Many airlines ignore the costs of wheel & brake repair and overhaul, and opt for flat rates on a per flight hour basis from third party vendors. Close examination of what influences and improves their costs can result in savings which combine to thousands of dollars per year.

Wheel & brake repair costs under the microscope

Wheels and brakes comprise one of five major aircraft component categories. There is little understanding of what affects the costs of wheel and brake maintenance, and the impact it can have on the total cost per aircraft flight hour (FH) or flight cycle (FC). This article will examine the maintenance requirements of wheels and brakes, the costs involved and how they can be reduced to save tens of dollars in maintenance costs per FH, and consequently thousands of dollars per year for a complete fleet.

Wheel & brake component

The wheel and brake component is composed of three main parts: the tyre, wheel rim and brake unit. All are maintained on an 'on-condition' basis.

The wheel rim consists of two halves bolted together, with a heat shield on the inside to protect from excessive brake heat. The wheel rim must be split in half for the tyre to be removed. Tyres are removed because of tread wear, which provides an opportunity for the wheel rim to be inspected for damage. The tyre and rim therefore have the same maintenance interval, which, like tyre wear, is determined by the number of FCs, rather than FHs.

The brake is a complex component. The brake unit works by a set of rotating brake discs (rotors) and non-rotating discs (stators) being interposed within each other and mounted around the wheel's axis. The set of stators and rotors are known as a 'stack', and are located inside the wheel rim. The brake unit also consists of a housing and torque tubes. Pistons in the housing squeeze the rotors and stators together, causing braking action. As the brakes are used the stators and rotors wear and their thickness and weight decrease. Again, wear is dependent on FCs, not FHs.

Wheel wear

Tyres and wheel rims can remain on the aircraft while their condition remains satisfactory. Tyre tread will wear due to landing and braking action, but also due to foreign object damage (FOD). There is canvas below the tyre tread and tyres can remain on the aircraft until the canvas is showing or severe FOD has torn the tyre.

Wheels will be removed at this stage, so that tyres can be remoulded to retain tread depth, or replaced. Removal intervals between tyre remoulds are several hundred FCs, but these do vary widely. Variance occurs between aircraft types, but also for the same aircraft type. The number of cycles depends on the type of operation, and include factors such as aircraft weight, runway length and use of reverse thrust.

"The variation of FCs between tyre remoulds is 400-800FCs," explains Tino Honore, product manager at SAS Component. "Tyre removal intervals are about 400FC for the 737, DC-9 and MD-80, and are in the region of 230FC for the 767. These are main wheel tyre intervals. Nose wheel tyres last about 1.3 times longer, because they have less severe landings."

Tyre repair & replacement

Tyres cannot be remoulded an indefinite number of times, and the maximum number is fixed. "Some tyre makes can be remoulded up to 10 times," explains Sahib Ajjam, section manager, wheels & brakes department at Lufthansa Technik. "Other tyres have a lower maximum number of remoulds. There is less experience with radial tyres, so these are only remoulded up to six times. The average number of remoulds for all tyres is about four. The actual limit on remoulds is determined by the manufacturers, and is basically linked to the strength of the tyre carcass. Cuts by FOD, however, prevent further remoulds."

The number of tyre remoulds also varies between types and within fleets. "The number of typical remoulds is one to three," says Honore. "SAS measures the number of re-treads, and we track the number of FCs between removals. We do this because by recording the tyre's history we can get approval for more re-treads. That is, if the number of re-treads and FCs is known then the approval authority can make an assessment about allowing more retreads. If the tyre's history is not known then an approval

Steel brakes have lower repair costs but shorter intervals between removals than carbon units. This makes the repair cost per FC similar between the types. In some cases steel units can have lower costs.

authority will not allow more than a small number of retreads. We record each tyre's history in an electronic logbook with its serial number. This way we and our customers get more retreads compared to tyres which do not have their histories recorded. The other benefit of tracking a tyre's life FCs is that warranties can be claimed if the tyre does not last the guaranteed life. This is obviously not possible if lives are not recorded. We are able to get at least three remoulds per tyre before they are replaced. Getting the highest number of remoulds is important, since a remould costs about a third of a new tyre. Aircraft types which get a high FC interval between remoulds tend to have a smaller number of remoulds before replacement. Larger aircraft types get about five remoulds before replacement because they have shorter remould intervals than smaller aircraft."

The cost of tyre remoulds is in the region of $250-300 for narrowbody types, and rises to about $350 for smaller widebodies like the 767 and up to $400 for large widebodies. New tyres cost 2.5-3 times more than remoulded tyres.

The intervals between replacements are therefore determined by the number of removals and the removal interval. The total number of removals before replacement is the average number of remoulds plus one. Thus, a tyre remoulded three times at an average interval of 300FCs will have 900FCs until the last remould and will be replaced at the fourth removal after a total life of 1,200FCs. The table *(see page 38)* summarises the remould intervals, the total number of remoulds, total tyre life, tyre remould and replacement cost and amortised cost per FC. Total aircraft tyre costs for a 737 are in the region of $17 per FC, and $32 for a 747. Average FC lengths then determine the cost per FH. A 737 will only operate cycles in the region of 1.4FH, so tyre remoulding and replacement costs are about $12 per FH. The 747 flies longer cycles of 5-11 FH, so costs will be $3-6 per FH.

This table gives the average number of remoulds and remould costs. The higher the number of remoulds the lower the overall cost per FC.

"Since SAS tracks the lives of tyres we can offer our customers a lower price. This is because we know the exact interval to amortise costs over. Many airlines pay a flat rate per FH," says Honore. "Customers always look for a cost per FH, even though maintenance is determined by FCs. We only offer the lowest possible costs to customers if the wheels are tracked."

Wheel rim repair

Wheel rims are the simplest component of the wheel and brake unit. A normal workscope requires disassembly and then non-destructive testing (NDT) to test for cracks, which can be caused by hard landings. Severe braking can also cause heat damage, in which case rims are replaced. Rims, however, do not have a fixed life and can last indefinitely.

"The workscopes, and so labour and material content, for wheel rim inspections are fairly constant," explains Honore. "The variation comes in the FH:FC ratio and additional costs if a large workscope is required.

"The workscope for rim repair is disassembly. The bolts are taken off, the rim is split into two halves, eddy current NDT test of wheel halves, every nut and bolt is NDT tested for cracks, bearings are inspected at every removal and the seal between the two halves replaced," says Honore. "There are actually two basic workscopes for wheel rims. The other is an overhaul, but the only difference is stripping and painting of the rim and disassembly of heat shields and extra NDT of hidden areas before re-assembly. Wheels go through the shop four times before they are repainted. Painting adds an extra man-hour.

"Workscopes do involve the scrapping of some bolts, but only about 50% of bearings get scrapped each year. The bearing failure rate depends on grease quality. We use an expensive grease, but bearing failure rate is low."

Workscopes do remain fairly constant, but Ajjam explains that as they grow older the NDT inspections become more detailed. "NDT inspections include eddy current, but also fluorescent inspections for deeper NDT. This requires the removal of paint," says Ajjam.

Each manufacturer provides operators with recommendations for wheel rim inspections. Messier-Bugatti normally recommends a complete wheel overhaul every fifth or seventh tyre change. "This means a detailed

Tyres and wheel rims have the same removal and repair intervals. Tracking tyre lives can extend the number of times they can be remoulded, thus reducing overall costs per FC. Tracking also makes it possible to claim warranties, which cannot be done without tracking.

metallurgical inspection is carried out on the highest loaded areas on wheel halves," explains Ken Hutchins, wheels & brakes marketing manager at Messier Services. "The miscellaneous hardware have a detailed inspection. This includes bolts, nuts, washers, hat shields and bearings. They are replaced if certain criteria are not met. Minor services are done every tyre removal, while major repairs are done every 1,000-1,400 cycles".

The workscope inputs for wheel inspections are in the region of $40-150 for materials and 3.5-5.0 man-hours (MH). Extras are incurred for bearing failures, even for the scrapping of a rim. Total cost for rim inspection is up to $600 for a 737, $700 for a 767 and $750 for a 747 wheel.

Wheels rims have no life limit, and only replaced if they are damaged. Honore explains that actual lives vary widely, in the region of 8,000-19,000FCs. "Wheel scrap rate rises as wheels get older. Rim failure is often linked to brake unit failure. Usually the inboard half of the brake is damaged and gets scrapped," explains Honore.

A small number therefore are replaced each year. Some can last an aircraft's lifetime. Honore estimates that only 1-2% of wheels are replaced each year.

The cost of new wheels is summarised in the table *(see page, 39)*.

Brake wear & removal

As described, the brake unit consists of a stack of rotors and stators, interposed with each other. The torque tube in the brake housing squeezes stators and rotors together.

As the brakes are used they wear and the thickness and weight of the rotors and stators decrease, thereby reducing their braking ability. Thickness is therefore monitored carefully. The brake unit has a wear pin, which protrudes from the side of the brake stack and indicates the degree of wear. As wear progresses, and stators and rotors decrease in width, the pin shortens. The legal limit for brake removal is when the length of the pin reaches zero.

There are two types of brake: steel and carbon. Carbon brakes are the result of recent technological advances, and have the advantage of being lighter and having longer removal intervals. However, the cost of their repair and replacement is higher.

"Line mechanics decide when to remove brakes. The wear pin in most cases is about 75mm for a new unit. High gross weight aircraft variants have shorter pins," explains Honore. "The brake housings can also leak, because of piston or tube breakage. Like wheels, brakes can in theory last forever, unless they get cracked. Only one unit in 100-150 brake overhauls will have a unit which is cracked and requires replacing."

Removal intervals are longer than wheel and tyre intervals. "Steel brakes have intervals of 600FCS, and up to 1,500FCs. Intervals vary by variant, because of weight. The 737-600, for example, has intervals in the region of 1,200FCS, while heavier -800s have an interval of about 800FCs," says Honore. "These are actually about half the promised life, so we can claim warranties. This half life means our throughput of brakes through the shop is double what we expected."

Removal intervals for steel brakes are about 1,000FCs for most types. A classic 737 may achieve 600-800FCs, aircraft in the A320 family about 1,000FCs, the DC-10-30 only about 600FCs and the 747-200/-300 about 850FCs.

Removal intervals for carbon brakes are in the region of 1,600-2,500FCs, depending on aircraft type. Some of the latest types can get up to 3,000FCs.

The 747-400 uses carbon brakes with intervals of 1,200-2,500FCs. The actual interval depends on braking action and the use of reverse thrust and flap settings at landing.

Repair process

Steel brakes have to be reassembled so that the stack has a minimum width and

TYRE REMOULD & REPLACE, WHEEL RIM REPAIR AND BRAKE REPAIR COSTS

Aircraft type	NW tyre remould FC	Times NW remoulded	Total FC for remoulds	NW remould cost $	Total remould cost $	New NW tyre $	NW tyre replacement FC	Remould & replacement cost $	Number wheels	Aircraft $/FC
737	150	2.5	375	300	750	600	525	1,250	2	5
A320	300	2.5	400	500	1,250	1,000	700	2,250	2	6
767	180	2.5	450	400	1,000	900	630	1,900	2	6
DC-10	130	2.5	500	350	875	1,000	630	1,875	2	6
747	200	2.5	500	350	875	800	700	1,675	2	5

Aircraft type	MW tyre remould FC	Times MW remoulded	Total FC for remoulds	MW remould cost $	Total remould cost $	New MW tyre $	MW tyre replacement FC	Remould & replacement cost $	Number wheels	Aircraft $/FC
737	150	2.5	375	300	750	800	525	1,550	4	12
A320	300	2.5	400	600	1,500	1,000	700	2,500	4	14
767	180	2.5	450	400	1,000	1,050	630	2,050	8	26
DC-10	170	2.5	500	400	1,000	1,000	670	2,000	10	30
747	200	2.5	500	350	875	950	700	1,825	16	42

Aircraft type	Wheel inspection FC	Wheel inspection $	Number of wheels	Total inspection cost $	Aircraft $/FC
737	150	600	6	3,600	24
A320	300	650	6	3,900	13
767	180	750	10	7,500	42
DC-10	180	700	12	8,400	47
747	200	700	18	12,600	63

Aircraft type	Brake repair interval FC	Brake repair cost $	$/FC cost	Number of brakes	Aircraft $/FC
Steel brakes					
737/MD-80	700-1,200	8,000-12,000	11	4	40-46
A300	700-1,200	8,000-12,000	11	8	80-91
DC-10	700-1,200	8,000-12,000	11	10	100-114
747-200	700-12,00	8,000-12,000	11	16	160-183
Carbon brakes					
A320	1,700-2,200	25,000-35,000	15-16	4	59-64
757/767	1,700-2,200	25,000-35,000	15-16	8	118-127
A330	1,700-2,200	25,000-35,000	15-16	8	118-127
MD-11/A340	1,700-2,200	25,000-35,000	15-16	10	147-159
777	1,700-2,200	25,000-35,000	15-16	12	176-191
747-400	1,700-2,200	25,000-35,000	15-16	16	235-255

weight, which provide sufficient braking power.

The same number of rotors and stators have to be re-assembled in the pack, but this can be a mixture of new and repaired units, provided the width and weight comply with certification requirements. A guide to the number of repaired and new discs, and the weight and width of the stack is given in the repair manual.

"The brake is disassembled, cleaned and the steel brake pads on the rotors are ground to provide an even wear surface. These can also be replaced. Pads can only be ground twice before being replaced. Rotors have to be replaced if their weight is below the minimum requirement," explains Honore.

In some cases, overhaul shops replace brake pads at every repair and shop visit, but this can increase material cost. Steel pads cost $3-5 each, and there are seven or eight on one side of the rotor. There are six rotors in most brake stacks, which means 48 in each stack at a cost of up to $250 per stack.

Carbon brake stacks have to be repaired so their original weight and thickness are maintained. "New carbon disks are solid, while refurbished disks are produced from two ground halves of original disks," explains Honore. "Carbon disks do not have pads that steel brakes do. The only option to re-attain the original thickness of carbon disks is to grind pads down to half their original thickness. They are then stuck together, to make one from two ground halves. Carbon rotors can thus only be ground once before having to be replaced. This results in only half the number of the original, so half have to to be replaced every repair. Besides the original equipment manufacturers (OEMs), SAS Component is one of the few shops with the capability to grind carbon discs and make one from two halves." In many cases the OEMs refurbish rotors for airlines.

Lufthansa Technik has a shop-visit pattern for carbon brakes of a repeating cycle of four workscopes. For example, the first is a visual inspection, followed by an o-ring change. The third is another visual inspection and the fourth is complete overhaul. This is a similar workscope pattern to that followed by Messier Bugatti.

Brake repair costs

The removal interval affects the brake repair workscope. Like wheel rims, brakes only have to be replaced if they suffer damage or cracks.

Honore estimates that 90% of a brake repair cost is accounted for by materials, and less than 10% by to labour. "Steel brakes have a repair cost of $7,500-12,000 on the basis that that pads are ground twice and are replaced every third shop visit."

Hutchins at Messier Services explains that repairing steel brakes is more labour intensive than carbon ones. This is because it is more time consuming to re-build the heat stack in the workshop. Hutchins puts average steel brake repairs at $8,000-12,000.

The problem is that independent shops have higher material costs because OEMs are able to provide themselves with materials at lower prices," explains Honore. "This explains why some independent shops are getting involved with OEMs. The independents perform work for the OEMs locally. That is, it is not economical for airlines in Europe to ship brakes to Honeywell in the US for repair, but cheaper to send them to a European shop."

Carbon brakes have higher repair costs because of the higher replacement rate of stators, which are more expensive than in steel units. Honore puts the average cost for a carbon brake repair at $25,000-35,000, but as high as $47,000 for an MD-11.

NEW WHEEL RIM AND BRAKE COSTS

Aircraft type	New wheel rim $	New brake unit $
737-200	6,700	10,400
737-300	6,900	12,400
717	11,600	16,300
737NG	13,400	20,000-24,100
MD-80	9,500	16,000
A300	10,900	21,900
A310	11,400	20,800
767-200	9,100	15,600
767-300	11,500	42,500
MD-11	19,000	67,400
A330/340	17,000	54,600-64,700
777	15,900	57,700
747-100	11,400	18,000

Hutchins says that while carbon units are more enduring, the material cost escalates the price of a shop visit. These can typically run to $21,000-25,000.

Amortised over removal intervals, these repair costs equate to about $10-12 per FC for steel brakes. Although repair cost varies with repair interval, the resulting cost per FC is similar for a range of removal intervals.

Aircraft brake repair costs per FC then depend on the number of main wheel units. A 737 or MD-80 with four main wheels will have an FC cost of $40-46. At a typical FC length of 1.5 FH, this is equal to about $27-30 per FH. Costs per FC are higher for larger aircraft types, and are as much as $160-85 per FC for the 747-200. Its FC length of about 7.0FH means the cost per FH for brake repair is about $25.

Average carbon brake repair costs of $25,000-35,000 and removal intervals of 1,700-2,200FCs, results in an average repair cost of $15-17 per FC for each unit. Despite having longer removal intervals for repairs, carbon brakes have higher costs per FC because their repair or shop visit costs are more than twice the cost for steel units. Since brake repair costs account for a large portion of total costs, aircraft with carbon brakes can have higher overall costs than aircraft with steel units.

An A320 with just four main wheels will have a cost of about $60 per FC, or $40 per FH. This will rise to the region of $250 per FC for the 747-400, which will be equal to about $25-35 per FH.

New brakes

Steel and carbon brakes can be repaired many times, but Hutchins explains that brakes are not expected to last forever, and are subject to many variables, including high temperatures. Some A300B4 brake units are still in operation after 15 years.

Honore recommends airlines should budget for a small percentage of brake replacements each year. Approximate costs for new units are $11,000 for a steel brake guaranteed to 1,500 landings, but these rise to $17,000 for a brake guaranteed to 2,000-2,500 landings.

New carbon units cost in the region of $36,000 for the 767, and $49,000 for the MD-11. A summary of new brake unit prices are given*(see table, this page)*.

Summary

Total costs per FC for nose and main wheel tyre remoulds and replacement, wheel rim inspection and repair, and brake repair are in the region of $86 for a 737 or MD-80 with steel brakes. This equates to about $60 per FH. A similar cost per FC is likely for the A320 with carbon brakes. The 767 equipped with carbon brakes should incur the same FC cost as a DC-10-30 with steel units. The cost per FH for both these types will vary widely, since their average FCs vary. The 747-200 with steel brakes will have an FC cost of about $290, while the 747-400 with carbon units will have a cost in the region of $360 per FC. These will both work out at about $40-45 per FH for the aircraft.