Engine thrust reversers are a major aircraft component, and their repair costs have an impact on total maintenance costs. Removal intervals can be managed and suffer little variation. Reliability of younger types is high enough for a shop visit to be performed only once every 8-10 years.

The economics of thrust reverser repair & overhaul

Aircraft components form a large percentage of total aircraft maintenance costs. The importance of major components is often overlooked, however. Major components include wheels and brakes, landing gear, auxiliary power unit and thrust reverser. In the continuing series of articles examining each of these major components in turn, this feature analyses what determines maintenance costs for engine thrust reversers and how these charges translate into costs per flight hour (FH).

Thrust reverser component

There are two main types of engine thrust reverser. The first is the clam-shell system, used in low bypass ratio engines. Examples are the JT3D, JT8D and Rolls-Royce Tay series. These clamshells are at the rear of the bypass duct and when deployed block all the engine exhaust and reverse its direction.

High bypass ratio engines, with wider intakes and bypass ducts, use blocker door reversers in the bypass duct only, and do not deflect exhaust from the core engine. The system works by the sliding section of cowl moving rearwards and exposing cascades. This allows the thrust in the bypass duct deflected by the blocker doors to exit sideways through the cascades in a reversed direction.

There are a few high-bypass engines, with extended bypass duct cowls, which use large clamshell-type reversers. One example is the CFM56-5C on the A340.

Although the thrust reverser is part of the engine nacelle, it has to be distinguished from the fixed engine cowl and engine pylon. “All thrust reverser component constituents come under Air Transport Association (ATA) Chapter 78,” explains Carlos Blohm, senior engineer thrust reverser overhaul and Lufthansa Technik. “This includes the actuation system, accessories, the blocker doors and thrust deflectors, the cascade vanes which the deflected thrust passes through on high bypass engines and the sliding cowl which exposes the cascades on high bypass engines”.

Charles Ryan, president of the Nordam Group says the thrust reverser can be broken down into three basic components. “These are the fixed structure, the translating engine cowl and the actuation system. The fixed structure includes the cascades and blocker doors. The fixed structure and translating cowl use bonded structures, which include composite materials,” says Ryan. The actuation systems consist of geared drive units which are either hydraulically or pneumatically powered. These require overhaul to be certified ready for operation once removed.

Most thrust reversers are operated by screw jacks. These units, composites, heat blankets and coatings in the cowls are the high degradation and cost items and so have the largest influence on maintenance and repair costs.

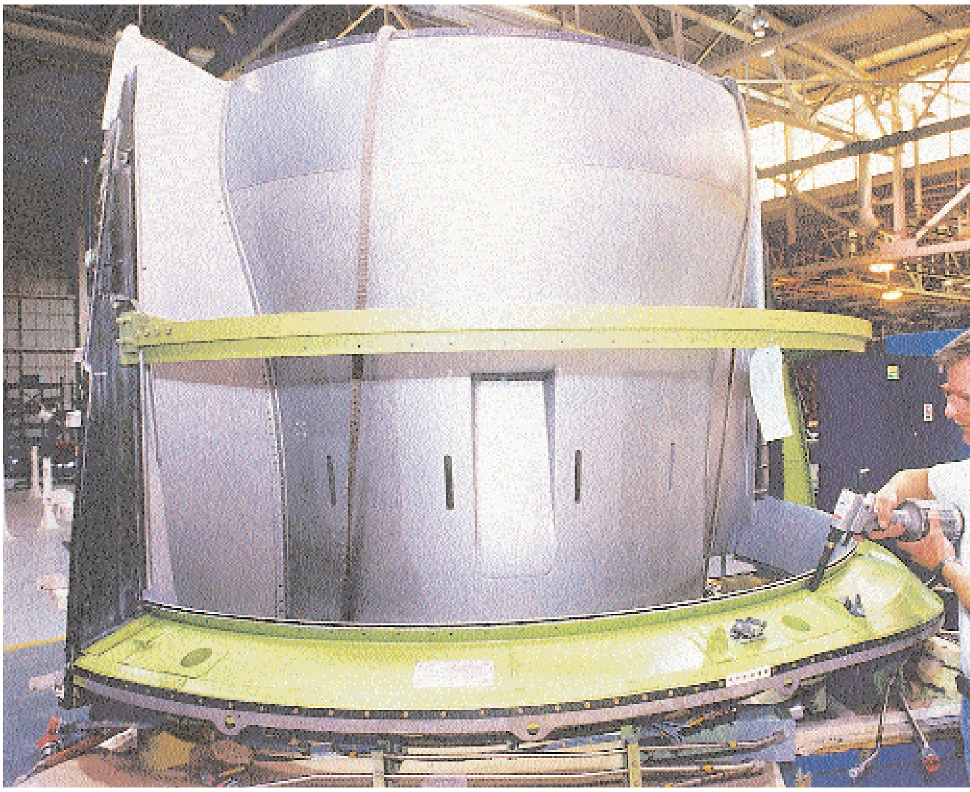
Thrust reverser maintenance is basically performed on an on-condition basis. The units therefore require regular inspection. Intervals vary, but are in the region of seven years for older models and longer for modern types. The actual rate of deterioration in condition depends on the style of airline operation. Hard reversing action at landing by flightcrew will accelerate weardown. The same applies to corrosive environments. Modern aircraft with sophisticated flight management systems can aid reduction in thrust reverser use, and so prolong on-wing life.

“Cascades being made of magnesium or composite have a tendency to become chipped owing to the ingress of foreign objects due to the conditions in which they operate, and this can result in downtime while replacements are found,” explains Peter Durdin, sales manager aircraft structures at Sabena Technics. “The actuator and gearbox system are prone to damage and wear and can be removed before time. This is due to malfunction caused by incorrect rigging or misuse while in service. They are also subject to side loading during operation, resulting in screw jacks having a wear problem. The overhaul cost of each unit is about $6,000, and for three units totals $18,000. Cost for spares takes the total to as high as $28,000. Screw jacks tend to have a high scrap rate”.

Heat blankets and composites also deteriorate because of heat from the engine. “The actual bonded parts get eroded and also suffer heat problems,” says Blohm. “These deteriorations are affected by flight time on-wing. Thrust reverser condition is therefore affected by flight hours (FH) and flight cycles (FC) on-wing.

Thrust reversers for most engine types comprise two halves: the engine cowl splits into parts around the engine so it can be removed from the wing for a shop visit, leaving the cowl and fan reverser unit in place. Rolls-Royce engine reversers are constructed as a single unit.

Thrust reverser removal intervals are generally stable. These have increased with modern and more reliable types. Resulting costs of maintenance per flight hour can be predicted if repair of the units is managed.



Removal intervals

"The reverser unit used to be considered part of the engine, and so was repaired at the same time as a shop visit" explains Blohm. "The reversers are now split from the engine and left on the aircraft during a shop visit, as well as during airframe heavy checks. Thrust reversers are now removed and repaired on their own programme, and work is done on an on-condition basis".

Removal for repair is therefore determined by rate of deterioration, and inspections and functional tests have to be performed regularly to decide when to remove. Soft removal intervals as a guide are decided by each airline and repair agency, rather than pure on-condition removals. "Measuring condition is hard in reality because of the composite components that are part of the structure," explains Blohm. "Insulating blankets are hard to monitor because they are buried in the walls of the cowls. The best way to monitor the structural condition of composites is with tap testing. This helps determine if there is delamination, and whether the soft time between removals needs to be adjusted".

Besides damage to the thrust reversers, previous maintenance will also affect on-wing times. "On-wing maintenance practices affect reverser reliability, and this varies widely between operators" explains Ryan at Nordam. "We provide customer support to airlines to help them assess the best removal intervals and preventative maintenance to prolong on-wing life. Minimal workscopes after removal will shorten subsequent removal intervals, while a comprehensive workscope will extend removal intervals".

Airlines that have gained a lot of experience with particular reverser types have soft times for intervals, which have become almost fixed. "We decided to use a fixed interval of about 6,000FC for long-range aircraft and 12,000FC for short-range types, plus a preventative maintenance programme," says Blohm. "This translates to 8-10 years for all our fleet. The FH intervals, however, vary. Long-haul aircraft achieve about 4,500FH per year, and so gain 36,000-45,000FH between removals. Short-haul aircraft will gain 20,000-25,000FH between removals".

Removal intervals for some carriers average less at about seven years. "The removals for older generation engines, such as the CF6-50, are shorter," says Durdin. "Also, they have a higher percentage of premature removals, which reduces the average interval. The actual percentage of premature removals depends on the style of operation and degree of corrosion and the rate at which screwjacks malfunction. Although intervals are in the order of seven years, they are most closely related to flight cycles (FCs). The average interval for older types like the CF6-50 and -80 is about 6,000FCs. This will be only about 2-4 years for short-haul aircraft and 4-6 for long-haul types.

Middle River Aircraft Systems (MRAS) is a specialist in CF6 family engine thrust reverser repair. "Removal intervals are typically 6,000-7,000FCs," says Norton Depinho, vice president of business development and product support at MRAS. "At average FC times of about 4 hours this translates to on-wing times of 25,000-30,000FH. The main removal causes are dis-bonding, screen erosion, and degradation of blocker doors and actuation systems".

Modern generation aircraft have longer intervals, because they are more reliable. The CFM56-3, for example, has a good on-wing life. Their main problems are delamination of the fan duct cowl and upper bifurcation ducts. Modern types use more advanced materials and their efficiency has increased".

Depinho says the CFM56-3 will typically stay on-wing for 30,000-40,000FH, and accumulates a similar number of cycles.

On-wing lives for A320 reverser units are as high as 12,000FCs, while those for A330, A340 and 777 are expected to be in the region of 6,000FCs.

Nordam recommends a sampling programme to build a database of thrust reverser reliability. It also makes suggestions to improve reliability and repair processes, and these have generally led to increased on-wing times.

Thrust reversers are removed at convenient times, usually during A checks, since removal and installation of a repaired unit requires 16-24 hours' downtime. Removals have to be staggered to provide a smooth stream of repairs and shop visits. Repairs for large engines take about 45 days turn time, and so substantial inventories of spare units are required. The on-wing lives of reversers on modern engines are expected to be so long that some airlines do not intend to have spare sets for the first few years of operation, and will rely on the spot market in the event of emergencies. If the expected removal interval of 12,000FCs is reached for the A320, the first aircraft will be about six years old before their reversers require a shop visit.

Repair process

Like most other components, the repair process is one of disassembly, inspection, repair, re-assembly, rigging and re-installation.

Workscopes will vary widely according to condition at removal. Workscopes in the manufacturers' manuals are supplemented by the individual repair shops.

Fan reverser repair or overhauls are based on the manufacturers' workscope planning guide, which include basic

The reliability of modern thrust reversers is high enough for airlines to avoid the investment in spare sets for the first years of operation of a type.

overhaul, routine repairs and out of workscope items. These are the replacement of parts due to conditions that exceed the repairable limits. Repairs of major components not covered by the manual can be based on approved company repair specifications. Repairs and corrective maintenance to a high standard are the key to ensuring the units stay on the engine throughout their intended life. Units removed following a long on-wing interval may require 100% core, skin and perforated skin replacement to guarantee the acoustical design properties.

Durdin categorises workscopes into three levels: basic, intermediate and major.

"A basic workscope will be required to make the unit serviceable and requires manual testing of the actuators. Wear strips, bushings, bearings and fasteners have to be repaired. Reverser condition varies widely due to core and skin delamination, and corrosion can be evident in many areas. On some reversers, like the CF6-50 and -80 family, the insulative coating MA25s becomes detached. This coating prevents premature delamination which results in unscheduled removals. It may then have to be stripped and replaced," says Durdin. "Cascades also have to be inspected and minor repairs made to the blocker doors".

An intermediate workscope requires removal, repair and re-installation of heat blankets. Cascades which have suffered damage due to foreign objects will also need to be re-welded, which requires a special technique because they are made from magnesium. Durdin adds that actuators require more extensive repair, and gearboxes have to be removed, benchtested and repaired. Slide tracks also have to be repaired.

A major workscope will involve replacement of hydraulic and pneumatic lines, the disbondment of composite materials, the re-skinning and replacement of engine cowls and complete overhaul of blocker doors. "A really bad condition level will result in a high scrap rate of parts, which increases costs" says Durdin.

Depinho also classifies repairs into three broad categories. "These are a cosmetic workscope, repair workscope and an overhaul. A cosmetic shop visit requires seals replacement, checking of kinematics and the geometry of the unit," says Depinho. "A repair involves more work, and includes isolated composite repairs and screen replacement, checking of actuation system functionality, and minor repairs. An overhaul requires complete disassembly and a workscope that effectively zero-times the unit".

Blohm at Lufthansa Technik explains that thrust reverser repair is an expensive process, since it requires autoclaves and other specialised equipment for repairing composites. Composites are re-bonded where necessary, and their repair is one of the most complex processes of the overall repair process. "Older thrust reversers do not use composites, but an aluminium bonded metal honeycomb instead. Metal bonding is also complex, and so also requires specialised and expensive repair equipment".

At removal the reverser goes through a functional test and inspection for missing, malfunctioning or damaged components. This allows collection of data to determine unit reliability. The unit is cleaned and stripped. Parts are evaluated for repairability, which determines part scrap rates. Bonded structures, accessories and actuation systems are repaired, prior to re-assembly and testing.

Inventories

Ryan at Nordam explains that turn times are extremely important in thrust reverser repair economics, since spare sets are expensive and inventories have to be kept to a minimum.

An average repair time of 50 days for larger thrust reversers means that if removals are possible one after the other, then seven can be repaired in a year. Removal intervals also play an important part in how much repair capacity is required. An average interval of seven years for larger engines on long-haul aircraft, means a single repair line can theoretically cope with about 50 units in this removal interval, equal to 25 twin-engined aircraft or 12 four-engined aircraft. One spare unit will be required to cover scheduled removals for these fleets. Larger fleets require more repair capacity and spare units. Another spare set will be required to cater for emergency situations and unscheduled removals. It is possible to get units for these occasions on the spot market to avoid excessive inventory costs.

Nordam estimates repair turn times for smaller thrust reversers like the CFM56-3 are shorter at about 18-20 days. A steady and constant stream of removals means 18-19 units can be repaired in a year on the same production line. Removal intervals are shorter for short-haul aircraft, but longer for modern generation types. If eight years is possible for the 737-300, then 145-160 units can theoretically be repaired on the same production line over the average removal interval, allowing just one spare unit for this number of reversers.

A turn time of 40 days would allow 8-9 units to be repaired in a year. An eight-year removal interval would then mean a single production line could handle about 65 units, meaning one spare unit could cover this number.

Again, access to emergency units will be required for unscheduled removals. The inability perfectly to stagger all removals when ideal for the airline, will reduce the number of theoretical repairs in the same interval, and the unit numbers that one spare reverser can supply.

"Airlines with smaller fleets tend to

ECONOMICS OF THRUST REVERSER REPAIR & OVERHAUL

Aircraft type	737-200	A320	747-200	A330	A340-300	777
Number of engines	2	2	4	2	4	2
Removal interval-FC	8,000	12,000	6,000	6,000	6,000	6,000
FH:FC ratio	1.1	1.2	7.0	4.0	8.0	8.0
Removal interval-FH	8,800	14,400	42,000	24,000	48,000	48,000
Repair costs per engine-$						
Basic repair	140,000	140,000	140,000	140,000	140,000	140,000
Intermediate repair	170,000	170,000	170,000	170,000	170,000	170,000
Overhaul	220,000	220,000	220,000	220,000	160,000	220,000
Aircraft costs per FH-$	32-50	19-31	13-21	12-18	12-14	6-9

use exchange programmes, rather than keep spare units," says Blohm. "Although this adds costs to the repair cost, it allows the airline to avoid keeping spare reverser sets, which is uneconomic for a fleet of four or five aircraft.

Blohm estimates that investment in spare reversers is about $1 million per half, and $2 million per engine set. This can rise up to $3 million for a larger engine set.

Durdin estimates exchange fees are in the region of $25,000. Increased competition in the thrust reverser repair market means that exchange fees have been reduced or even absorbed into repair costs, effectively providing spare reversers almost free of charge. Some repair shops have also made arrangements with spares supplier companies to do exchanges with the airlines as part of a three-way arrangement. Exchange fees or inventory costs are now being reduced by the increased reliability of thrust reverses of modern aircraft. "Sabena is not taking delivery of spare reversers for its A320 until 2002 or 2003, since we expect them to be very reliable and have extensive on-wing times, while Swissair holds spare sets for Sabena's A330 fleets".

Repair options

There are several repair arrangements airlines can select from when using third-party contracts. Some large maintenance facilities, such as Lufthansa Technik, offer total support contracts and thrust reversers are included in an all-inclusive package. Carriers can also opt for fixed price repairs or fixed cost per FH deals, with the onus on the repair facility to minimise the actual cost of material and labour. This is a more common method, and time and material deals are more usually acquired on the spot market when airlines are looking for repair capability at short notice.

Choosing the method to use for payment of repair is often complicated by the fact that some carriers have their own facilities for removal, disassembly, inspection and test. They therefore only require third-party capability for items that are outsourced for repair.

Repair costs

Costs of maintenance and inventory per aircraft FH are determined by five main factors: the number of engines on the aircraft; the average removal interval in terms of FC; the FH:FC ratio which affects the actual FH between removals; the size of the engine; and the repair or overhaul workscope, and so cost incurred.

Old aircraft have shorter removal and repair intervals. Narrowbodies such as the 737-200 have intervals in the region of 8,000FC *(see table, this page)*. These will operate typically on an FH:FC ratio of 1.1FH, and so will get an FH interval of about 8,500FH between repairs. The range of shop visit costs will result in cost per aircraft FH of $32-50 *(see table, this page)*.

Blohm estimates overhaul costs for this size of engine at about $40,000 per half, or $80,000 per engine set. For both engines this would be equal to about $17 per FH. A 6,000FC soft time that Lufthansa Technik gets for the JT8D would then result in a cost of about $24 per FH.

A younger type like the A320 would have a longer interval of up to about 12,000FC, or 14,400FH. A similar overhaul cost would then translate into a lower cost of $19-31 per FH for both reverser units *(see table, this page)*.

An old widebody engine like the CF6-50 would have a reverser removal interval similar to the JT8D, at about 6,000FC. An average FC time of 7.0FH would increase interval to about 40,000FH. Cost of repair will start at about $70,000 for a basic workcope for one half, $85,000 for an intermediate and $111,000-120,000 for an overhaul. These costs would be doubled for each engine, and result in a cost per FH of about $13-21 for the 747-200 *(see table, this page)*.

Depinho warns that costs can escalate. "The problem occurs because damages are found after the unit is disassembled and each component is inspected. There is therefore a basic cost and an 'over and above' cost. Basic cost is the in the $85,000-115,000 per half range and 'over and above' costs are $500-15,000 per half," says Depinho.

Costs for younger widebodies will vary widely because of the range of applications they now operate. Some widebody twins operate average FCs of 2-4FH, while the 777-200ER/LR will operate up to 9-12FH cycles in some carriers. Four-engined aircraft, such as the A340, will have twice the number of engines as their competitors, but should have lower costs per unit because the engines are smaller than on big fan powerplants like the Trent 800 and GE90.

An A330 or 767 operating average cycles of 4FH can get intervals of about 6,000FC and 24,000FH between removals. Overhauls of $240,000 per unit will result in costs of $20 per FH.

The A340 should achieve similar intervals of 6,000FC, but this will be equal to FH intervals of 48,000 with longer cycles. A lower overhaul cost of $160,000 per unit translates into a cost of $12-14 per FH for the aircraft *(see table, this page)*.

A 777-200ER/LR will achieve similar removal intervals to the A340. Overhaul costs will translate into a cost of $6-10 per FH *(see table, this page)*.