There are many elements which influence the cost of providing and maintaining an inventory of line replaceable units and rotables. Close examination reveals that airlines could achieve higher efficiencies for each of these, leading to a significant reduction in inventory-related costs.

The challenge of lowering rotable inventory costs

Rotable and line replaceable unit (LRU) inventory accounts for a large percentage of maintenance costs. Airframe and component related costs for an A320, for example, are about $555 per flight hour (FH) *(see Airbus & Boeing narrowbodies: maintenance cost analysis, Aircraft Commerce, October/November 2002, page 23)*. The cost of supplying and repairing LRUs is about $195 per FH, equal to 35%. This makes it a target for cost reduction.

LRU inventory supply

The logistics of supplying an inventory of LRUs and rotables have many stages that influence final cost. These are all linked to ensuring an adequate supply of LRUs to maintain operation, which have to be balanced with costs.

Hundreds of different line items must be available, each with its own mean time between failure (MTBF) and removal (MTBR). The removal rate of each part, aircraft utilisation and fleet size partially determine the inventory required. Airlines decide the confidence level of part availability under which they are prepared to operate. A 94-96% confidence level will ensure spare units are available on 94-96% of occasions. The inventory required for this will be about half compared to a 100% confidence level.

There are many elements which affect inventory require, including airline operation; number of home bases; routes and line stations; aircraft types, fleet sizes and fleet commonality; confidence level and access to parts when components fail in the event that the airline does not have parts in stock; the reliability of components and portion of parts that are removed and subsequently have no fault found (NFF); the cost and time to perform repairs; and maintenance philosophy on deferring the repairs of unserviceable items.

These all provide an opportunity for a reduction in the inventory required.

Airline operation

LRUs fail randomly, so there must be a system of making components available or serviceable at main bases and line stations to maintain operation. It is economic to keep an inventory of LRUs at a main base, but not a similarly sized inventory at each line station. The inventory at all stations can be minimised.

The first stage determines how essential components are to operation.

There are hundreds of different LRUs for an aircraft type, including avionics, cabin items and wheels and brakes. "A widebody aircraft has about 1,000 different line items, while a narrowbody uses about 800. About another 70 line items are required for engine LRUs; the exact number depending on the engine type," explains Armin Hillen, product manager of aircraft component services at Lufthansa Technik. "A fleet of 20 aircraft requires a total investment of $15-25 million, depending on the aircraft type and service level."

Each aircraft manufacturer provides a recommended spare parts list (RSPL) for each operator. The RSPL is categorised into essentiality codes: EC1, EC1 and EC3. The failure of an EC1 component, such as power control units, command sensor units and ground proximity warning computers, prevents an aircraft from operating. An EC2 item, for example Air Data Inertial Reference Units, fuel pumps and generator control units, prevents operation if it is affected by an EC1 item that has already failed. An EC3 item does not prevent operation in the event of failure.

The rate at which these parts fail is determined by a combination of fleet size and operation. Each component's MTBR must be considered against the annual FH of the fleet across the network. For example, a fleet of 10 aircraft operating 3,000FH each year will have a total utilisation of 30,000FH. An MTBR of 10,000FH means that the airline can expect three failures and removals of that part on average per annum. It may be determined that one spare item is sufficient, but the airline's route network will influence this.

Airlines operate from at least one home base or 'hub' airport, with routes to line stations (some routes have multiple line stations) line stations can be major airports and hubs of other carriers operating the same aircraft type, while others can be remote.

Airlines will generally concentrate most of their inventory at their home base, with smaller quantities held at line stations. The amount required at each line station can vary. "The annual FH to each line station for an aircraft type and the MTBR of a part will determine the probability of it failing on that route," explains Jorg Asbrand, aircraft component services at Lufthansa Technik. "If a line station is a busy airport then the inventory held by the airline can be minimised, since it can acquire components under various arrangements from other carriers or sources. What also has to be considered is the amount of labour and tooling available to replace a failed part. More inventory and support will be required at a remote line station."

Redundancy & deferral

Many essential components have redundancy built into them. Avionics, in particular, have up to three back up systems. The failure of a circuit board powering, for example, the flight management system, will result in the second circuit board automatically taking over. Although a message can be conveyed to the crew indicating failure of the circuit board, the aircraft continues operating. The unit can be replaced if the

Inventories held at line stations are kept to a minimum. This is aided by component redundancy, deferred defects, essentiality classification and component reliability. The level of stock held at line stations can be minimised, and the majority held at home bases. This makes a contribution to lowering overall inventory investment.

circuit board fails when the aircraft is at its home base.

"Examples of other parts with redundancy built into them are hydraulic, pneumatic, fuel and oxygen system components," says Hillen. "In some cases there is redundancy for individual components, and redundancy for whole systems in other cases."

Replacement can therefore be deferred if the aircraft is at a line station, obviating the need to replace it immediately. This contributes to the reduction of line station inventories.

Failure of another EC1 item, such as a wheel, requires replacement, however. Spare wheels must be held, or be made available somehow, at line stations.

In addition to components with built-in redundancy, the removal and repair of some parts can also be deferred.

"The minimum equipment list (MEL) defines the installed number of components on an aircraft, the minimum number required for aircraft dispatch, as well as guidelines describing if other units have to be serviceable if a unit has a defect," explains Hillen. "There is, however, no certain defined limit of deferred defects."

Even essential items that have failed, and do not have redundancy can be deferred in some cases. "Replacement of one of three inertial navigation systems, for example, can be deferred if the failure occurs at a line station and the aircraft is being flown back to the airline's defined home base, where it is replaced. If the failure occurs at the home base the item has to be replaced before the next flight. This means aircraft have to leave the home base with all EC1 items operational."

Deferring defects will depend on the airline's maintenance policy. Deferred defects are kept in a remaining items-log and then cleared at a convenient line check, such as an overnight, weekly or A check. The time limit for category A items is stated in the MEL: Category B items should be repaired within 72 hours; Category C items within 10 calendar days; and Category D items within 120 calendar days.

"Minor faults or discrepancies can be allowed. Clearing them requires replacement parts, and the process of ordering new ones determines inventory required," explains Lars-Anders Lorvik, director of material planning and purchasing at SAS Airlines Technical Services. "If parts are ordered just one or two days before they are required the inventory held has to be large, so as to minimise the risk of parts not being available because it is hard to predict which parts will be in demand. If it is possible to order items further in advance then it is easier to determine which line numbers will actually be required, and so reduce the inventory. It is therefore better to defer minor defects for a period and plan maintenance tasks in advance to make spares demand more predictable."

Parts that have redundancy or that can be deferred may be removed from the inventory required at an outstation, leaving components that have to be replaced. This quantity can be further reduced.

Alternative sources

Airlines will be prepared to risk having an incomplete inventory of rotables and LRUs by eliminating parts that have low failure rates or are expensive. Airlines will find it more economic to replace a failed part using sources other than their own inventory.

Alternative sources of inventory include original equipment manufacturers (OEMs), various on-line portals, independent maintenance suppliers and other airlines.

Carriers which compete on a commercial level will lend parts to each other. Airlines can use, for example, the International Airline Technical Pool (IATP). Parts can be borrowed under the IATP by paying an access fee plus one-off charges for borrowing and repair. Airlines also pool inventory at various locations.

The cost of borrowing parts under various systems requires careful consideration. "Loan charges are relatively high, and increase in steps. They are often 1.0% of OEM's list price per day for the first 10 days, 1.5% per day for 11-20 days and 2.0% per day for 21 or more days," explains Asbrand. "An airline will pay 45% of list price for a part borrowed for just 25 days; in addition to the repair and administration fees. Returning the borrowed part as serviceable may incur even further costs. These all have to be weighed against keeping an inventory. Typical list prices for avionic units and control units are $165,000-330,000."

It is not possible to buy components in an aircraft of ground (AOG) situation, since it takes several hours to receive a serviceable unit. It is therefore common to take a loan unit, or do an exchange.

A busy line station may have a large number of flights by the same carrier, and so justify the cost of holding an inventory, tooling and mechanics. Other line stations will have a large operation by other carriers with the same aircraft type. The cost of technical support can be justified as a group activity by several carriers.

Remote line stations pose different problems. Ho Chi Min, for example, may cause difficulties for European carriers operating with 777s or A340s. A European carrier may consider using local airlines such as Thai, Malaysian Airlines, Singapore Airlines and China Airlines when a component fails that it does not itself hold. "The certification standards held by these airlines' technical departments have to be considered. They would need to have Joint Airworthiness Regulations (JAR) certification to assist a

Tracking systems have been devised to follow components through the inventory cycle. This provides data on component reliability, allows all warranties to be claimed, highlights excess inventory and locates components in emergency situations.

European carrier," explains Asbrand. "If support from any carrier in the region is not possible, the choices for the airline would be reduced to its own inventory, or using the OEM. The costs of these have to be considered against the probability of each part failing."

On-line portals aid airlines in identifying appropriate sources for material when emergencies arise. This includes the closest suppliers, and parts can often be shipped to aircraft in a few hours to allow replacement to be made. This can cause long delays on a few occasions, but contributes to minimising the inventory held at line stations. Failures of a part not held when the aircraft is at its home base causes less of a problem, since an airline will have scope to re-schedule other aircraft.

Flyaway kits

Some airlines operate with 'flyaway kits', which are a small quantity of essential items, in particular wheels, that are carried on the aircraft and can be changed with relatively simple tooling. "There are only 5-10 items in a flyaway kit, and these are starters, starter valves, hydraulic pumps, weather radar transceiver, wheels and a standard kit of lamps and small items," says Hillen.

Overall, airlines attempt to minimise the risk of a major component failing at a line station that does not have the inventory and technical support necessary to make a repair. These events result in AOG situations, which can only be resolved by the airline flying its own technical team, or a third-party's, to the aircraft to complete a lengthy repair. The consequent cost of delaying or re-routeing passengers has to be weighed against the probability and cost of occurrence. These events can be minimised further by good maintenance practice. Recording failure rates of parts can make it possible to predict failures, and so remove parts before they fail.

The minimal amount of inventory that airlines normally hold at an outstation comprises wheels and brakes. "Airlines flying to new line stations can often borrow parts from other carriers already operating there, or use the IATP pool," explains Asbrand. "The amount of inventory required at each line station can be reduced to the minimum. It is even possible to keep the inventory as low as $200,000 at a long-haul line station. This usually consists of wheels, window wipers, smaller cabin parts, galley components and in-flight entertainment components. This investment level is lower than older types, since modern aircraft have higher reliability and failure monitoring systems."

Line station inventories can be reduced to the minimum. "We only hold a few components, including wheels and brakes at line stations, plus a few cabin items such as seat belts and simple consumables. We are able to fly home in the case of most other parts failing. Avionics rarely cause delays, because of redundancy," explains Lorvik. "Aircraft at the main base overnight go through a check, where parts can be replaced. Overall, redundancy and the ability to defer items means we rarely experience serious failures that result in AOG situations. This is aided by the on-condition monitoring system in modern aircraft types, which anticipates failures."

The amount of labour required at line stations varies. "This can be zero staff if technical services are sub-contracted, or one person supervising sub-contracted mechanics. On average only 2-4 staff are required," explains Hillen. "Component failures can also be predicted and removed at convenient locations because of computerised checks and troubleshooting, instead of trial and error on aircraft without these systems."

Component reliability

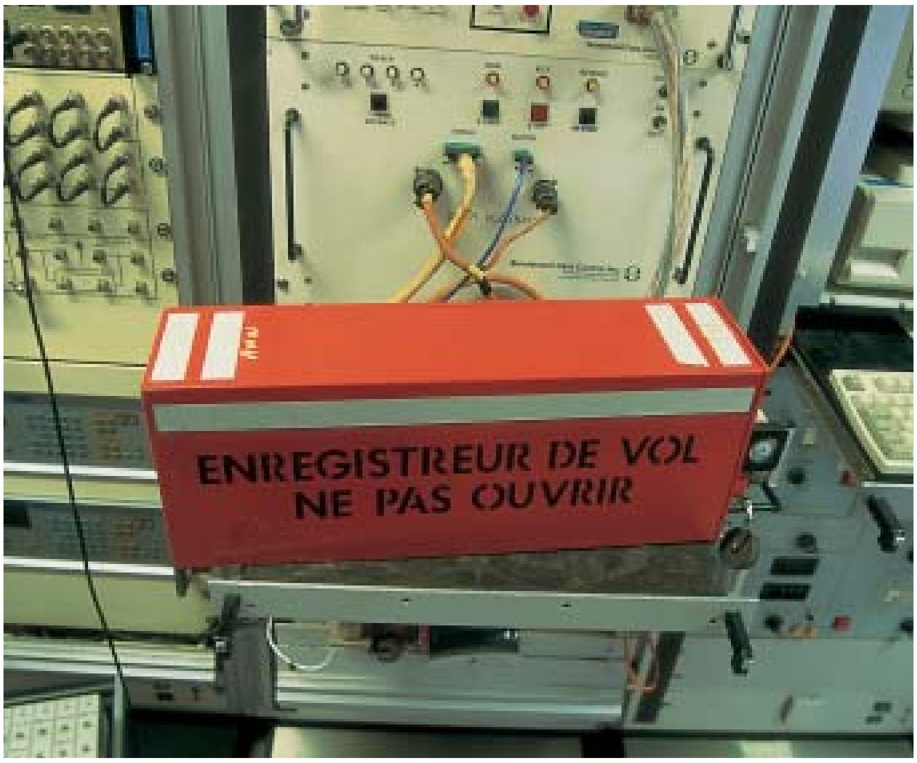
Component reliability will naturally reduce inventory required. While components of modern aircraft have higher levels of reliability, they generally are more expensive than equivalent parts of older types. Improving reliability can contribute to lower inventory costs. This can be achieved through reliability programmes, which are often used to identify which part numbers have the poorest reliability, and which repair vendors supply parts with the poorest reliability record.

"Reliability can also be improved with modifications or upgrades to units by converting to later models or dash numbers," says Asbrand. "These are done using service bulletins, but are relatively expensive. The economic feasibility has to be examined, since the cost of modifications depends on fleet size and the interchangeability of a part with other aircraft types. Modifying the stock of parts for a whole fleet can take several years. Cost for an item can be zero or tens of thousands of dollars if expensive parts have to be added."

Reliability of components goes in hand with NFF. "The occurrence of fault found on removed items can be as high as 50% of removals, and so has a huge impact on inventory required," says Lorvik.

NFF is a frequent occurrence with modern aircraft, since it is the lack of knowledge of a new aircraft by line engineers which contributes to components being incorrectly removed. NFF can be reduced by using various techniques to isolate faults.

"The problem with NFF is that it is even warranty related. Although the OEMs pay for repairs of components under warranty, we have to pay for testing and transport costs of NFF parts under warranty," says Lorvik. "One way to reduce NFF is by tracking parts and vendors with the worst NFF record to



Components are constantly updated with later dash numbers. This can soon result in sub-fleets, with groups of aircraft only be able to use certain dash numbers, and subsequently inflating inventory requirements. Modifications keeps each line number updated to the latest specification. This maintains a uniform fleet and so helps reduce inventory.

identify the root-cause. Good knowledge by line mechanics also makes a large contribution to minimising NFF."

Training of line mechanics in troubleshooting to find other possible faults is a requirement for reducing NFF. "While certain climatic conditions can increase the rate of NFF, there are also rogue units which cause problems," explains Asbrand. "This is one reason for using systems to track individual components."

Commonality

Fleet size has a large impact on inventory required per aircraft. Lorvik estimates that the maximum economies of scale can be reached with a fleet of 50 aircraft. Fleet commonality, however, is complicated by there being several build standards of the same type. Early line numbers of a type from the production line have LRUs and units of early dash numbers. Later production aircraft are built using later dash numbers of the same unit. This results in different specification and build standards, and so sub-fleets. Each sub-fleet requires a different inventory of the specific component, which results in more inventory per aircraft than a fleet with a uniform specification. Older units can, however, be upgraded to later dash numbers and so produce a uniform fleet. The problem many airlines have is that parts with later dash numbers are purchased, and components with earlier dash numbers are left in the inventory because of fears that this will affect reliability. Tracking systems use the serial number of every component to track where in the inventory cycle they are. This allows excess and older units to be indentified so that modifications and disposals can be made.

"Standardisation of several fleets operated by a group of airlines will thus increase commonality if it is repeated for all part numbers on the aircraft," says Lorvik. "We introduced a fleet standardisation programme for our MD-80s and those we provide component support for operated by Spanair, Lionair and MDAir. Even if an expense for standardising component configuration may occur, the inventory cost per aircraft will be reduced." If fleet standardisation through modifying parts is not followed, part numbers will remain the same while later models are continuously introduced. Later dash and part numbers also generally have better reliability than older units. Fleet standardisation therefore becomes an on-going process."

Tracking

Tracking systems for parts can have several other advantages. Mike Hickey, executive vice president of Spirent Systems Aerospace Solutions says IT tracking systems started with airlines simply wanting to know where their components were in the inventory cycle, and their state of serviceability or repair. Spirent's AuRA system tracks parts and allows them to be requisitioned from other stores of parts, which may occur during temporary shortages.

Further sophistication allows the system to tell which dash numbers, models or parts can be used on which aircraft. Parts can also be segregated by ownership, so that borrowed parts, for example, can be returned to owners quickly before daily charges start to escalate. Airlines have often found that borrowing charges have been twice the original list price because the parts were lost in the system.

Other benefits come in the form of managing warranties. These apply either to new or young parts which fail in their warranty period, or repairs which fail within a warranty period. All warranties can be claimed in both cases.

Tracking systems can also be used to keep a database of reliability data for each line number, as well as repair cycle times. Tracking systems allow reliable data to be established.

Hickey estimates that an airline with a fleet of 35 aircraft will have an inventory of $70 million, for which a tracking system can generate annual savings of up to $1.6 million through improved warranty claims and other savings. Many airlines had poor or no data on the reliability of their components, and so were forced to keep an excess of inventory, often buying parts in an emergency if staff did not know exactly where parts were. These parts were then rarely sold again.

Cycle time reduction

Following removal, items are sent for repair and then repositioning in inventory stock. This total time is one influence on the amount of inventory required. Lorvik explains the repair time for components is relatively fixed at 10-15 days. This leaves transport time as a target for reduction and improvement.

"If this can be reduced there is a large knock-on effect in terms of inventory reduction. In our initial analysis for assessing inventory required for the A321 fleet we calculated that for a given number of aircraft reducing transport time from 19 to five days would reduce the amount of inventory from $23 million to $18 million. The relationship between inventory required and transport time is similar to the relationship between inventory per aircraft and fleet size. Reducing transport time requires a number of measures, and we introduced a proactive inventory control to aid this. This means we are measuring the time assets stayed in non-value adding locations." AC