Of all the major component categories, having accessing to and repairing line replaceable rotables and repairables has the largest numbers of variables that affect its cost. What determines inventory requirements, how can stock be acquired and what costs can airlines expect?

The economics of acquiring & maintaining LRU inventories

Accessing, managing and repairing inventories of line replaceable units (LRUs) is one of the hardest items of maintenance for monitoring costs. There are many elements involved in the process of acquiring and managing spare parts.

LRUs, or line items, are a major component category, and comprise items that can all be removed on the line after failure and replaced with a serviceable unit. LRUs can be sub-divided into rotables and repairables. Rotables are high-cost items and repaired continuously to last the aircraft's lifetime. These include avionics, hydraulic pumps, complex items in the environmental control systems, slide shafts and engine starters. All rotables have a serial number.

Repairables are lower-cost items, and repaired only a certain number of times, until it is more economic to buy replacement units.

Airlines also include consumable parts and expensive rotables referred to as insurance items in their inventories. Consumables are used during checks. Insurance items are control surfaces repaired during heavy checks. Damaged control surfaces will prevent an aircraft from flying, but spares are rarely required on the line and are expensive.

LRU cost complications

The factors determining the costs per flight hour (FH) of having access to and managing and repairing an inventory of components is complicated.

Several hundred different line items have to be kept for each aircraft type in an airline. These all have different and varying failure and removal rates. Most LRUs are items essential to the operation of the aircraft and can fail anywhere on an airline's network. This means they need to be replaced, even at the remotest outstations an airline flies to.

"The type of components that have to be kept in a stock of LRUs are no-go items. Failure of this type of part prevents departure of an aircraft," explains Lars-Anders Lorvik, director material planning and purchasing at SAS technical division. "SAS has three home bases and many outstations, and we need support at each one, as does every airline at its base. Essential or no-go items have to be kept at outstations, and additional parts are kept at the main bases."

This means airlines always need access to replacement no-go LRUs. Absence of a spare part, and qualified person to install and test it, will ground an aircraft. "An airline cannot allow flight cancellations because of lack of spares," says Lorvik "and so must have access to parts by whatever means".

One difficulty in assessing stock requirements is that parts are constantly improved and modified, and airlines have to keep track of which parts can operate on which aircraft. Another problem is that the thousands of parts in stock have to be tracked to avoid holding excessive or obsolete inventory.

Inventory requirements

The first stage is to assess which, and how many part numbers are needed. Each component has an average failure interval measured in aircraft FH, but individual failures occur at random around this average. Airlines have to consider the is a risk that a component will fail earlier than its average failure interval. The probability of failures is expressed mathematically by a Poisson distribution. The longer a component has been on an aircraft, the higher the probability of failure.

An airline can hold enough components to always have sufficient for a failure, which is known as a 100% confidence level. The inventory held can literally be halved by reducing confidence level to the 94-96% range.

"When assessing the number of spares required for a fleet, the data for mean time between removal (MTBR) and mean time between failure (MTBF) of each part is provided by the original equipment manufacturer (OEM)," says Lorvik. "We then monitor the MTBRs and MTBFs of items in operation. This experience is necessary to modify inventory requirements".

The algorithm then considers fleet size and total FH utilisation each year. An average failure interval of 3,000FH will mean a line item has to be kept in stock for a fleet of one aircraft. If two aircraft operate at 2,500FH each, one part will still be needed. The probability of two failing at the same time on both aircraft will be small enough for a stock of just one spare to be held at a 94-96% confidence level. As fleet numbers and total aircraft FH increase, so does the number of spares needed, but the number per aircraft reduces.

The algorithm also considers the number of bases the fleet operates from and number of outstations served. As this increases, the higher is the probability of a failure, and so a larger number of components are required.

The number of spares for each line item required is also affected by repair turn time. Shorter turn times reduce inventory.

The total number of parts which have to be held for each fleet depends on how the airline organises its support. "If an

It is essential that inventory managers have systems for tracking rotables. Hardware and software exist which allow rotables to measure their own failure interval. Components are then tracked while on the aircraft, during repair and when in storage. Tracking allows up to date MTBR data to be maintained, parts which require modification to be monitored, inventory requirements to be continually re-assessed, warranties to be claimed, and obsolete and surplus parts to be identified and sold.

airline is completely self supporting, about 800 different rotables are required for each aircraft type," says Michael Delion, head of business development component services at Lufthansa Technik. "Adding all necessary repairables increases these numbers to about 4,000 for the 747-400, 2,200 for the A320 and 2,500-3,000 for the A340."

"If an airline relies on independent vendors then the number of rotables and repairables is reduced to 500-800 line items," says Delion. "Many can be acquired from independent suppliers or replaced during airframe checks. About 500 different line items are required for a fleet of 25 A320s and 800 line items for fleets of 15 A340s or 747-400s."

The algorithm then takes the number of spares needed for each of these items to determine total inventory. "This will be about 1,100 for 25 A320s, 2,150 for 15 A340s and 2,250 for 15 747-400s," says Delion. "There will only need to be one part for certain line items and up to five parts for others, as an example."

The calculation of total inventory required is usually initially made by the aircraft manufacturers for airlines when they are taking delivery of a new fleet. The OEMs supply parts for major airlines when they take delivery of new fleets. Small airlines often use the third-party inventory management services supplied by major airlines, such as Lufthansa Technik and SAS Component. SAS Component, for example, supports the DC-9, MD-80/-90, Fokker 50, 767, 737NG, and in the future will also support the A320, A330 and A340.

Younger fleets can be also be supported by specialist companies, such as Airline Rotables which has A320, 737 and 757 inventory.

Fleets of older aircraft are often supported by specialist spares suppliers, which include The Ages Group, AAR and Source One Spares. There are also major maintenance providers, such as FLS Aerospace, which also offer inventory management services.

The final consideration in inventory requirements is fleet size. The inventory required per aircraft reduces fast as small fleets get larger. "Inventory for one A320 would cost about $12.4 million, but the total amount would hardly increase for another aircraft. Thus cost per aircraft would halve for two aircraft. The inventory investment would be $12.5 million for two aircraft, and only increase to $13.4 million for four, and $15.8 million for 10, $20 million for 20 and $23 million for 30," explains Delion. "A further doubling of fleet size to four halves inventory per aircraft again to about $3.3 million. For a fleet of 15 aircraft the inventory per aircraft is 10% of what it is for one. Once fleet size has reached 30 aircraft, inventory investment rises by only $300,000-400,000, and investment per aircraft hardly changes. This explains why pooling for small airlines is so efficient."

The effects that fleet size has on reducing inventory investment per aircraft is illustrated by the chart *(see page 37)*.

Modifying requirements

Once the major influences of the stock required have been considered, the number of items needed can be modified and adjusted downwards for many reasons. This will reduce investment and repair costs.

The minimum equipment list can first be sub-divided into categories of items or types of failure which affect an aircraft's ability to fly. "Essentiality one (EC1) are failures which will not allow a flight to proceed," explains Stuart King, commercial manager at Airline Rotables. "Essentiality two (EC2) are failures which are 'no-go' only if something else has also failed. For example, an ADF instrument can fail on its own, but will be 'no-go' if the VOR has also failed. Essentiality three (EC3) are items which do not cause a no-go situation".

The EC1 category includes major avionic items and certain pieces of safety equipment such as floor strip lighting. LRU inventories therefore have to hold a large number of different items, which vary in complexity and cost.

"The first stage is to divide the MEL into EC1, EC2 and EC3 items. EC3 can generally be left out of the inventory that has to be held at all times. The inventory kept by an airline can be EC1 and EC2 parts," explains King. "Airline Rotables bases EC1 and EC2 parts with high

Inventory has to be classified into 'no-go' items and parts which do not prevent aircraft departure if failure occurs. An airline must have some means of accessing no-go items at every airport it operates to. Besides having its own stock of parts, it can borrow from or pool with other carriers, exchange parts, carry flyaway kits or acquire from a vendor at short notice. These techniques all contribute to lowering investment in stock while minimising risk of being grounded.

failure rates at an airline's base. The remainder of the stock, including EC1 and EC2 parts, is based at our Stansted headquarters, and we supply the airline when parts are required. An airline will just buy or acquire EC3 parts when it needs them."

Airlines hold all line items at their main hubs, but keep only no-go items at line stations. "We can reduce the number of items held at line stations by borrowing parts from other airlines. These carriers then have a reciprocal agreement with us for when they need a part at our hub," explains Lorvik. "Borrowing agreements usually include the borrowed item being returned within a certain period. Airline alliances have the advantage of increasing the scope of borrowing agreements. Although no-go items have to be available at every line station, we can rely on our Star Alliance partners, as can the airlines we support, at all the airports they operate to, to provide no-go parts when required.

"Stock for long-range aircraft at outstations can also be reduced by the OEMs guaranteeing to supply no-go items at outstations within a certain time period," continues Lorvik. "Airbus has guaranteed that it will supply us with certain proprietary parts for our A330/340 fleet within a certain space of time. This reduces our inventory."

Many OEMs have parts located close to major airports and airline bases on all continents. The parts that airlines rely on from these stores will be high-cost parts with long intervals between failures.

Savings can also be made in reducing the number of EC1 and EC2 components kept by identifying those with high failure intervals, as high as 99,000FH, and also high list prices. These parts are often not required until the fleet is a few years old. Acquisition costs can then be reduced by taking the risk of not having these in stock, and acquiring them through another source at short notice when failure occurs. Methods include the Inventory Locator System, which keeps a record of parts available from specialist spare parts companies which include The Ages Group, AAR and Source One Spares. Components for modern generation aircraft can sometimes only be acquired from the OEM. Airlines, however, often pool or borrow parts. There is also the International Airline Technical Pool (IATP), which provides a system whereby airlines at remote outstations will borrow parts. The IATP basically works by member airlines paying an access fee for parts availability. If parts are needed the airline pays a one-off fee for using the part plus a charge for the repair of its failed item. It then has a time limit within which to return the borrowed part.

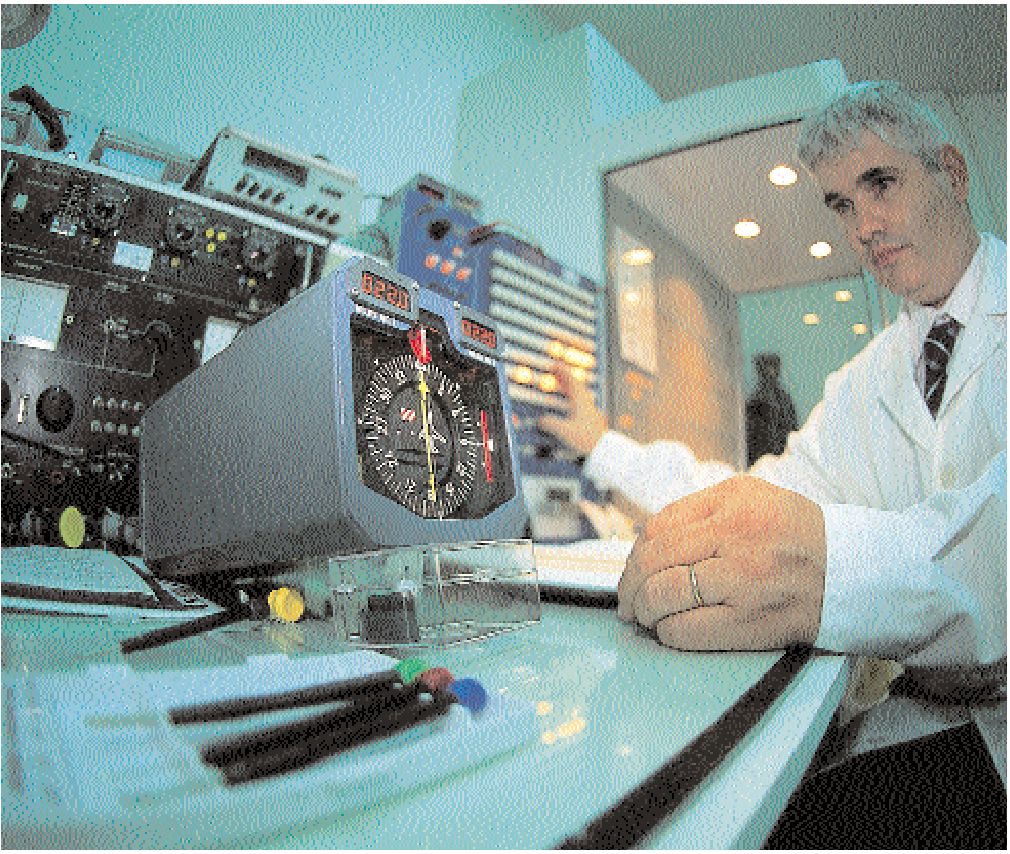
Another method for reduction is pooling of parts. Airlines share items between them. "Pooling usually works best for expensive parts with high removal intervals and list prices, and also insurance items. These are high cost parts with high MTBRs. Examples are nacelle components or flight control surfaces," says Larvik. "It also works best when the cost of components can be spread over a large number of aircraft. For example, we pool 767 parts with Martinair, Spanair and LOT. We are also planning to pool 737-600 and A321/330/340 parts with our customers."

Some airlines also use a system of 'flyaway kits'. These are a small inventory of spares carried with an aircraft that can be used in the event of failures. This technique is usually used where airlines want to avoid holding an inventory of parts at remote or seldom used outstations so as to minimise the amount of inventory held. "One example where we use this is where we might fly one aircraft for a short period on a route when we know we will soon start to use another type," says Gerd Reuter, coordinator of line maintenance for Lufthansa. "In this case it is not worth placing an inventory of parts for the first type if they will only be required for a short period. A flyaway kit will cover most eventualities."

Commonality

Larger fleets reduce the inventory needed per aircraft while maintaining the confidence level. This applies to aircraft families with parts commonality. That is, a family such as the A320, with four types, uses many of the same rotables and LRUs. It thus operates as one fleet, rather than four. This allows the number of parts held per aircraft to be reduced. The economies of scale for larger fleets was illustrated by Delion's example of A320 inventory.

Commonality between family members is not always as straightforward as it appears. "As an example, only 60% of flightdeck components are common between the 757 and 767," says King. "Therefore there will be three inventories. One that is common to both, one for the 757 and the third for the 767. The 737-300/-400/-500 has about 80% LRU commonality and the A320 80-90%," says King.



MTBRs for most rotables have increased to the point that few airlines have the throughput of parts to test and repair which justify the operating cost and investment in their own facilities. Airlines which acquire inventories from third party vendors have the choice of paying repair and management on a time and material basis, or a flat power-by-the-hour rate.

Tracking inventory

With thousands of parts kept for a fleet, and there being several hundred different line items and in some cases several dash numbers of the same line item, being able to track components accurately is essential.

Airlines need to be sure they have enough stock, need to check turn times for repairs are on schedule, monitor failure rates, order new parts when required and know when they should sell or dispose of obsolete parts.

This requires each part to be identified, usually by a bar code. Parts can then be swiped each time they change their position in the use, remove, repair and storage cycle. Tracking systems have now evolved where components can record the time they spend on the aircraft until its next failure. This way failure intervals of the higher cost items can be tracked. Airlines will thus have accurate and up to date data, allowing them to continually re-assess their inventory requirements.

Until this information is accurately known, airlines have to base their inventory requirements on manufacturers' estimated or average failure intervals. Real data allows airlines to more confidently track reliability. This has the benefit of highlighting parts which require upgrades to improve reliability.

Stock levels of each line item are often duplicated by different dash numbers being held for each part. Upgrades to a line item can make earlier dash numbers surplus or obsolete. These are often held for no reason other than airlines do not have the accurate data and tracking systems to identify excess and surplus stock. It is estimated that airlines hold about $30 billion in excess, underused or out of date parts. An accurate tracking system will allow these stocks to be identified and sold.

Another benefit is that components have warranties against failures for 36-60 months after purchase. The thousands of parts that have to be managed means inventory managers are often too busy to make many warranty claims, and so pay for repairs. A tracking system will automatically alert inventory managers of parts which have failed during warranty periods, and allow all claims to be made.

One example of a system is Spirent Systems' Aura.

Acquisition choices

Airlines have several choices for acquiring or accessing inventory. The first is buying stock from the OEM. This is usually the only choice when the type is still operated in small numbers. OEMs also try to limit the amount of inventory that becomes available through other suppliers for the youngest types.

Once a larger number of a type is in operation third party specialists usually acquire inventory. Because of the effects of fleet size on inventory requirements, major airlines with large fleets support smaller carriers without adding to the total amount of stock. This improves utilisation for the larger airline's inventory and offers an economic option for small airlines.

Carriers operating younger types can lease inventory from independent suppliers and airlines. Parts with longer removal intervals can be acquired through a variety of means, including pooling and exchanges, when they are required.

Disposal of older fleets also allows independents to acquire more inventory. Major airlines also often keep inventory, which is fully depreciated, for aircraft types they no longer operate, and use it to support smaller airlines.

Stock can also be acquired through exchange programmes. This avoids having to pay a lease rate. Instead a one-off fee is paid for using a part, and another paid for its repair when required. Exchange agreements can be made by an airline with several suppliers across a route network and operation. Exchange fees are about 8-10% of a part's list price, and a repair fee is also charged.

"Airlines can also use consigned stock," says Bill Cumberlidge, executive vice president of The Ages Group. "This is where the underutilised stock of one airline is made available to other smaller airlines. The smaller airline pays an access fee and an agreed price for repair. The stock is managed by us."

These airlines can thus avoid buying or leasing virtually all of their inventory. "Most airlines will do their utmost for some other party to have ownership and hold their inventory," explains Cumberlidge. It is not uncommon for a freight carrier now starting an operation with a small fleet of A300s or DC-10s to risk not owning any inventory at all, and acquire and repair components through a combination of consignments, exchanges, pooling arrangements, simple borrowing, and buying time-continued parts where necessary or when most economic.

Acquisition & repair costs

The simplest way to illustrate probable acquisition and repair costs is to examine cases where inventory is acquired through lease programmes and a separate power-by-the-hour (PBH) rate paid for repair and management.

Inventory for a fleet of 10 A320s is about $15.8 million, and $20 million for

20 *(see table, this page)*.

Similarly inventory investment for various aircraft types benefits from economies of scale, and cost per aircraft reduces as fleet size increases.

Older types will have lower capital cost because of increased availability on the market. Inventory for a fleet of 10 737-200s or DC-9s will cost about $4 million.

The downside of older aircraft types is that because of higher failure rates the inventory per aircraft will not reduce as fast with increasing fleet size as in younger types. While a fleet of 20 A320s may require about 30% more than a fleet of 10, a 737/DC-9 fleet will need about 40% more for the same increase. A similar factor can be applied for other older types like the 747-200 and DC-10.

Another disadvantage of older aircraft is that their shorter remaining lives will mean a higher lease rate or shorter depreciation term will have to be used. The third disadvantage is that a higher cost for repairs will have to be paid because of poorer parts reliability.

Monthly lease rates vary, depending on age of the aircraft and stock supporting it. Lease rates for inventory for younger aircraft will be in the region of 1.2% per month. These will be nearer 1.5% per month for older types like the DC-10 or 747-200.

A320 inventory lease rate would then be about $20,000 per month for 10 and $12,000 per month for 20. A utilisation of about 2,500 flight hours (FH) per year would result in a lease rate cost of $91 per FH for a fleet of 10, and come down to $58 per FH for a fleet of 20.

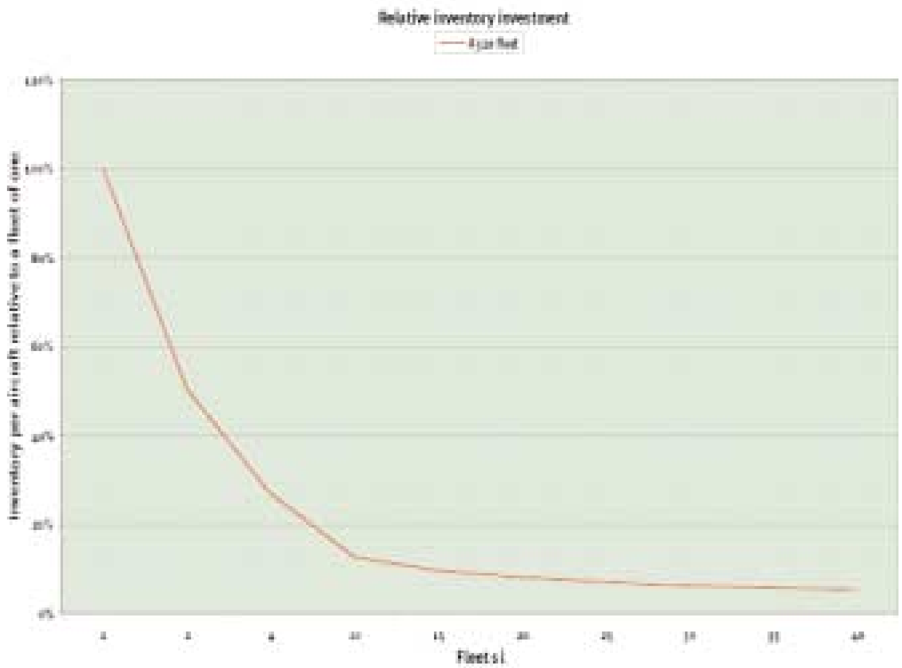
Investment and lease rates for inventory for fleets of 10 and 20 aircraft for the 737-200/DC-9, 737-300/MD-80, 757, DC-10, 747-200, 767, MD-11, A330/340, 777 and 747-200 are shown *(see table, this page)*.

The lease rates translate into cost per FH based on utilisations of 2,500 for short-haul aircraft and 3,700-4,800 for widebodies.

There are several options airlines have for the ways in which they can organise and pay for the repair and management of their owned or leased inventories.

Large airlines will have their own test and repair facilities. Airlines using third party repair services can either pay for time and material or a fixed PBH rate. The PBH rate charged for repair also includes an element for management. This refers to transport, storage, tracking and warranty claims.

Airlines will pay on a time and material basis if they feel it is more economic in the long run. Third-party vendors which lease inventory to airlines often charge repairs on a time and material basis if the vendor has no repair shops and control over the repair costs.



LRU INVESTMENT, LEASE COST AND PBH REPAIR CHARGES

Aircraft type	Fleet size	Inventory investment ($)	Lease cost ($/FH)	Repair PBH $/FH	Total cost $/FH
737-200/DC-9	10	4,000,000	29	150	179
	20	5,600,000	20	150	170
737-300/MD-80	10	9,000,000	52	210	262
	20	12,150,000	35	210	245
757	10	12,000,000	58	245	303
	20	16,200,000	39	245	284
767	10	15,000,000	58	275	333
	20	20,250,000	39	275	314
MD-11	10	15,000,000	48	300	348
	20	20,250,000	32	300	332
A330/340/777	10	18,000,000	54	300	354
	20	23,400,000	35	300	335
747-200	10	12,000,000	51	400	451
	20	16,200,000	35	400	435
747-400	10	20,000,000	60	375	435
	20	26,000,000	39	375	414

The advantage of PBH is that it is predictable. It will probably be more expensive in the long run, however, since an insurance level for higher than average cost for repairs has to be built in.

The PBH rate varies less with aircraft size than inventory investment *(see table, this page)*. Overall, total costs of lease and PBH repair per FH increase with aircraft size, but economies are achieved with larger seat numbers. The 737-200, for example, will have a seat cost of about $1.8 per FH, while the 747-400 will have a seat rate of about $1.1 per FH. These rates will also reduce as fleet size increases. AC