The long intervals between landing gear overhauls and the high capital cost of repair facilities has led to most airlines sub-contracting landing gear maintenance to specialist providers. The overhaul process & other factors influencing the cost of leading gear maintenance are reviewed.

Landing gear repair process & economics

Major and heavy components account for 10% of total aircraft maintenance costs. This includes the cost of repairing and overhauling landing gear.

Landing gear component

The landing-gear component is classified under air transport association (ATA) Chapter 32. Wheel rims, tyres and wheel brakes are also classified under ATA Chapter 32, but these are separate components to the landing gear.

The landing-gear shipset for an aircraft is a nose gear leg plus two to four main gear legs, depending on aircraft type. The main components of each leg are the inner and outer cylinders of the leg strut, which effectively work as a shock absorber. The shock absorber is filled with oil and air, and the internal mechanics of the cylinders provide a critically damped action to prevent hard landing or excessive aircraft bounce on landing. "The inner and outer cylinders of the main strut require the heaviest rework during the overhaul process," says Paul Ruprecht, operations manager at AEM, Ametek MRO.

The nose gear on all aircraft types, and the two inner main gears on the 747, also have a steering collar and associated controls for use during taxi. "Other components are side and drag braces and struts, and various hydraulic cylinders that are all part of the gear lowering and raising mechanism," says Andreas Tielman, vice president of landing gear services at Lufthansa Technik. "Attached to the bottom of each main strut is the bogie beam, which then has one, two or three wheel axles."

There are many other smaller components and sub-assemblies in the overall landing-gear component, including: electrical harnesses; truck-beam assembly; the trunnion assembly; pins; torsion links; and bushings. The bushings are made principally from aluminium-nickel-bronze and corrosion-resistant steel, in the case of the 737 for example, and are used to take the wearing action between two major moving parts, such as struts and braces. There are a large number of bushings, with more than 100 on a single landing-gear shipset.

The main cylinders, struts, bogie beams and axles are manufactured from reinforced, high-strength steel. There are also particular areas with cadmium and chrome surfaces. "The components with chrome surfaces are joined/interface with bronze bushings," says Tielman.

Overhaul intervals

The overhaul intervals of landing gear sets are determined by the need to inspect for, and treat, corrosion. "Component assemblies that contain bushings are the most susceptible to corrosion," says Ruprecht. "There is also the potential for cracks to form in the main structural components. Joints can be lubricated during regular aircraft maintenance to limit, or reduce the effects of, corrosion.

"Overhaul limits for the landing gear on most aircraft types are in the region of 10 years plus a flight cycle (FC) limit," continues Ruprecht. "However, the calendar limit on Boeing Business jets, for example, is longer at 12 years. The FC limit on all types is higher than most airlines' rate of FC utilisation, so the calendar limit is nearly always reached first."

Tielman says that while older variants of the 777 have a calendar limit of about 10 years, younger examples have limits of 11 years. "The actual interval depends on corrosion prevention, so will be influenced by the materials used in the manufacturing process."

The FC limits mandated in the maintenance planning documents (MPD) of various aircraft types are as high as 20,000FC in many cases. "Some operators cut this limit in accordance with their economic needs," says Karel Obrazek, director of landing-gear maintenance at CSA Czech Airlines. "The life limit of many of the gear's parts are 75,000FC, and these are rarely exceeded. Some operators plan for three overhauls during a gear shipset's life, based on an interval of eight or nine years."

Overhaul process

The overhaul process starts with an inspection of the documentation and a visual inspection. "The FC accumulated for the life limited parts (LLPs) on the gear set are checked, while part and serial numbers are cross-checked with those that are presented on the customer's 'off-log'," says Ruprecht.

"The whole gear is completely disassembled, and all bushings and paint are removed. The paint is either stripped chemically or, where permitted, it can also be taken off by blasting with an approved fine plastic bead," continues Ruprecht.

Tielman makes the point that the maintenance of landing gears mainly involves preventing and removing

The long intervals for gear overhaul and the capital required for repair shop facilities means most airlines now sub-contract the maintenance of landing gears.

corrosion. "Preventative maintenance is performed on the components on the landing gear that are maintained on an on-condition basis," says Tielman. "The first action after the stripping of paint is to inspect for corrosion. Some non-destructive tests (NDT) are carried out at this stage."

It is mandatory on Boeing landing gears that all high-strength steel components have the protective cadmium plating surface taken off to reveal the base steel material. "The first inspections involve checking the dimensions of all major parts, along with visual inspections for wear, corrosion and damage, explains Ruprecht. "Once this initial inspection has been completed then the workscope can be defined."

The repair cycle of different components, parts and sub-assemblies starts with an oven treatment of all structural parts. All parts that are prone to cracking have to undergo an NDT inspection, followed by stripping of worn or damaged electroplating, using a chemical bath. "The problem is that some chemical treatments can make the base material brittle, so another oven treatment can be required to remedy this," explains Ruprecht. "Any corrosion is then mechanically removed after the chemical bath, which is followed by a Nital Etch inspection. This is an acid-based bath used to ensure that there are no hardening or softening indications in the base material, caused either by an in-service incident or incorrect machining. The presence of hardening or softening indications may mean that some parts need to be scrapped, although some can be repaired.

"This process is followed by a dual NDT inspection, which involves both a magnetic particle and dye penetrant check to ensure check to ensure that all corrosion has been removed from a component. Parts that have been machined are then put through a shot-peening process, which toughens the surfaces, and make it less prone to cracking," says Ruprecht.

Nickel-plating is generally used to build the surface of a plated zone back to a particular dimension. The chrome plating is applied to the inner cylinder of the main landing gear leg, pins and all other components that have either a sealing or sliding surface.

Plating is followed by a third oven treatment, which removes from the components the brittleness caused by the hydrogen molecules imparted during the plating process. The plated components are then machined to component maintenance manual (CMM) dimensions. As this can also have a weakening effect, a fourth oven treatment may be required. Cadmium plating is then applied as a protective coating to those areas of the base material defined in the CMM.

After a further oven treatment and an NDT inspection, parts go through a passivation process to seal the cadmium that has been applied as a primary protective coating to the areas defined in the CMM.

Reassembly then commences, followed by a test prior to shipping. "The total downtime for a landing-gear shipset is about 28 days for a 737, but shipping and receiving time has to be added to this. Some customers schedule their own collection," says Ruprecht.

The total downtime, which includes all removal, packaging, logistics and transport, combines to add additional days to the overhaul process. Some overhaul shops define the total downtime when negotiating complete support packages for customers. Sabena Technics, for example, usually offers a package of six to eight weeks.

Sabena Technics also provides long-term contracts to its customers for complete fleet landing-gear maintenance and overhaul programmes. These can include assistance with the timing of removal of gear shipsets for overhaul.

Maintenance requirements

Tielman says that the downtime for a narrowbody landing-gear shipset is about 35 days, and 50-60 days for a widebody landing-gear shipset. The 10- or 11-year interval of most landing gears means that a shipset will only go through two or three overhauls in its operational life. "The gears on older aircraft types require a lot more rework at their second and third shop visits, compared to what is expected for the gears on younger types," says Ruprecht.

The labour required to overhaul a gear shipset for a particular aircraft type is predictable, since most of the workscope is routine. It is only the non-routine repairs that arise when corrosion, damage or weakness are found, which vary between different shipsets. Most of the cost involved in the overhaul process relates to the tooling and equipment, and parts and materials consumed.

Bushings account for one of the biggest costs of parts and materials, as do the seals, bearings, nuts, washers, paint, and the nickel, cadmium and chrome plating materials. Overhaul shops incur several other consumable costs in respect of: acid baths and other chemical treatments; oils, greases and paints; and machinery parts used in the grinding processes.

"Occasionally large parts and components have to be replaced as a result of failing an initial inspection because they are beyond repair or OEM concession limits," says Ruprecht. "A large inner cylinder on a 737 main landing gear can cost about $130,000, for example. Fortunately fewer than 5% of cylinders and other major parts have to be replaced."

The percentage of bushings that are replaced depends on airline policy.

The factors that affect the cost of

Airlines can keep spare gear shipsets to keep their aircraft operational when gears are removed for overhaul. Landing gear repair & overhaul specialists, however, provide spare gears either through loan or exchange programmes.

overhaul are therefore the airline's operating environment and its pattern of operation. Corrosive environments, such as salty atmospheres near coastal and oceanic areas have a detrimental effect; as do higher than average amounts of rainfall, ice and snow, which contaminate landing gears during the landing phase. "Some operators make the mistake of regularly washing and cleaning their landing gears during routine line maintenance," says Obrazek. "This removes grease, which actually acts as a protective layer against corrosion; while the water used for washing is also corrosive. It can even halve the overhaul interval. It is also extremely harmful to use chlorine-based disinfecting agents."

Besides these, there is also the standard of the previous shop visit, and the service bulletins (SBs) and airworthiness directives (ADs) that have been applied.

Operators should also be careful to have an exact record of what parts and components have to be sent to the overhaul shop, and which parts have been removed. Missing parts are often a cause for additional cost.

Costs of gear overhaul

The long intervals between gear overhauls result in relatively few annual shop visits for most airline fleets. This means that the number of gear overhauls per year will only be 10-12% of aircraft in the fleet. Gear overhauls may also not be evenly spaced because of the fleet's original build and delivery profile, while the capital investment for a gear overhaul shop and all its associated equipment and tooling is high. As a result, many airlines, even large ones such as British Airways, outsource landing-gear overhaul to specialists.

Third-party providers offer a variety of services, but many airlines are primarily concerned with the provision of spare units while the gear sets they have removed are being overhauled. Many third-party providers provide such support under either exchange or loan programmes, and charged as pre-agreed fees. This means that airlines do not need to carry the cost of investing in their own spare gear inventory. The third-party providers therefore carry one or more spare gear sets for each aircraft type.

The simpler option is a loan programme, whereby the gear shop provides the airline with the designated spare gear set, which is fitted to the aircraft while the airline's gear set is overhauled. The spare gear set is then removed when the airline's overhauled gear is returned. The loan fee charged by the gear shop will be determined by: how many times the spare shipset can be loaned each year, and within its own overhaul interval; its own overhaul costs; and its capital cost and accrued interest. A loan fee can be less than an exchange fee. "A simple loan can be more economic if the gear removal is timed to coincide with a heavy airframe check which has a downtime that exceeds the length of the gear overhaul. This allows the operator to keep its aircraft flying and generating revenue," says Ruprecht.

The negative aspect of a gear loan, however, is that the spare gear has to be returned to the repair facility, which involves removing and installing a gear shipset twice for every gear overhaul.

Under an exchange programme, a spare gear is installed on the aircraft, and the gear shop and airline exchange ownership. Once the airline's gear has been overhauled after 30-60 days, it then becomes the spare gear set, and is exchanged with the next airline that removes a gear set.

The exchange fee is again determined by the number of overhauls the spare gear set can support within its own overhaul interval. This will be more than in a loan programme, since less time will be spent transporting and shipping the gear set, and installing and removing it from the aircraft.

The second element of the cost of landing-gear overhaul, as charged by a third-party provider, is the fixed cost of repair and overhaul that can reasonably be predicted. This cost is intended to cover all expected work, including: facility tooling, equipment and overheads; labour; consumables; materials; the replacement of LLPs; and the consumption of parts that can be reasonably predicted.

A third element of sub-contracted landing-gear overhaul is the variable

There are generally three main cost elements for landing gear overhaul. These are the exchange fee, fixed or pre-agreed overhaul cost, and cost of non-routine repairs. Additional costs can be incurred for service bulletins and upgrades.

costs; or those of unexpected work and non-routines that arise from inspections and failed parts. This clearly varies between individual gears, and on a small number of occasions can be high when items such as main strut cylinders fail inspection. "The decision to replace parts is taken by the original equipment manufacturers (OEMs). The limits in the CMM have to be consulted when findings are made, which are sent to the OEM by the overhaul shop," says Tielman.

A fourth cost element, which is not always included for each gear set, is the incorporation of SBs, which will be upgrades released by the OEM since the last overhaul. Tielman points out that the number of SBs released generally declines as the associated aircraft type ages.

Some third party providers, however, offer time and material contracts, so that while there is less predictability, the airline pays for what is actually used on each gear shipset.

There are several factors that affect the total cost of landing-gear overhaul. The first is clearly the size of the gear and the number of main legs and wheel axles. There is clearly less variance in this between narrowbodies, since the 737 and A320 families have a lot of commonality in the gears used on each variant. The 757, however, has a larger gear, with two wheel axles on each main gear.

There is more variance with widebodies. Many types have two main gear struts, but the DC-10, MD-11 and A340 models have a third centre main gear. The 747 and A380 have four main gears, and two have steering columns. All widebodies have two wheel axles on the main gear legs, except the 777 which has

Not only do widebodies have more legs and axles than narrowbody gear sets, but the larger size of widebody gears also means their repair and overhaul takes longer. Larger gears also require larger equipment, such as chemical baths, lathes and grinding machines.

Some of the factors affecting the total cost have been described, and all relate to the level of non-routine repair and parts replacement required. Ultimately this depends on the style and environment of operation, and maintenance practices. A simple procedure is to routinely lubricate moving joints and parts.

Economics of overhaul

There are several major providers of landing-gear overhaul and management services. Market rates for exchange fees and fixed overhaul costs depend on supply and demand for repair services. These is less variance in market rates for the main types in the jet fleet: the 737NG, the A320 family, the 757, 767 family, A330/340 family, 777 and 747-400. These are stable fleets, often with few aircraft available on the used market at any one time.

The availability of fleets of aircraft types in large numbers on the used market means that components, including landing gears, are available in large numbers on the used market. This reduces exchange and loan fees. While repair fees may not differ much from older types, the availability of large numbers of parked and stored aircraft means gears can be removed from them. This is only economic, however, if there is a reasonable amount of calendar time remaining on the gear until its next overhaul.

Some examples of these three main fees for some Boeing aircraft indicate how market rates have changed over the past 10-12 years *(see The economics of landing gear maintenance, Aircraft Commerce, July/August 2000, page 29).*

The MD-80 is now an ageing fleet, so exchange fees are relatively low at $140,000-170,000 for a shipset. Fixed cost overhaul fees are also low at $180,000-200,000. Additional non-routine costs may average $45,000; taking the total cost for a shipset to $365,000-415,000.

Demand for the 737NG will clearly be higher than for the 737 Classics, with the 737NG being in a phase of steadily increasing demand as the fleet grows. Exchange fees for a shipset are typically $200,000, fixed overhaul costs at $250,000-275,000, and non-routine costs average $45,000. Total for the three elements is thus $500,000-525,000.

The 757 fleet is operating in large numbers, with the aircraft still in high demand. Exchange fees charged by overhaul shops vary from $125,000 up to more than $200,000. Fixed repair and overhaul costs are $250,000-375,000, and an additional $50,000 can be expected for non-routine costs for most gear sets. This takes the total from $450,000 to $575,000 for gears that are required for higher gross weight, later-build 757s.

Rates for gears on the 767 family vary with different models and variants. The 767-200/-200ER fleet has now diminished, while the 767-300ER is still operated in large numbers. Current market exchange fees are $260,000-365,000, repair and overhaul fees $375,000-440,000, and additional non-routine costs of up to $80,000 take the total to $715,000-885,000.

Market rates for the 747-400 have dropped in recent years following the retirement, parking, and scrapping and parting-out of a large percentage of the fleet. Exchange fees have dropped to $100,000-150,000. Fixed repair and overhaul fees are $475,000-500,000, and additional non-routine charges can average $100,000 for most shipsets. This therefore takes the total to $675,00-750,000. AC