the compulsory reliability programme, which keeps data relating to the time between failures of condition-monitored items. Airlines use the reliability programme to analyse the removal or failure intervals for each component, and with statistical analysis can determine 'soft times' for removal and inspection. These are intended to pre-empt failures. A large amount of data is collected by an airline with several years' experience and a fleet of at least five aircraft. High-quality reliability data will allow an airline accurately to forecast component failure rates, and so modify its maintenance programme and reduce the rate of random failures.

Local authorities also require airlines to keep these reliability programmes, and may enforce the change of a component's status from condition-monitored to hard-time, if it has a history of poor reliability. It is then up to the airline to determine the cause of the drop in reliability, cure the problem and demonstrate improved reliability to its authority before the component can be changed back to a condition-monitored maintenance programme.

In addition to soft times, airlines can also record findings from the removed components such as the maintenance required and its cost. Enough detail can eventually be compiled for the airline to make an accurate estimate of cost per FH relating to these components.

Similar data can be accrued from on-condition components, to establish soft times that can also be used to estimate maintenance costs.

Failure rates for condition-monitored and on-condition components generally increase as the aircraft ages. Predicting this is another task for reliability engineers and maintenance planners.

Maintenance planning

Whether components are hard-time, on-condition and condition-monitored, it is still necessary for maintenance tasks to be planned, repair facilities to be available, and serviceable items to be in stock or supplied.

This is relatively straightforward with hard-time items, since maintenance planners will know in advance which components will have to be removed, repaired or replaced at each check, and will therefore be able to prepare accordingly.

Furthermore, few hard-time components are located deep in the structure, thereby avoiding the long downtime required by a D or structural check. Most hard-time items can be removed relatively easily, so their maintenance can be planned during overnight, weekly or A checks if required.

There are still a few components and

related parts that are deeply embedded in the aircraft, and despite being on-condition in some aircraft types, they require deep access for inspection and possible removal. "Examples are some pneumatic and hydraulic system components, and flight control cables," says Joerg Asbrand, manager aircraft component services at Lufthansa Technik. "Most mechanical parts are accessible."

For example, flight control cables run through holes down the length of the aircraft's structure. These are visually inspected in structural checks or equalised C checks. Their inspection requires deep access, and they will have to be removed if their condition is worse than specified limits. Flight control cables are still hard-time items on older aircraft types. "In the case of the DC-10 and MD-11 flight control cables have to be removed every second D check," explains Marc Bakker, maintenance programme engineer at KLM Engineering & Maintenance.

Average removal intervals for on-condition and condition monitored components can be recorded, such as the average number of flight cycles (FCs) for a hydraulic pump.

Soft times that have already been established can be used to plan maintenance checks, and align the tests and inspections of the components with checks. This can simplify the supply of the right components for each check.

While these issues all have to be considered when planning base checks, the component portion is now relatively small.

Components still fail at random during operation, despite soft times, and have to be replaced during line or light checks. Removal and replacement may be immediate if the component is a 'no-go' item, or it may be possible to defer them for a short period up to an overnight, daily or weekly check. "What has to be borne in mind is that long-haul aircraft do not have overnight checks, so components should, where possible, be removed before failures occur," says Bakker. "Some components do not provide you with enough removal or failure data to give you a soft time for removal. We try to improve maintenance programmes to avoid problems."

Organising the timing, facilities, labour, equipment, tooling and replacement units to take care of these failures is carried out by maintenance control departments, and may have to be done in a few hours. An example is the rudder servo, whose replacement comes under non-routine maintenance, and whose randomness of failure which makes maintenance costs hard to predict.

LRUs

Many on-condition and condition-monitored components are accessible and can be removed and replaced in a short period during line-and-ramp checks after failing at random during operation. These are line replaceable units (LRUs).

LRUs are also items that are more critical to the continued operation of the aircraft in the event of failure, such as avionics. Stocks of these are kept at the main operating base and at some outstations across a carrier's route network. Airlines can own a complete inventory of LRUs themselves, or be supplied by a third-party supplier, in which case airlines are usually provided with a leased homebase stock of the items that are the most critical and have the highest failure rate. They then pay a pool access fee to the provider to supply the airline with any required component within an agreed time period. The supplier also repairs and manages the stock of parts for the airline customer.

Component categories

There are five sub-categories of components.

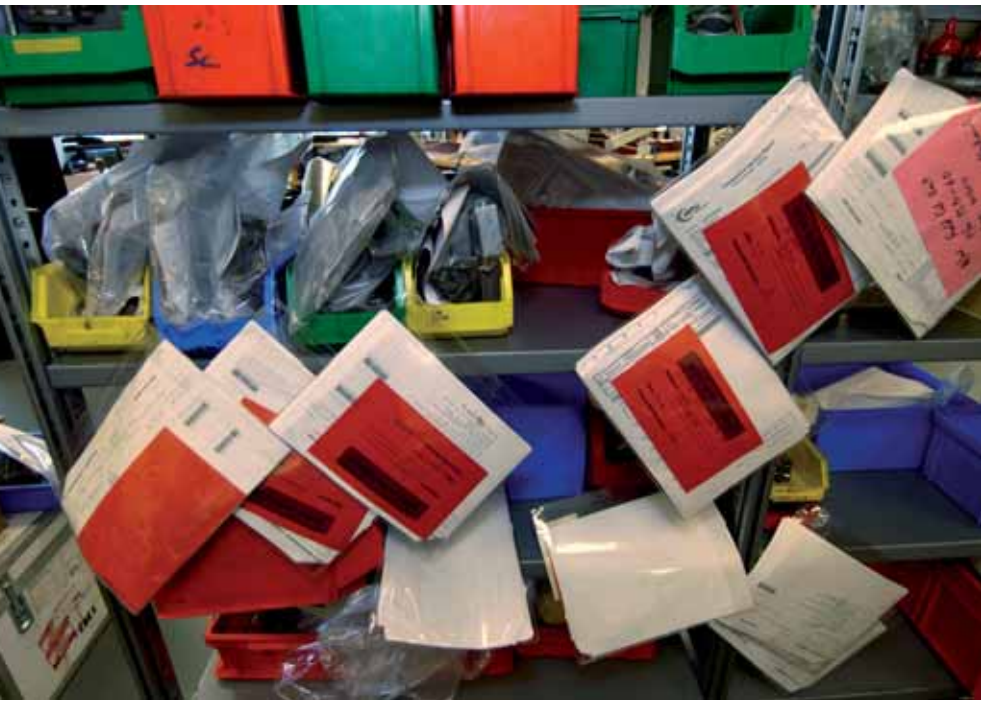
First, there are the hard-time components, whose costs per FH are relatively easy to assess. This group is small in modern aircraft.

The next four groups include components that are on-condition and condition-monitored. All four groups will have open- and closed-loop items.

The first of these are the LRUs.

The second group comprises those that are usually inspected and tested during base checks, and which may result in non-routine maintenance.

The third are those that are allowed to fail at random and can then be removed and replaced during a few hours' downtime, such as an overnight, daily, weekly or A check. An example would be a flying control surface servo.



Rotable support contracts will have differing levels of the components that are included and excluded. This will be partly influenced by the term of the contract. Contract suppliers provide the function of managing the repair, certification and management of rotables and repairables for airline customers.

The fourth group comprises heavy components, which includes: wheels and brakes; landing gear; thrust reversers; and the auxiliary power unit (APU). Although wheels and brakes can be removed relatively easily, these items are grouped separately because they are not condition-monitored, several hours' downtime are usually required to remove and replace them, and they are not inspected or tested during base checks. Wheels and brakes, thrust reversers, and the APU are on-condition components. The landing gear is a hard-time component.

The dividing line between each group is not always clear, and a component type can actually fall into more than one category according to some definitions. Wheel and brake units, for example, can be treated as a heavy component by some airlines, while regarded as an LRU by others. Estimating the cost of supplying and repairing these per FH requires extensive reliability and other data.

Rotable support contracts

As described, airlines can be supplied with rotable and repairable support contracts. The vague dividing lines between component categories means that contract suppliers have to consider which items will be included and excluded.

The small number of hard-time and heavy components are excluded from most contracts.

Rotable support contracts are based on LRUs, and so include all or most items that are regarded as line replaceable, or those that can be replaced in a few hours' downtime. They do not usually include items that require non-routine repairs as a result of tests and inspections made during checks. These are usually part of a long-term contract with other suppliers. "Components that have repairs related to base and heavy checks, whether hard-time or non-routine repairs, are charged on a time and material basis," says Asbrand. "In some cases repairs can be charged at a fixed rate, which includes an administration fee. This simplifies matters."

"We supply many airlines with power-by-the-hour (PBH) rotable or LRU support contracts that include all rotable and repairable items, and specify the list of components for each ATA Chapter," says Conrad Vandersluis, commercial manager at AJ Walter. "We arrange the positioning and repair of all components, but there are exclusions, such as items that are bespoke or unique to the aircraft, passenger seats, in-flight entertainment equipment, and life limited parts or hard-time components. Flight control surfaces and landing gear doors are also excluded. Lifed items and exchange rotables can, however, be added to a contract. The requirement for non-routine repairs or exchange of rotables found during base checks has to be considered."

Suppliers of rotable support have many factors to consider when assessing the costs of contracts. "Suppliers take into account included and excluded components, statistics of removal and failure rates, the ratio of test, repair and overhaul of each part number, the rate of no-fault found for each part number, the cost of different levels of repair and overhaul, and costs of transportation and storage," says Asbrand. "Estimates can be refined as the volume and accuracy of statistics improve. A contract can initially be difficult to price, so a supplier can offer the contract on the basis of labour time and material, rather than charging at a fixed rate per FH. We prefer to offer PBH contracts from the start, since they are simple compared to collecting time and material data.

"There are several other issues that have to be considered, such as reliability monitoring of components by the support contract providers, which is an overhead that has to be borne by the supplier, together with the cost of financing the components," continues Asbrand. "Another major overhead is the cost of the equipment and facilities for repairing and testing components. This is a large overhead and the main reason why many airlines rely on third-party support contracts. Another direct cost is for certification of repaired parts and the associated paperwork."

Providing estimates for support contracts is more difficult with aircraft types that have been in operation for a short period.

Summary

The five sub-categories of components mean that their repair and maintenance costs can be more easily identified. For example, the costs of hard-time and heavy components can be determined relatively easily. If LRUs are supplied by a third-party contract, the costs per FH for all part numbers included in these contracts can also be easily identified. Some or all of the part numbers which are removed and replaced after random failure may also be included in these contracts but may be dealt with on an ad-hoc basis. The cost for items that require repairs after inspection or testing during maintenance checks will be included in the total cost for the check. AC