Landing gears, and wheels and brake systems represent a small but vital part of overall airframe maintenance. Each component undergoes wear and tear in everyday operation. While the landing gear is a heavy component that is often hard-timed, wheels and brakes are monitored on-condition. An overview of each component's maintenance requirements is provided.

Landing gear, wheels and brakes maintenance

In day-to-day operations, the landing gear, and wheels and brakes undergo stress – or wear and tear – during take-off and landing. Their performance during these stages of flight is critical, and regular monitoring is essential. Maintenance of the landing gear, and wheels and brakes is, therefore, most affected by flight cycle (FC) utilisation.

Components for the landing gear and wheels and brakes are grouped under ATA Chapter 32, which details each component and system required to activate the landing gear system. Acknowledged as part of 'airframe maintenance,' ATA Chapter 32 is one of 38 chapters relating to the airframe. Other chapters cover the auxiliary power unit (APU), hydraulics, flight controls, electrical power, fuel, pressurisation and so on. A further 17 chapters pertain to engine maintenance.

Landing gear maintenance, per Chapter 32, covers the maintenance of: gear doors, retraction system, gear, brake controls, tyres and wheels, hydraulic controls, steering and indication *(see The economics of landing gear maintenance, Aircraft Commerce, July/August 2000, page 29)*. Maintenance of the landing gear, wheels and brakes is, therefore, generally grouped together as its own area of airframe maintenance, repair and overhaul (MRO). This does not, however, mean that removal intervals are aligned between these components. As will be discussed, there are elements to gear, wheel and brake maintenance that are relatively easy to plan for, while other elements prove more difficult to schedule.

Where possible, this article will give build variations, observations and costs for aircraft, including A320, A330, 737, 747, 757 and 777 fleets. Considerations include cost of repairing common findings, non-routine (NR) shop visits (SVs), overhaul processes and sub-contracted fees, and operational factors that affect these costs.

Maintenance planning

Landing gear maintenance is generally determined by parameter-defined intervals, making it easy to plan into routine maintenance. These parameters are a set number of flight cycles (FC) or years, whichever comes first (wcf) for the aircraft per its operational profile. These intervals, combined with aircraft utilisation, make it easy to predict when a landing gear requires an SV, that is, whether the calendar or FC parameter is likely to be met first. Unless defects or observations arise in day-to-day operation, maintenance planners can opt to coincide landing gear maintenance with a routine base check, or plan to swap gears during aircraft operation.

Predictable maintenance is also beneficial from a cost perspective. Most landing gear maintenance is sub-contracted to specialist MRO providers or the original equipment manufacturer (OEM), which poses a logistical consideration for airlines. These gears will, therefore, often need to be shipped to a landing gear shop for maintenance. Such providers will have a pool of spare landing gears available to exchange, or an airline will need to have an inventory of spare landing gears themselves to keep aircraft flying during the SV. Airlines often do not want the maintenance of a landing gear spares inventory, so they will rely on the exchange gear pool offered by the landing gear shop. The lead time for a landing gear SV can take weeks to procure parts and perform specialist repairs; shipping and exchanging gears must be factored in to minimise operational disruption, which means additional overhaul costs, but reduced downtime for the aircraft.

Airlines will require provision of spare landing gears while their own units are overhauled to keep aircraft operational. Since maintenance of a spares pool can be an unwanted logistical and economic consideration for the operator, the landing gear MRO will, therefore, often provide the spare, either via a loan programme, so that the airline receives its own gear back after its overhaul, or by a direct exchange. Overall costs can be minimised for operators that plan landing gear SVs during routine heavy base maintenance, if the downtime of the base maintenance exceeds the SV duration of the landing gear. This is not guaranteed, however, and loan gears may be required. Loan agreements also incur a loan fee, and the cost of transporting the spare gear to and from the spare provider's facility, and of removing and installing it twice.

A direct exchange, however, means that upon removal of the landing gear for overhaul, a spare is installed on the aircraft and the provider and airline exchange ownership of the gears. The gear that is admitted for overhaul becomes part of the landing gear shop's spares inventory after overhaul. Logistically, this is easier for the airline, since it has mitigated against the risk of a potentially disruptive landing gear SV, but an exchange fee still has to be factored in.

Another option is fixed overhaul fees, which allow cost transparency between the provider and the airline, unlike a time-and-materials (T&M) arrangement. Fixed overhaul fees also remove bidding and SV availability issues as and when

ICF MRO SPEND FORECAST (CONSTANT 2016 $) - BY AIRCRAFT TYPE

Aircraft Type	2016 $	2021 $	2026 $	10 Year CAGR
Landing Gear				
737	126,607,924	172,959,470	233,317,783	6.3%
757	12,941,871	15,153,349	8,807,196	-3.8%
767	39,279,625	22,680,664	16,844,494	-8.1%
777	106,106,000	110,074,169	118,474,149	1.1%
A320	164,749,970	216,958,652	286,786,845	5.7%
A330/A340	128,597,411	109,383,526	105,065,685	-2.0%
Others	142,382,401	199,848,250	268,191,157	6.5%
Wheels &Brakes				
737	1,071,024,431	1,510,547,070	1,829,370,863	5.5%
757	68,348,554	42,214,873	18,018,807	-12.5%
767	141,171,422	98,624,382	66,543,386	-7.2%
777	496,112,887	493,336,094	376,295,720	-2.7%
A320	1,290,127,338	1,751,379,270	1,983,752,344	4.4%
A330/A340	375,824,342	391,104,170	350,689,507	-0.7%
Others	1,231,267,956	1,610,700,814	2,131,974,077	5.6%

Source: ICF

landing gear maintenance is needed in the fleet. A large portion of landing gear maintenance costs can be predicted within an overhaul workscope, and so fall within a standard fixed overhaul fee. This typically covers the routine workscope, labour, tooling, consumables and the landing gear shop's general overhead. Other elements, such as NR work, service bulletin (SB) actions, airworthiness directives (ADs) and part replacement requirements, fall outside such an agreement.

Meanwhile, wheel and brake maintenance is monitored and carried out on an 'on-condition' basis. This means that there are no calendar, flight time or flight cycle parameters defined by the OEMs to dictate when tyres, wheel and brake systems should come off for inspection. Instead, line mechanics make these decisions when performing daily inspections during operation. It is, therefore, important for an operator to emphasise the monitoring and condition of its fleet's wheel and brakes within its aircraft maintenance plan (AMP) to avoid additional non-routine SV costs. Compared to landing gear MRO, wheel and brake maintenance is smaller in terms of workscope, yet higher in terms of volume and frequency. A greater number of variables also affects wheel and brake maintenance due to on-condition maintenance requirements.

The global market

A 10-year forecast for the global MRO spend on landing gear, wheels and brake maintenance is provided by ICF *(see tables, this page and page 62)*. This data is divided by aircraft type across several fleets and by region. According to ICF's figures, landing gear maintenance activity for the 737 (Classic and NG), A320 and 777 fleets will continue to rise over the next decade, while MRO requirements for the 757, 767 and A330/A340 will decline as the fleet further shrinks. Asia Pacific and Europe remain the two most active regions for landing gear, wheels and brakes maintenance. Within the decade, however, North America's activity will have increased to match Europe's SV volume.

Suppliers

ICF lists 10 main landing gear providers that service the A320, A330, 737, 757, 767 and 777 global fleets. Safran has MRO locations in Singapore, France, UK, US and China. It offers landing gear maintenance across A320, A330, 737 and 777 models. Meanwhile, UTC Aerospace (based in Canada and Miami, FL) can service landing gear for the 737, 757, 767 and 777.

Lufthansa Technik (LHT) maintains A320, 737 and 767 systems from its Beijing facility; A320, A330 and 737 gear from its Hamburg base; 737, 757, 767 and 777 from its UK office; and A320, A330, 737, 757 and 767 systems in California.

ST Aerospace services A320 and 737 landing gear in Singapore, while GAMECO has capability for the A320, A330 and 737. Landing gear maintenance for the 777 is in development.

Revima, based in France, can perform MRO on A320, A330, 757 and 777 landing gear. HAECO has a shop for A320, 737, 757, 767 and 777 gear in its Xiamen MRO facility.

Dublin Aerospace offers landing gear maintenance for A320, A330 and 737 fleets at its Dublin shop. AAR offers full gear, wheels and brake maintenance for the A320 and 737 from its Miami facility.

Leading wheels and brakes MRO providers again include AAR, Safran, UTC Aerospace and LHT. In addition, Honeywell performs this MRO for the A330, 737, 767 and 777.

Air France Industries and KLM Engineering & Maintenance (AFI KLM E&M) offers A320, A330, 737 and 777 via its Orly and Charles De Gaulle airport facilities.

Aviall (a Boeing company) has seven US locations that can perform wheels and brakes maintenance across all the listed types. Last, World Aero can provide wheels and brakes MRO across all types via its facility in Sussex, UK.

Landing gear system

"The main landing gear shipset requiring hard time overhaul is consistent in both Boeing 737NG and Airbus A320 aircraft. This consists of the main landing gear and dressing assembly, a side stay with locking actuator, and retract actuators," says Paul Brennan, head of landing gear services at Dublin Aerospace. "There are also forward and aft pintle or trunnion pin assemblies. In addition, Boeing also include the uplock assembly for overhaul."

"Meanwhile the nose gear shipset comprises a leg and dressing assembly and forestay across both Boeing and Airbus models. There are however some variances on units included as part of the gear installations, such as swivel attach bearings on A320 aircraft, but no hydraulic steering module. Meanwhile, the retract actuator on the B737 nose landing gear is not included for overhaul however the Steering Metering Valve is included as part of the installation, so there are subtle variations between the fleets' landing gear system configurations," adds Brennan.

Brennan explains that the complete landing gears are typically removed either because they are due for overhaul, or


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ICF MRO SPEND FORECAST (CONSTANT 2016 $) - BY REGION

Landing Gear				
Aircraft Type	2016 $	2021 $	2026 $	10 Year CAGR
Africa	24,484,470	30,477,015	38,723,871	4.7%
Asia Pacific	228,069,118	347,240,797	327,305,388	3.7%
Europe	206,048,670	164,896,992	242,974,774	1.7%
Middle East	51,800,643	95,316,973	118,971,512	8.7%
North America	156,265,571	152,987,586	242,729,516	4.5%
South America	53,996,731	56,138,715	66,782,248	2.1%
Wheels &Brakes				
Africa	146,865,514	208,292,684	282,838,317	6.8%
Asia Pacific	1,668,119,851	2,146,801,636	2,470,406,185	4.0%
Europe	1,147,516,555	1,369,294,349	1,510,821,549	2.8%
Middle East	367,542,990	518,363,753	593,627,950	4.9%
North America	1,045,353,651	1,255,643,050	1,445,779,950	3.3%
South America	298,478,370	399,511,201	453,170,753	4.3%

Source: ICF

some incident related reasons. The original equipment manufacturer (OEM) component maintenance manuals (CMMs) outline tolerances that determine what repairs can be carried out when each landing gear requires overhaul, and when parts require mandatory replacement. During periods between overhauls defects will be observed and monitored by line or base maintenance mechanics while the aircraft is in operation or during scheduled base maintenance.

AAR overhauls landing gear, wheels and brakes in Miami. In addition, this facility can carry out full landing gear maintenance requirements, including: inspection, plating and machining; non-destructive testing (NDT); engineering, painting & assembling; and brush manufacturing. "Removal intervals are determined by the OEM's maintenance planning document (MPD) or operator maintenance plan (MP)," explains Scott Ingold, vice president & general manager at AAR Landing Gear Services. "They can take place when an overhaul is needed, when a repair is needed, or if the operator wants to swap gears."

Brennan of Dublin Aerospace places average landing gear overhaul removal at 20,000 FC or 10 years, wcf.

"The specifics of each platform depend on the OEM's MPD," continues Ingold. "Typically, Boeing's product line recommends a time before overhaul (TBO) of 10 years or 18,000FC, wcf. The recommendation on Safran's product line is 10 years or 20,000FC, wcf.

Shop visit

The process of inspecting, removing and overhauling the main landing gear is determined by OEM guidelines. "OEMs such as Boeing and Safran provide the necessary guidelines, including the Aircraft Maintenance Manual (AMM), which is used to remove the landing gears from the aircraft," says Ingold. "After we perform an initial inspection to evaluate the condition of the gears, we disassemble the gears in accordance with the respective component maintenance manual (CMM), military technical orders (TOs) and the OEM's standard overhaul practice manuals (SOPM). This is necessary to break down each landing gear, which translates to processing the gear by each single component it comprises (for example, main fittings, pistons, axles, pins, brackets and nuts).

"Each component is inspected according to CMM and TO guidelines," continues Ingold. "For instance, Boeing Service Letter 737-SL-32-165-A regarding 737NG landing gear restoration requirements states that restoration is achieved by returning components to a design condition by replacing worn bushings, replacing the sacrificial/protective finishes that protect the parts from corrosion, and inspecting for and correcting defects.

Brennan explains that the expected turnaround time for a landing gear overhaul SV is 35-45 days, depending on the workscope. Spares availability can also impact this downtime. Dublin Aerospace's landing gear SV guide typically involves: pre-clean of the gear; check-in and list of missing/excess parts that arrive with the shipset; disassembling the gear into piece parts (gear assembly, side strut assembly, uplock assembly, and walking beam assembly); clean and paint strip; performing the full inspection and NDT, using methods such as magnetic particle inspection or dye penetrant inspection, adds Brennan. Findings can include worn parts, corrosion, or crack detections. After necessary repairs are performed (see repair processes), each part is then re-protected with electro- or dip-chemical plating, and fully repainted. The landing gear system is then re-assembled, tested, certified and returned to the customer.

The importance of proper maintenance, including service and re-greasing schedules can significantly impact on the final overhaul costs for a gear set, as this will reduce wear corrosion and heat damage during the operational 10 year life cycle of the gear.

Repair process

In addition to overhaul, a landing gear may require an SV for repair or exchange. This can be due to NR findings that arise while the aircraft is in operation. These NR findings might be observed due to hydraulic leakage or excessive vibration during taxi, or while the gear is extended or retracted in operation, in addition to brake seizures causing heat damage.

Typical findings for a landing gear in an SV include bushing wear, chrome wear on inner cylinders, and base metal ladder cracking on sliders, according to Brennan. "Excessive corrosion, bent or broken fasteners, improper maintenance during gear operation and mishandling during gear removal from the aircraft are the most common repair causes," says Ingold. The CMM and SOPM outline appropriate repair guidelines for each aircraft type.

If corrosion is found, machine removal is required to remove corrosion, normally. Grinding, boring, or hand blending are common repair methods for the landing gear, according to Dublin Aerospace. Electroplating is then utilised to coat or 'reprotect' the gears in durable, non-corrosive substances. Brennan advises that the most common plating processes are anodising, cadmium, chromium and nickel-based coatings. Each offer wear resistance and corrosion protection, while nickel is also used for dimensional restoration if corrosion needs to be removed.

Overhauls

Landing gears tend to be overhauled every 10 years. "These can be overhauled any number of times as long as the total life of the gear, usually set by the OEM at 60,000-70,000FC, is not exceeded," says Brennan. "The total safe limit of the components is determined in the MPD," adds Ingold. "Typical safe life limits for new components range from 50,000FC to 100,000FC." An overhaul workscope for the landing gear largely comprises routine work, so a large percentage of costs are predictable. NR work is mostly due to the findings listed above. While a large

WHEEL RETREAD & REPLACEMENT EXAMPLE COSTS - VARIOUS AIRCRAFT

AIRCRAFT TYPE	RETREAD ALLOWED	RETREAD INTERVAL	TYRE RETREAD $	LIFECYCLE RETREAD $	NEW TYRE COST $	NO. TYRES IN SHIPSET
MAINWHEEL						
A320	4	400	750	3,000	1,800	4
737NG	6	175	600	3,600	1,655	4
A330	4	350	950	3,800	3,100	8
757	6	300	450	2,700	1,150	8
767	6	225	600	3,600	2,025	8
777	4	300	950	3,800	2,800	10
NOSEWHEEL						
A320	4	350	450	1,800	730	2
737NG	10	125	225	2,250	460	2
A330	4	300	550	2,200	1,500	2
757	6	200	275	1,650	675	2
767	10	200	335	3,350	1,100	2
777	4	300	550	2,200	2,150	2

Source: World Aero

NOTE: Guideline only. To be treated an example of cost & maintenance management considerations. Lifecycle costs will vary according to the operation of individual aircraft.

percentage of parts and materials costs relates to consumables, such as bushings, washers, nuts and plating materials, the cost of the grinding/plating machinery, and chemical treatments also needs to be taken into account.

Maintenance costs due to NR findings, treatments and landing gear overhaul will also be subject to the maintenance strategy the operator has for these components, that is, whether the airline operates via an exchange programme, T&M, or a fixed overhaul agreement for the fleet's landing gear.

Maintenance costs

The three separate elements to take into consideration when summarising landing gear MRO are: average exchange fees; expected fixed overhaul fees; and general NR costs over the lifetime of the landing gear shipset and SV turn around times. These vary substantially between narrowbody and widebody landing gear systems. As widebodies are larger and have a greater number of landing gear legs and axles, larger equipment is needed to clean, inspect and repair them. This all impacts the cost of overhaul *(see landing gear repair process and economics, December 2011/January 2012, page 30)* and varies across aircraft types. For example, the 747 and A380 each have four main gears, two of which have steering columns. While most widebodies have two wheel axles on the main landing gears, the 777 has three. There is further commonality among the main narrowbody fleets. For example, 737 and A320 systems are structurally very similar, with six wheels in a shipset, set at the same configuration.

SGI Aviation has provided some guideline figures for landing gear maintenance across the A320, A330, 737NG and 777. According to Remko Bruinsma, head of asset & lease management at SGI Aviation, exchange fees for the A330's gear shipset are $180,000-200,000.

Meanwhile, the fixed overhaul fee for a 737NG landing gear is $150,000-200,000. Expected non-routine costs can be $200,000-250,000 across the 10YR interval of a full 737NG landing gear shipset Fixed overhaul fees for the A320 are a little higher at $200,000-250,000, although expected NR costs are the same. For the 777, Bruinsma estimates the average fixed overhaul fee to be $400,000-500,000, while expected NR costs can reach $500,000-600,000 between intervals.

The emergence of the A320neo (new engine option), 737MAX and, eventually, the 777-X suggest design improvements that either prolong the removal interval or reduce costs for landing gear maintenance. "The A320neo and 737MAX offer a lot of corrosion-inhibiting design improvements, such as heavier chrome deposits in seal areas, and the use of high velocity oxygen fuel (HVOF) finishing to reduce wear" says Brennan.

"Application of new surface finishes, such as HVOF or thermal spray, enhances wear resistance on major components, and these are present on many new-generation models," says Ingold. "New material, such as titanium, also significantly improves corrosion resistance and expedites the repair process." AAR Landing Gear Services is working on implementation of this HVOF application technology.

Availability of spares across both Boeing and Airbus airframes influences maintenance downtime for landing gear SVs. Brennan says that consumable spares availability is generally good for both models, though there may be some delay issues on high cost parts such as inner cylinders, sliders, barrels, or some specialised oversized bearings.

Wheels & Brakes

Wheels

Regular inspections are vital to control and mitigate against unscheduled wheel SVs. By doing so, operators with high utilisation, such as low-cost carriers, can prevent unnecessary repair work or downtime that causes disruption.

The problem is that tyre and wheel system inspections are open to interpretation by mechanics. A 'visual inspection' can be carried out differently from mechanic to mechanic during the line maintenance / pre-flight check. While guidelines on removal, repair and overhaul are provided by respective maintenance manuals, instructions for inspections are relatively vague. An operator, therefore, is responsible for incorporating such frequent or extensive inspections into its own AMP, so the regularity and extent of such maintenance varies from operator to operator, and region to region.

According to AAR, under normal circumstances the tyre will dictate the removal interval of the wheel. The condition of these parts, therefore, is vital to avoiding unforeseen SVs. As wheel maintenance is on-condition, removal intervals can vary widely. This is especially the case for systems that are monitored on-condition. An SV may, therefore, result from observation by a line mechanic during a routine daily inspection, or it may arise during an A or C routine check. "Wear, cuts, loss of pressure, rejected take-off and foreign object damage are all reasons for wheel removal," says Ingold. "Other factors affecting removal intervals are runway conditions, temperature and proper tyre maintenance. During summer months, tyres wear out quicker than in winter. Also, operating under-inflated tyres can lead to excessive tread shoulder wear, resulting in early removal. Main wheel tyre treads vary from 175FC to 250FC between tyre tread intervals. Nose wheels can vary from 250FC to 350FC."

"The wheel shipset comprises the tyre, bolts, bearings, heatshield and wheel hub," says Phil Randell, managing director at World Aero. The UK wheels and brakes company has recently undertaken its 20,000th component repair, after commencing this type of MRO in 2008.

Randell advises the need for regular overhaul inspections of the wheel system as well as tyre changes, in order to prevent additional non-routine (NR) costs due to major defects and repair. In a tyre change SV, the wheel system will be dismantled, cleaned and inspected for wear and tear. "One of our clients has 80% of its fleet wheels go through these SVs at no additional costs due to the frequent inspections," he says. "18% go through needing new bearings and items such as tie-bolts heatshields, which require minimal part investment. Last, only 2% of the fleet on average require specialist repair or machining."

If, however, an operator only brings its wheels in for overhaul, having carried out its tyre changes to differing standards, it is common for unforeseen costs to escalate. "In our experience, 100% of overhaul SV-only customers need piece part replacement, with about a quarter requiring additional costs due to specialist repair or part replacement," explains Randell.

Tyres

AAR advises that tyres be removed when wear level reaches the bottom of any groove or 'tread'. "The tread minima for tyres is often are little ambiguous," says Randell. "The tread is therefore often visually determined by line mechanics and can vary between operators with differing opinions."

On average, Randell advises that tyres are changed on a wheel four to six times before the wheel rim needs an overhaul. The tyre change itself is simple, taking 1-2 man-hours (MH). Randell estimates that a tyre change costs $1,000 for a nose wheel and $2,000 for a main wheel, depending on aircraft type. On average, a nose wheel tyre is expected to last 250FC before change is required, whereas a main wheel should perform up to 350FC.

Approximately every five changes, overhaul of the wheel is needed. This happens, therefore, on average, about every 2,000FC according to Randell. He also explains that tyre maintenance and changes will sometimes be undertaken by local suppliers to an operator, because they do not travel long distances well, in addition to the relatively light nature of their maintenance requirement.

Repair processes

Repairs to the wheel system are most commonly a result of non-routine observations during shop visits.

The wheel system may need repairs to bearing bore bushes due to wear and tear. The wheel hub may also sustain foreign object damage (FOD) while in operation. "A damaged hub can be machined out to oversized dimensions before a sleeve is inserted to return the hub to the required fit for the wheel system," says Randell. This repair takes about 8MH to perform if needed.

Other than these, a large part of the wheel system comprises consumables. Bearings and tie bolts, for example, will be replaced rather than repaired if an inspection during the SV indicates wear or corrosion. "A bearing costs about $160, so repair is not economical," says Randell "The essence of wheel maintenance is low-cost but high volume. The wheel hub is the most expensive part in the system: an A320 main wheel hub costs $10,000-15,000, so it would be repaired rather than replaced, unless the

GUIDE WHEEL RIM LIFECYCLE MAINTENANCE COSTS

AIRCRAFT TYPE	REPAIR INTERVAL FC	NO. OF INSPECTION	INSPECTION COST $	OVERHAUL COST $	NEW RIM COST $
MAINWHEEL					
A320	400	4	450	2,000	13,000
737NG	175	5	450	2,000	7,500
A330	350	4	450	2,000	14,000
757	300	4	450	2,000	7,500
767	225	5	450	3,000	8,500
777	300	4	450	3,000	15,000
NOSEWHEEL					
A320	350	4	300	600	11,000
737NG	125	5	300	600	3,500
A330	300	4	300	750	10,000
757	200	4	300	750	6,500
767	200	5	300	800	6,500
777	300	4	300	800	13,000

Source: World Aero

NOTE: Guideline only. To be treated an example of cost & maintenance management considerations. Lifecycle costs will vary according to the operation of individual aircraft.

damage exceeds the dimensions we can repair to. In this case the hub is scrapped and replaced."

"Wheels can go through four or five tyre changes between overhauls," says Ingold. "Various repairs can be performed in between. On the wheels, the most common repair is local blending and polishing to remove minor corrosion and dents. Heavier corrosion is removed by machining. A baring bore repair is performed quite often when the bearing bore is worn beyond limits and requires installation of a bushing. This repair could be performed several times as long as the wheel stays within minimum limits.

"Alternatively, a flame spray procedure could be performed where the bore is filled and machined," continues Ingold. "Another common repair involves machining the torque bar hole when it has worn to the maximum limit and installing a bushing. This repair can be carried out until the hole has reached the maximum allowable limit, after which the wheel must be scrapped."

Cost data logic

It is not easy to compile a truly representative set of costs for the lifecycle of wheels and brakes systems, because of the on-condition nature of maintenance. SV frequency and workscope can be determined by a variety of factors, and these will inevitably vary among operators. "Wheel and brake maintenance is subject to the greatest number of variables within overall airframe maintenance," says Randell.

Costs are, therefore, difficult to rationalise or predict. Factors that influence this maintenance include:

- Climate: "Performance and maintenance costs can vary extensively according to the region," says Randell. "For instance, a cold environment is generally more favourable than a hot one, in terms of product longevity. We have seen Scandinavian operators double the life of their tyres, for example, compared to operators in southern Spain." Furthermore, different regions, under different regulation, will have varying standards for what constitutes satisfactory tyre life remaining, and removal intervals, because of the subjective nature of visual inspection."
- Utilisation: Combined with climate of operation, utilisation has a significant impact on removal intervals between operators. "Operators with long sector utilisation, and, therefore, lower FCs over the same period of time, experience different removal and overhaul frequencies to those with higher rates of FC utilisation," explains Randell. "This will affect long-term overhaul patterns and costs."
- Seasonal variations: These have a huge impact on wheel and brake maintenance. "High FC utilisation to warmer airports, such as during summer months in the Northern Hemisphere, naturally causes a peak in wheel and brake SV activity in Europe," says Randell. "Whereas airframe maintenance peaks in winter months to benefit operators, activity drives wheel and brake maintenance into the busiest periods of operation. It can almost be termed out-of-phase (OOP). It can be beneficial to prevent disruptive maintenance occurring by scheduling overhauls into the quieter months where a longer SV is easier to manage, leaving just quick tyre changes for the busy months."
- Bias and Radial tyre technology: Bias is the main type of tyre used by the ageing fleet of commercial aircraft. Radial technology offers a lighter option with usually longer tread life. But radial tyres, are more difficult to 'retread', that is, to restore tread lost by a tyre as it undergoes wear and tear. There are, therefore, pros and cons for each technology.

"Different options on equipment fit also influence cost," adds Randell. "For example, a 757 steel brake overhaul costs about $15,000, whereas an overhaul of carbon brakes costs about $75,000."

The tables *(pages 66 and 67)* feature the most popular options for each aircraft (see table notes for information) and provide general information, such as average removal and repair intervals that are dependent 'on condition' (and are subject to climate and utilisation). Costs are approximate and illustrate considerations and patterns within wheel and brake maintenance lifecycles.

Maintenance costs

See table *(page 67)* for a breakdown of general routine NR and lifecycle costs across wheel and tyre maintenance, provided by World Aero. As explained, these are guidelines of expected and considered costs, and should not be treated as indicative of costs across all regions, utilisations and operators.

Brakes

The brake systems on these aircraft types typically consist of a complete brake assembly in each main wheel, according to Ingold at AAR. The brakes comprise three major components.

- The piston housing contains a series of actuating pistons/adjuster assemblies that engage and disengage the brake and maintain correct running clearance while the brake is wearing.
- The heat sink, which comprises rotors (rotating disks) and stators (stationary disks), made of either carbon or steel (brake pads). "Rotors rotate with the wheel, while the stators are fixed to the brake," explains Ingold. "Rotors have drive slots on the outside diameter that engage in the wheel, so they turn with the wheel. The stators have drive slots in the inner diameter that engage in the torque plate and do not turn with the wheel.

Stators and rotors are assembled alternately on the brake, with the stators having a rotor on each side."

- The torque plate holds the pressure plate and the stators and rotors in place and in alignment. "The piston housing is also attached to the torque plate," says Ingold. "The torque plate is attached to the axle, so it transfers all the braking force to the axle."

Two wear pins attached to the pressure plate on the brake provide a visual indication of the amount of wear remaining on the brake. "When the pins are flush with brake pressure applied, the brake must be removed for servicing," says Randell. "This is visually determined by line mechanics comparing the length of the pin to the piston housing. Brakes are removed mostly due to this type of wear and tear, which accounts for 95% of World Aero's brake SVs."

"Removal intervals on these aircraft vary widely," adds Ingold. He explains that one reason is that there are mainly two types of brakes: steel and carbon. Traditional steel brake comprise wear pads and steel rotors.

"The new carbon brakes consist of all carbon disks," continues Ingold. "Steel brakes on the 757 and 767 range from 1,200FC to 1,800FC between removals. Carbon brakes last longer, and on the A320, A330 and 777 can last for 2,000-3,000FC. Just like the tyres, brakes are also affected by temperature, length of runway and aircraft operations."

Randell outlines benefits provided by each type of brake. "While steel brakes are cheaper to buy and repair, cost per FC for carbon brakes is lower because they last for a greater number of cycles, even though their purchase and repair costs are roughly twice as much. For instance, a 737NG fitted with steel brakes will undergo an SV every 800-1,000FC, but a 737NG with carbon brakes could last upwards of 2,000FC. Carbon brakes are designed to make the repair/overhaul process quicker and cheaper.

"Most significantly, carbon brakes are lighter, so will offer a weight saving for operators, but the extent to which this translates as a significant financial benefit will depend on each operator's flight profile," continues Randell. "There are many possibilities to retrofit, to take advantage of the newer technology present in carbon brake systems, However, a lot of wheels and brakes come under a larger component deal for airlines, because some suppliers, such as Honeywell, will also supply many other components, such as the radar and APU. The operator's choice of brake system will, therefore, align with the portfolio offered by this supplier. One of our customers has chosen to stay with steel brakes, as carbon only offers a negligible benefit: the fleet is fairly mature, and the flight profile consists of short sectors. Given their FC utilisation, steel brakes are the most economical option for them.

"With the exception of some carbon stacks manufactured by certain OEMs, spare parts are readily available through OEM or OEM-authorised distributors," says Ingold. "Lead times, however, vary between three and 90 days."

BRAKE UNIT MAINTENANCE COSTS

AIRCRAFT TYPE	AVERAGE REMOVAL FC	AVERAGE OVH $	MAINTENANCE RESERVE $/FC	BRAKES IN SHIPSET	SHIPSET RESERVE $/FC
A320	2,000	40,000	20	4	80
737NG	850	20,000	24	4	95
A330	2,000	60,000	30	8	240
757	1,000	15,000	15	8	120
767	2,250	55,000	24	8	196
777	2,250	70,000	31	12	373

Source: World Aero
NOTE: Guideline only. To be treated an example of cost & maintenance management considerations. Lifecycle costs will vary according to the operation of individual aircraft.

Repair and overhauls

Randell explains that repair-related brake SVs most commonly replace worn surfaces. "They may also be as a result of a hydraulic leak observed, though this is rare," he says.

Overhaul of the brake system commonly occurs every four repair SVs, although due to the on-condition nature of this maintenance, there remains no set rule to this frequency in terms of calendar or flight time for operators. "In fact, we often see that operators are unsure as to the repair history of the brake requiring the SV," Randell adds. "We have seen many operators that do not know how many repairs the brake system has had, and, therefore, whether the system is actually due for a full overhaul. It is important that maintenance planners know the repair history, so that they can establish whether the brake system would benefit from an overhaul instead, and so prevent problems arising in operation. If the repair history is unknown, overhaul is the best option to reset the repair history for the brake system. It means that the brake is going back to a known safety and regulatory standard," adds Randell. "This helps to keep ongoing maintenance more predictable for the operator."

"Repairs on carbon brakes are limited to the piston housing and torque plate," says Ingold. "Any repair required on the carbon disks themselves would have to go to the OEM.

"Steel brakes are somewhat similar to wheels in the sense that repairs can be performed on various parts to save the unit," continues Ingold. "Cracks or elongated rivet holes on pressure plates and torque tubes can be weld-repaired. Worn torque tube lugs can also be filled and machined to bring the part back to original dimension. Rotors can be surface-ground to remove high spots and wear grooves, and the torque and bearing bushings on the piston housing can be replaced when worn or damaged."

Again, overhauls are determined on-condition, and FC usage will affect the durations between brake overhaul. This overhaul interval varies from aircraft to aircraft, though it tends to be about every four SVs.

According to Ingold, brakes usually are overhauled at every second heat stack change. As wheel and brake systems are not life-limited parts (LLPs) these can be overhauled until they scrap out or reach a state beyond economic repair (BER). "It is best to consider wheels and brakes as 'lifed' items that can be 're-lifed' by overhaul," says Randell. "As these systems are not referenced as LLPs by the OEM, nor referenced in an MPD, maintenance management can be easily overlooked. Also, these components are almost over-engineered, so if the component is performing well with the exception of the odd tyre change, operators do not feel a need to pay more attention to these parts."

Maintenance costs

See table, *(page 66)*, for a breakdown of expected brake maintenance costs provided by World Aero. These are approximate, and subject to the assumptions listed in 'cost data logic,' combined with the AMP strategy each operator has for brake maintenance. - *CLD* AC