Being the simplest of components, the maintenance costs of wheels, tyres and brakes are often overlooked. Analysis reveals they account for a substantial portion of total maintenance costs, and so should be considered and monitored closely. The salient factors affecting costs are examined.

Wheels, tyres & brakes maintenance & repair costs

Aircraft and engine maintenance tends to get the most attention when focusing on airframe maintenance costs. The cost of maintaining heavy components, including tyres, wheels and brakes, however, accounts for a large percentage of total aircraft maintenance costs, so careful attention to detail can realise useful savings. An analysis is made here of the factors that determine: the timing for tyre, wheel and brake removal for maintenance; the maintenance processes and workscopes; and the cost of inputs and resulting cost per flight cycle (FC) of these components.

Tyre, wheel & brake component

Tyre, wheel and brake components are all covered by air transport association (ATA) chapter 32. The maintenance of the three components is inter-related, and the removal and repair intervals of all three are measured in FC. Maintenance is performed on an on-condition basis.

The condition of tyres, wheel rims and brake units is inspected prior to each departure. The condition of tyres is affected by: wear, which is caused by taxiing, take-off and, in particular, landing; cuts in the treads; and the presence of foreign objects in the tyre material.

Tyres are removed when treads are worn to below a legal minimum, when cuts of more than a certain size are found, or if foreign objects are embedded. Tyres can be remoulded to restore original tread depth, provided the tyre's physical condition is above a specific legal minimum. There are various limits to how many times tyres can be remoulded. After this they have to be replaced with new tyres.

The removal of tyres requires the removal of the entire wheel unit from the aircraft, so an inventory of spare wheel units at line stations and light maintenance hangars is needed. The wheel hubs are inspected or overhauled when tyres are removed. Wheel inspection and repair may result in wheels having to be replaced, mainly due to cracks or corrosion. The percentage of wheel rims that have to be replaced is generally small.

Brake units comprise sets of rotating brake discs (rotors) and non-rotating discs (stators) that are interposed with each other. These rotors and stators are referred to as a stack or heatpack, and the brake unit is located within the wheel rim. The brake unit achieves a braking action by torque tubes and pistons squeezing the stators and rotors together when pilots apply the brakes. Braking action wears the stators, and their thickness reduces with operation.

The thickness of brake discs is monitored using a brake thickness pin in the side of the brake unit. The length of the pin is typically 75mm, or three inches, on a new brake unit. The pin shortens as the brake discs wear, and the brake unit has to be removed for refurbishment when the length of the pin has been reduced to zero. Inspection of the brake pin length is performed as a daily line maintenance task by line mechanics, in accordance with the component maintenance manual (CMM) and aircraft maintenance manual (AMM). The repair of brakes can then be planned into a daily, overnight or weekly check as appropriate.

Two categories of brake unit are those with steel rotors and carbon rotors. Carbon brakes are used on more modern aircraft types. The advantage that carbon brakes have over steel units is that carbon brakes are lighter and their rotors last longer so that their removal intervals are about twice those of steel brakes. The repair costs of carbon brake units are higher than for steel, however, so the two types may have similar resulting costs per FC.

Tyre repair & replacement

As described, tyres wear with utilisation in aircraft operations, and removal is determined by their condition. The rate at which tyres wear, and the number of landings they can achieve before remoulding is required partly depends on the severity of use. Hard landing and braking action will accelerate the rate of wear, and reduce FC intervals between removals. Tyre removal intervals will also vary with the different types of construction used by different manufacturers.

Since nosewheels are narrower, and experience more pressure and friction from steering, than mainwheel tyres, mainwheel tyres generally have longer removal intervals than nosewheel tyres.

There are two main types of tyre construction: bias tyres and radial tyres. Radial tyres are stronger, and are best used on heavier aircraft, such as higher gross weight versions of the 777 or A340. Bias tyres account for the majority of tyres used on most aircraft. They have shorter removal intervals for retreads or remoulds, but they also have lower list

MAINWHEEL & NOSEWHEEL TYRE RETREAD & REPLACEMENT LIFECYCLE COSTS

Aircraft type	No of retreads	Retread interval-FC	Tyre retread cost-$	Lifecycle retread cost-$	Tyre lifecycle FC	Tyre removal cost-$	New tyre cost-$	Tyre lifecycle cost-$	Tyre lifecycle cost-$/FC	Tyres per shipset	Total tyres cost-$/FC
Mainwheel tyres											
A319	4	375	1,000	4,000	1,875	600	1,800	8,800	4.7	4	19
A320	4	350	1,000	4,000	1,750	600	1,800	8,800	5.0	4	20
A321	4	320	1,100	4,400	1,600	600	1,800	9,200	5.8	4	23
737 Classic	4	215	650	2,600	1,075	600	1,300	6,900	6.4	4	26
737-700	4	225	900	3,600	1,125	600	1,300	7,900	7.0	4	28
737-800	4	190	1,000	4,000	950	600	1,300	8,300	8.7	4	35
757-200	4	200	1,100	4,400	1,000	850	1,600	10,250	10.3	8	82
767-300ER	4	200	1,250	5,000	1,000	1,300	3,000	14,500	14.5	8	116
A330-200	4	255	1,500	6,000	1,275	900	3,500	14,000	11.0	8	88
A330-300	4	230	1,500	6,000	1,150	1,000	3,500	14,500	12.6	8	101
A340-300	4	260	1,500	6,000	1,300	1,200	3,500	15,500	11.9	10	119
777-200	5	275	1,500	7,500	1,650	1,200	5,500	20,200	12.2	12	147
777-300	5	260	1,500	7,500	1,560	1,200	5,500	20,200	12.9	12	155
747-400	4	175	1,400	5,600	875	1,200	4,000	15,600	17.8	16	285
Nosewheel tyres											
A319	5	250	700	3,500	1,500	550	800	7,600	5.1	2	10
A320	5	250	700	3,500	1,500	550	800	7,600	5.1	2	10
A321	5	240	700	3,500	1,440	550	800	7,600	5.3	2	11
737 Classic	5	160	600	3,000	960	550	700	7,000	7.3	2	15
737-700	5	200	650	3,250	1,200	550	700	7,250	6.0	2	12
737-800	5	170	650	3,250	1,020	550	700	7,250	7.1	2	14
757-200	5	160			960	800				2	
767-300ER	5	170			1,020	1,250				2	
A330-200	5	190	800	4,000	1,140	850	1,800	10,900	9.6	2	19
A330-300	5	185	800	4,000	1,110	950	1,800	11,500	10.4	2	21
A340-300	5	170	800	4,000	1,020	1,150	1,800	12,700	12.5	2	25
777-200	5	254	800	4,000	1,524	1,150	2,000	12,900	8.5	2	17
777-300	5	205	800	4,000	1,230	1,150	2,000	12,900	10.5	2	21
747-400	5	155	750	3,750	930	1,150	1,900	12,550	13.5	2	27

prices. Their construction means that radial tyres can be retreaded or remoulded more times, however.

The range of mainwheel and nosewheel tyre removal intervals for the main jetliner types is one factor that determines their maintenance costs per FC. Intervals tend to be longer for the smaller members of aircraft families because of their lower gross weight.

Mainwheel tyre removal intervals for the A319 vary from 375FC to 500FC, and average about 435FC. Marginally shorter average removal intervals are experienced for the A320 and A321 *(see table, this page)*, although intervals will be slightly smaller in some cases because of the aircraft's higher weight. The A321 experiences the shortest intervals of 240-430FC, which average 320FC, on account of its heavier weight.

Averages vary between operators, and there are also small variations between tyre manufacturers for the same type of tyre. "These are only about 20FC," says Philippe Delisle, executive vice president of component services at Sabena Technics.

Mainwheel tyre removal intervals are shorter on the older 737 Classic models, and average 215FC. Similar intervals are generally experienced by airlines for the 737NG models. These average 225FC for the 737-700, and 190FC for the -800 series. Some operators achieve intervals of up to 250FC on the 737-800 *(see table, this page)*.

Delisle gives an average interval of about 200FC for the mainwheel tyres on the 757-200.

With the most numerous widebody types, the mainwheel tyres on the 767-300ER experience an average removal interval of 180FC to 230FC *(see table, this page)*.

As with narrowbodies, tyre removal intervals tend to be higher for the Airbus widebodies. Removal intervals are 230-300FC for the A330-200, and average 255-270FC. They are slightly shorter at 230FC for the heavier A330-300. Even though the A340-300 is heavier, its intervals vary from 230FC to 330FC and average about 260FC. This longer average interval may be because the A340-300 has two more main wheels than the A330.

Philippe Servant, wheels, tyres and oxygen workshop manager at Air France Industries, gives an average mainwheel radial tyre removal interval of about 275FC for the 777-200, and 260FC for the 777-300. "This is almost the same as our mainwheel tyre removal interval for the 777-300," says Ozgur Dizar, chief of the wheel & brake shop at Turkish

Even the on-going maintenance costs of tyres can be substantial when removal intervals, number of retreads, cost of retreading, cost of changing tyres and cost of new tyres are all considered.

Technic.

The 747-400, using bias tyres, has shorter intervals of 155-200FC, with an average of about 175FC. "We also operate the 747-400ERF, which has a higher gross weight than the -400," says Servant. "The -400ERF has a mainwheel tyre removal interval of 165FC, which is slightly higher than the -400's interval of 155FC.

Nosewheel tyre removal intervals are similar or smaller than those of mainwheel tyres *(see table, page 26)*.

"At removal, tyres undergo a non-destructive test (NDT) using laser shearography before a decision whether to retread or not is taken," says Ruben Coco, wheels, brakes & emergency equipment production manager at Iberia. "Most do not reach their maximum allowable limit for retreads because they are found to be defective due to damage."

Tiago Martins da Fonseca, components maintenance engineering & quality department at TAP Maintenance & Engineering, comments that in TAP Maintenance & Engineering's experience, radial tyres can usually go through five retreads before the deterioration of their structure prevents further retreads.

Dizar says that in THY's experience radial tyres can be retreaded an unlimited number of times, due to the technology used in their manufacture. The number of times that tyres can be retreaded are described in the manufacturer's manual.

Delisle adds that X tyres have a stronger and more efficient carcass, which includes a metallic structure. "This makes it a stronger tyre, which is why it can be retreaded up to 10 times."

The cost of remoulding is generally cheaper for nosewheel tyres. Smaller aircraft types also generally have lower costs for remoulding than larger ones.

Coco and da Fonseca put the average cost of mainwheel tyre remoulds for the A320 family at about $1,050. Dizar, however, comments that the cost can be a little higher in some cases; reaching as much as $1,400.

Mainwheel tyre remoulds for the 737 family types are generally lower. "Remoulding costs $750-1,000 for mainwheel tyres on the various 737 family members," says Dizar. "The higher end of their remould cost is therefore about the same as the average remould cost for the A320 tyres, which are bigger."

Remoulds for 757 mainwheel tyres cost about $1,100, and about $1,250 for 767 mainwheel remoulds.

Remould costs for A330/340 mainwheel tyres are $1,700 to $2,300; averaging about $1,500. Dizar says the cost of retreading 777 mainwheel tyres is similar, although it could be $100-200 per tyre higher. Costs of 747 mainwheel bias tyre retreads are about $1,400.

Nosewheel tyre remoulds are 45-60% the cost of mainwheel tyre retreads. These are $550-750 for the A320 family, and $400-600 for the 737 family.

Nosewheel remoulds for the 757 are about $750, and for the 767 are in the region of $800.

Remoulds for widebody nosewheel tyres average $800 for the A330/340 family types and 777 family, and higher about $750 for the larger 777 tyres.

These prices for remoulding tyres can be as low as about 40% of the price of a new tyre. "The cost of retreads can be higher, however, and the actual cost will depend on the size of the fleet, economies of scale and other factors such as the cost of transport and logistics," says Delisle.

"In addition to the actual cost of the tyre remould, the cost of material and labour for changing the tyre has to be taken into account," adds Delisle. "For mainwheel tyres, this is $550-600 per tyre change for A320s and 737s, $800-900 for a 757, $1,200-1,400 for the 767, and $900-1,000 for the A330/340 and other larger types *(see table, page 26)*. The cost of tyre changes for nosewheels are only $30-40 less."

The cost of new tyres can be 15-100% more than the cost of retreads. The cost of the most expensive mainwheel tyres for the A320 family is $2,250, but most are $1,600-2,000. New mainwheel tyres for the 737NG are $1,100-1,400.

New mainwheel tyres for the 757 are about $1,600, and about $3,000 for the 767-300.

The cost of new mainwheel tyres for the A330/340 family is $3,000-3,500. The cost of new radial tyres for 777 mainwheels is up to $5,500. New bias tyres for the 747-400 are $4,000 each.

The price of new nosewheel tyres is 35-55% the cost of mainwheel tyres. New tyres for A320 family aircraft are $700-850, and $500-700 for 737 family types.

For widebodies, the cost of new nosewheel tyres is $1,500-2,000 for the A330/340 family members. New tyres for 777 nosewheels are up to $200 higher.

As with tyre remoulds and retreads, the cost of labour and materials used for changing tyres has to be added when considering new tyres.

Taking the retread intervals and costs for mainwheel and nosewheel tyres, the number of retreads, associated costs of changing tyres, and the replacement costs of tyres it is possible to calculate the lifecycle costs of each tyre for a single wheel on each aircraft type. These range from $6,900 to $20,200 for mainwheels, and $7,000-12,900 for nosewheels *(see table, page 26)*. Once the number of tyres in an aircraft shipset and total lifecycle interval are considered, the total cost per FC can calculated. These are $19-35 per FC for the mainwheels of narrowbodies mainwheel, and $88-285 for the mainwheels of widebodies *(see table, page 26)*. Costs for nosewheels are $10-27 per FC for all types. This includes the cost of labour and materials for changing tyres, and so are higher than reserves that only include the cost of retreads and tyre replacement.

MAINWHEEL & NOSEWHEEL WHEEL RIM LIFECYCLE MAINTENANCE COSTS

Aircraft type	Repair interval FC	No of insp	Insp cost-$	O/haul cost-$	Lifecycle repair costs-$	Lifecycle repair interval-FC	New rim cost-$	Lifecycle rim cost-$	Total lifecycle cost-$	wheel lifecycle cost-$/FC	Shipset lifecycle cost-$/FC
Mainwheel tyres											
A319	375	4	500	1,700	3,700	1,875	15,000	1,500	5,200	2.8	11
A320	350	4	500	1,700	3,700	1,750	15,000	1,500	5,200	3.0	12
A321	320	4	500	1,700	3,700	1,600	21,000	2,100	5,800	3.6	15
737 Classic	215	4	500	1,600	3,600	1,075	28,000	2,800	6,500	6.0	24
737-700	225	4	500	1,600	3,600	1,125	41,000	4,100	7,700	6.8	27
737-800	190	4	500	1,700	3,700	950	41,000	4,100	7,800	8.2	33
757-200	200	4	650	1,900	4,500	1,000	45,000	4,500	9,000	9.0	72
767-300ER	200	4	750	1,900	4,900	1,000	52,000	5,200	10,100	10.1	81
A330-200	255	4	750	2,200	5,200	1,275	54,000	5,400	10,600	8.3	67
A330-300	230	4	800	2,300	5,500	1,150	54,000	5,400	10,900	9.5	76
A340-300	260	4	800	2,300	5,500	1,300	54,000	5,400	10,900	8.4	84
777-200	275	4	800	2,400	5,600	1,375	28,000	2,800	8,400	6.1	73
777-300	260	4	800	2,400	5,600	1,300	28,000	2,800	8,400	6.5	78
747-400	175	4	800	2,400	5,600	875	30,000	3,000	8,600	9.8	157
Nosewheel tyres											
A319	250	4	350	1,200	2,600	1,250	11,000	1,100	3,700	3.0	6
A320	250	4	350	1,200	2,600	1,250	11,000	1,100	3,700	3.0	6
A321	240	4	400	1,200	2,800	1,200	11,000	1,100	3,900	3.3	7
737 Classic	160	4	350	1,100	2,500	800	12,000	1,200	3,700	4.6	9
737-700	200	4	350	1,100	2,500	1,000	12,000	1,200	3,700	3.7	7
737-800	170	4	400	1,100	2,700	850	12,000	1,200	3,900	4.6	9
757-200	160	4	450	1,300	3,100	800	12,500	1,250	4,350	5.4	11
767-300ER	170	4	500	1,300	3,300	850	12,500	1,250	4,550	5.4	11
A330-200	190	4	500	1,500	3,500	950	11,000	1,100	4,600	4.8	10
A330-300	185	4	550	1,600	3,800	925	11,000	1,100	4,900	5.3	11
A340-300	170	4	550	1,600	3,800	850	11,000	1,100	4,900	5.8	12
777-200	254	4	550	1,700	3,900	1,270	11,000	1,100	5,000	3.9	8
777-300	205	4	550	1,700	3,900	1,025	11,000	1,100	5,000	4.9	10
747-400	155	4	550	1,700	3,900	775	11,000	1,100	5,000	6.5	13

Wheel inspection & repair

Wheel rims are the most straightforward of the three main components. Wheel rims will be inspected or overhauled when tyres are removed due to wear and require a retread or replacement. "When wheels have been removed they are first inspected, and then overhauled if they require it," says Coco. "An inspection starts with the tyre deflation and removal, and the removal of the wheel bearings. All other parts and components and the wheel rim are removed and cleaned. A visual and dimensional check of the bearings, nuts, and o-rings is made. The wheel rim is split in two halves and an eddy current NDT is performed on the wheel rim. Another visual inspection of the wheel rim is made prior to the installation of the new or retreaded tyre and bearings. A leakage test is then conducted."

Dizar at Turkish Technic explains that the main issues of wheel inspections are to look for cracks or damage to the wheel rim, and corrosion of the rim and other parts.

Wheel overhauls are a larger workscope. "These include the cleaning and stripping of paint and alodine or anodising layers on the wheel rim," says Dizar. "There are also detailed visual and NDT inspections made for wear and correct dimensions of all the removed components, and the paint and alodine or anodising layers are reapplied."

Some wheel rim manufacturers recommend an overhaul is performed on a wheel every fifth to seventh removal. Wheel inspections are performed at all other removals.

The cost of wheel rim inspections and overhauls is highly variable, and depends mainly on the percentage of parts that has to be replaced. The labour and list price of components vary little between wheels for narrowbodies and widebodies. Wheel inspections often require 4-6 man-hours (MH), and the materials used vary, since there is no defined list of parts that have to be replaced. Only damaged parts have to be changed. Delisle estimates that parts and materials cost $150-340.

The labour requirement for wheel rim overhauls is larger at 16-20MH per unit. A larger number of parts will be used, and paint remover and new paint is also required. Delisle puts the cost of parts and materials at $400-900, depending on workscope and size of wheel.

The overall cost of wheel rim overhauls can vary widely with workscope. Fully burdened labour rates for component shops with specialist NDT equipment can be high, so the labour

The shop visit costs of steel brake units are a third or less the cost of the shop visits of carbon units. Carbon brake units have longer removal intervals, but reserves are overall higher than that of steel brakes.

portion of a wheel overhaul can approach $1,500. With all materials and parts included, the total cost for narrowbody nosewheels can reach $1,200, and $1,700 for widebody nosewheels. The total cost for mainwheels can reach $1,600-1,900 for narrowbodies, and up to $2,400 for widebodies.

In addition to the cost of maintenance, there are wheel rims that have to be scrapped because they have not passed the inspections and overhaul workscopes. Scrap rates are generally low at 1.5-4% of wheel rims that pass through the shops each year.

The cost of replacing wheel rims should be factored into the budget for wheel rim maintenance. The price of new wheel rims has no correlation with the size of the aircraft. The list prices of nosewheel rims are $12,000-15,000 for 737 family members, $11,000 for the A320 family members, $11,000 for the 777, and $10,500 for the A330/340 family members *(see table, page 29)*.

The list prices of new mainwheel rims are $28,000 for 737 Classic variants, $41,500 for 737NG variants, $14,500 for the A319/320 family members, $21,000 for the A321, $27,500 for the 777, and $54,000 for the A330/340 family members *(see table, page 29)*.

The lifecycle costs for wheel rim maintenance will be for four consecutive inspections and then an overhaul at the fifth removal. The lifecycle interval will therefore be 825-1,900FC for mainwheels, and $825-1,300FC for nosewheels. The costs of the four inspections, overhaul and a wheel rim replacement rate of 2% of are all factored in to provide the overall reserve for wheel rim maintenance. The reserves for complete shipsets are $11-36 per FC for main wheel rims on narrowbodies, and $39-167 per FC for widebodies *(see table, page 29)*.

Additional reserves for nosewheel shipsets are $6-8 per FC for narrowbodies, and $8-12 per FC for widebodies.

Brake removals

Brake units can only be removed once the wheel has been removed. The removal intervals for brakes, however, are usually longer than the intervals for tyre retreads and wheel inspections or overhauls.

Besides the reduction of brake disc thickness, brakes can also be removed due to oil or fluid leaks from their torque tubes or piston housing because of cracks that can result from heavy landings.

The rotor discs of steel brakes have seven or eight brake pads mounted on one side of the disc. There are six discs in each brake unit. These pads wear due to braking action. To provide enough braking action, a stack of brake rotors and stators must have enough weight and brake pad thickness to absorb the heat and energy from braking. As brake pads wear and their thickness is reduced, the brake stack's ability to absorb energy is diminished and the brake has to be removed for repair. Other reasons for brake removal are oil leaks.

The jetliners that have steel brakes, and are operated in large numbers are the 737 Classic family, the 737NG family, and the MD-80. The 737NG also has an option of carbon brakes. Older widebody types like the A300, DC-10 and 747 Classic models also have steel brakes.

The removal intervals for steel brakes on the 737 Classics and 737NG are 700-1,200FC, and average about 900FC. Intervals for brakes on widebodies are similar.

The removal interval for carbon brakes on the A320 family can be as low as 1,200FC, and more than 3,000FC. Intervals for brakes on the A321 tend to be shorter than for units on the A319/20. Delisle estimates an average interval of 2,100FC across the A320 family.

Carbon brakes on the 737-800 have similar average intervals, while intervals for the 757-200 are shorter at 1,300FC.

Delisle says the average removal interval for carbon brakes on the 767-300ER is about 1,600FC.

Operator experience of mainwheel brake removal interval on the A330-200 is up to 2,500FC, but most are about 1,500FC. Again, brake removal intervals on some A340-300s can be high, up to 3,000FC, but most are about 1,500FC.

THY records similar intervals for brake removals on the 777-300. Similarly, brake intervals on the 747-400 are 1,700-2,200FC.

The rotor discs of carbon brakes have three or four carbon rotor discs in a brake stack. Like steel brakes, the rotors of carbon brakes wear with utilisation, and reduce in width. The brake unit has to be removed for repair and refurbishment when its weight and thickness have been reduced to a particular level.

The A320 family, A330/340, 757, 767, 777 family, 747-400, 747-8 and A380 all have carbon brakes.

Brake repair process

The rotors in a steel brake stack can be a combination of old and new discs, as indicated in the brake unit repair manual. The work pads can be ground so that they have even surfaces. They are then put back in the brake stack, provided they have enough remaining thickness and the brake stack has enough weight. Pads may undergo a maximum of two grindings before they have to be replaced, so pads are likely to be replaced either at the second or third shop visit. Each steel pad costs about $5, and the seven or eight pads in each disc mean that the cost

BRAKE UNIT MAINTENANCE COSTS

Aircraft type	Average removal interval-FC	Average overhaul cost-$	Maintenance reserve $/FC	Brake shipset	Shipset reserve $/FC
A319	2,200	30,000	13.6	4	55
A320	2,200	31,000	14.1	4	56
A321	2,200	34,000	15.5	4	62
737 Classic-steel	900	10,000	11.1	4	44
737-700-steel	900	10,000	11.1	4	44
737-800-steel	850	10,000	11.8	4	47
737-700-carbon	2,200	30,000	13.6	4	55
737-800-carbon	2,200	31,000	14.1	4	56
757-200	1,800	33,500	18.6	8	149
767-300ER	1,600	35,000	21.9	8	175
A330-200	1,500	36,000	24.0	8	192
A330-300	1,500	36,000	24.0	8	192
A340-300	1,500	37,000	24.7	10	247
777-200	1,600	37,000	23.1	12	278
777-300	1,600	39,000	24.4	12	293
747-400	1,800	36,000	20.0	16	320
747-400ERF	1,900	36,000	18.9	16	303

per disc is up to $40. The six rotors in the brake stack mean the cost of new pads for the whole brake unit is about $250.

"Each rotor and stator disc in a steel brake costs $2,000-3,000 each, and a minimum of two get replaced at each shop visit," explains Dizar.

Besides rotor discs, the torque tubes and brake housing are disassembled, and all removed parts are cleaned. "Paint is also stripped and all removed components undergo NDTs," says Coco. "There may also be a hardness check for torque tubes, and visual and dimensional checks of the tubes and brake housing. After piston springs have been tested and torque tubes and the housing have been repainted, and a new heatpack has been constructed the brake is reassembled, and leakage and functional tests are carried out."

The refurbishment of carbon brakes requires the restoration of rotor disc thickness. There are three or four rotors in a carbon brake. Their thickness will have been reduced through operation. Thickness can be restored by grinding the worn rotor to half its original thickness, and then bonding two halves together to provide a disc of the original thickness. This means that it is only possible to grind each disc once, and that half the rotors are replaced at each shop visit. In most cases, the rotors are sent to the brake original equipment manufacturer (OEM) to be ground, because few other independent or airline shops have the required tooling.

At the shop visit of carbon brakes, the refurbishment of the heat stack is carried out by brake manufacturers in most cases, plus a few other specialist shops.

The cost of maintenance on carbon brakes therefore comprises: the heat stack exchange fee; labour; and parts and materials for the remainder of the workscope as described.

Airlines also have to take into account the replacement of brake units. "Only 2% of brakes have to be replaced," says Coco. Brake units are only usually scrapped when they suffer foreign object damage. The heatpack of brakes can become lose or worn, and so has to be replaced, but not the whole brake unit.

The cost of brake disc repair and overhaul mainly comes from materials and parts, and in particular pads for steel brakes and discs for carbon brakes. Repairing carbon brakes is more expensive than steel, because of the cost of carbon rotor discs. This higher cost is partially offset by their longer removal intervals.

The repair of brake units will use about 8MH, while the overhaul of brakes will consume about three times the amount of labour. The labour element of the shop visit accounts for $400-600 for repairs and $1,500-2,000 for overhauls, depending on the burdened labour rate.

There is a standard list of parts that are replaced at each shop visit. These are smaller consumable items and may only cost $200-300. The main parts in steel brakes are brake pads and rotor discs. At least two rotor discs will need to be replaced at each shop visit, each with a list price of up to $3,000.

The overhaul cost for a steel brake unit will therefore be $8,000-12,000.

Other costs will be incurred for materials such as new paint and cleaning fluids.

Carbon brakes will have similar inputs and costs for labour, consumables and materials. The exchange fee for the heatpack is $17,000-30,000 for narrowbodies, and $30,000-45,000 for widebodies. Actual fees depend on the size of the aircraft. Examples of heatpack exchange fees are $28,000 for the A319/20, $31,000 for the A321, and $33,000 for the A330/340.

"Heatpack exchange fees come with guaranteed removal or overhaul intervals from the brake manufacturer," explains Delisle. "This can can be 2,200FC for the A320 and 737NG, 1,700FC for the 767, and 1,500FC for the A330-200."

The total cost of overhauling the brake unit for a narrowbody aircraft type can therefore be $30,000-31,000 for the A319/20, $33,000-34,000 for the A321, and $36,000-37,000 for the A330/340. Costs for brakes on the 737NG will be similar to the A320 family, while they will be $2,000-3,000 higher for a 757 brake unit. Costs for brakes for the 777 family and 747-400 will be similar to those of the A330/340 family.

The maintenance reserves for individual brake units for different aircraft types vary between $11 per FC and $19 per FC for narrowbodies, and $19-25 per FC for widebodies *(see table, this page)*. The number of brake units in an aircraft's shipset affects the overall total.

Summary

The costs of maintenance and repair for tyres, wheel rims and brakes are clearly high on a cost per FC basis. A main factor in determining cost per FC is the number of wheels the aircraft is equipped with. An example is the contrast in shipset reserves for tyres, wheels and brakes between the A321 and 757, which are similar-sized aircraft. The 757 is clearly at a disadvantage because of its eight main wheels compared to the A321's four main wheels. Another example is the difference in reserves between the 777-300 and 747-400. These two perform similar functions, but the 747's costs are higher because of its larger number of wheels.

The costs have also increased over the past 10 years *(see Wheel & brake repair costs under the microscope, Aircraft Commerce, August/September 2001, page 34)*. This is mainly due to cost of new tyres, parts used in shop visit events, and the cost of heatpack exchanges on carbon brake units.

The cost of these basic components should clearly not be overlooked, as evidenced by their size. AC