Thrust reversers are classed as a structural component.They are removed for maintenance on an on-condition basis. The main removal causes, removal intervals, shop visit repair process, economics of shop visits, and the process for acquiring spare units are examined.

Thrust reverser repair process & economics

Thrust reversers are one of four types of heavy components. The cost of repairing, modifying and maintaining these units receives little attention. They can, however, account for up to $60 per flight hour (FH) of an aircraft's maintenance costs.

Thrust reverser unit

The thrust reverser unit is classed as an element of the engine exhaust system. This is included in Air Transport Association (ATA) Chapter 78. The engine nacelle and cowling is comprised of three main sections. The forward section is the engine intake nacelle.

The centre or middle section of the nacelle comprises two symmetrical halves that can be raised. These are opened to gain access to the engine's accessory line replaceable unit (LRU).

The rear part of the nacelle forms the thrust reverser in most engine types.

Three main types of thrust reverser have been developed for jet aircraft. The choice of thrust reverser type is influenced by: whether the engines are mounted at the rear of the fuselage or under the wing; the design of the cowling; and the engine's bypass ratio.

Most older generation, low bypass ratio turbofans used clamshell type thrust reversers. Two main reverser doors from the top and bottom halves of the cowling slide from a stowed position, where engine exhaust flows rearwards, to meet and complete a block of the engine's entire flow of exhaust gases at the rear of the cowl. When deployed the reverser doors deflect the engine's exhaust through more than 90 degrees, and by as much as 135 degrees. This results in the aircraft decelerating during landing.

The use of a clamshell-type thrust reverser was used by the Pratt & Whitney (PW) JT8D, and Rolls-Royce (RR) Tay, Conway, BR715, and AE3007A engines. Clamshell reversers were also used on some variants of the JT3D and JT4D on some aircraft applications.

The majority of modern engine types use the sliding sleeve type of thrust reverser. Current generation engines powering regional jets and narrowbodies have bypass ratios of 4.3:1 to 6.0:1. These include the CF34, CFM56-3, CFM56-7B, V2500 and PW2000.

Engines powering the majority of widebodies in service have bypass ratios of 4.8:1 to 11:1. These include the PW4000 family, the CF6-80C2, GE90 family, and the Trent family.

The bypass ratios of these engines mean that the volume of air passing around the engine's core is greater than the volume passing through the core. The fan diameter is therefore large compared to the core engine diameter.

"The sliding sleeve type of thrust reverser achieves reverse thrust by the outer wall of the third rear section of the engine cowling sliding backwards," explains Dr Christian Sauer, manager of engineering and planning, aircraft-related components at Lufthansa Technik. This sliding action exposes cascades, or grilles, in the walls of the cowling. In reverse mode, blocker doors are moved from a stowed position to block the path of the bypassed air through the duct. This forces the air to pass out through the cascades. "The bypassed air has to turn through more than 90 degrees, and exit through the side of the engine cowling," adds Sauer.

Sauer explains that the third type of thrust reverser uses pivoting doors in the third section of the engine nacelle. These pivoting doors are an alternative to a combination of a sliding cowling sleeve and cascades. The pivoting doors provide both the blocker action, in the bypass duct, and the opening in the nacelle when in the thrust reverse position. The CF56-5A, -5B and -5C engines use this type of thrust reverser.

In the case of sliding sleeve and pivoting blocker door types of thrust reverser, only the direction of the bypassed air is reversed, while the direction of core airflow is unchanged.

In all three types, the sliding sleeve, blocker doors, pivoting doors, and clamshell reverser halves are activated and moved by actuators. On some older aircraft types, such as the 727 and the 747-400, the actuators were powered by the aircraft's pneumatic system.

The reverser actuators are hydraulically powered in the CFM56-5C, CFM56-7B, V2500-A5, Trent 700 and GE90 engines. Actuators are pneumatically powered on the CF6-80C2 and -80E1 engines. Reversers for the A380, A350 and 787 are electrical.

The power from the actuators is used to turn screwjacks in sliding sleeve cowl reversers. "The actuator can be regarded as a separate rotable component, related to the airframe," explains Bora Aykut, structural maintenance engineer at Turkish Technic.

Reverser components

"The thrust reverser comprises four main structures or components," says Aykut. "Thrust reversers comprise a shipset of two symmetrical halves. Sliding sleeve and pivot door reverser halves have a central main structure of a semi-circular C-duct. This has an outer and inner wall, and forms the bypass duct for bypassed air. The rear portion has the cascades or air grilles through which the reverse flow passes. This main section is made of carbon fibre, metal alloys, or glass fibre."

Jody LaChance, general manager of MRO product development at Delta TechOps, explains that this main structure can also be constructed of aluminium composite acoustic, although the cascades are made of graphic composite or magnesium.

Sauer makes the point that the inner wall needs to be heat-resistant, since it is

The majority of in-service and in-production thrust reversers are the sliding sleeve type. The aft section of the engine cowl sliding rearwards exposes cascades, or grilles, through which bypassed air is forced to pass through by the closing of blocker doors in the bypass duct.

close to the core engine. This wall can be protected by a metallic heat shield filled with ceramic insulation material.

There are also various supports and attachments, made of metal alloys.

The second main component is the translating sleeve. "The blocker doors in the bypass duct are made of metal or aluminium honeycomb composites, as is the cowling sleeve in many cases," says LaChance. "A honeycomb material called Nomex is used between the sleeve skins."

The third main component is the set of blocker doors. "The fourth is the actuation system," says Don Brugman, senior manager of global maintenance repair and overhaul at Spirit Aerosystems. "The materials used for the majority of components are mainly made from aluminium, particularly the fittings, and from composites, especially panels."

Maintenance intervals

Thrust reversers are removed and repaired on an on-condition basis.

There are some general visual inspections for thrust reversers on an aircraft's maintenance planning document (MPD). These check for delamination, blocker door damage, and hydraulic leaks. The inspections are performed during line or base airframe maintenance checks. "The possibilities to determine the thrust reverser's actual condition and maintenance status are limited if the inspections are performed by line mechanics," says Sauer. "This is because the inspections are only rough visual or basic functional checks. Some problems can be identified by nacelle experts, or need more extensive reverser disassembly than that done during an A check."

A better opportunity to detect various degrees of reverser deterioration is during base checks, or when the engine cowling and C-duct halves have to be opened when an engine is removed.

There are several main types of deterioration. "A main problem is delamination between the various layers of the main structure, blocker door deterioration and delamination, and sliding sleeve cowl," says Thibaut Campion, head of sales component services at Sabena Technics. "This happens on all structures that use composite materials. Delamination occurs where honeycomb is bonded to a metal structure. Humidity gets between the composite and metal, and freezes when the aircraft is operating at altitude. The ice then expands. This process is repeated every time the aircraft flies, and eventually causes the separation between the composite and the metal. Corrosion is another significant problem. The degree of delamination and corrosion is therefore exacerbated by a harsh operating environment."

The maintenance condition of a thrust reverser is largely determined by non-routine effects. "Accumulated FH and flight cycles (FC) both affect the rate at which a reverser's hardware deteriorates," says Sauer.

The number of FH on-wing has an effect on the 'flowpath surface'. "This is by causing erosion, impacts, lightning strikes, and some disbonding or delamination on the flowpath inner skins," says James Kornberg, at customer support aerostructures at Air France Industries KLM Engineering & Maintenance. Delamination is exacerbated by harsh environments.

It used to be standard practice to use thrust reversers at every landing, but their use increases fuel burn. It is not necessary to use thrust reversers for all landings, but this does reduce the deterioration of wheel brakes. There is therefore a trade-off between the maintenance costs of thrust reversers, and wheel brakes.

"Landing weight has almost no effect," says Campion. "Landing severity is mainly affected by runway length, the condition of the airport, and the operating environment."

Other issues are mainly non-routine, such as foreign object damage (FOD), hence the influence of runway condition. "FOD and ingestion and vehicle damage often have a large effect on thrust reverser conditions," says Aykut. "There is generally no other specific damage that is related to, or caused by, accumulated FH on-wing. Deterioration, wear or damage to blocker door bearings, and stone chip damage are related to accumulated FC."

Other influences include the maintenance workscopes of previous shop visits, the operating profile of the aircraft, and whether the aircraft is being utilised for passenger or cargo operations.

LaChance adds that the need to carry out airworthiness directives (ADs) and service bulletins (SBs) also influences removal timing when applicable.

Removal intervals

While thrust reverser maintenance is performed on an on-condition basis, some airlines do have approximate or soft removal intervals. Brugman explains that a thrust reverser should periodically have new seals and bushings, and these can result in soft times for some airlines. "Most carriers, however, remove purely on-condition, and the main removal causes are ADs, SBs or deteriorating condition,"says Brugman. "Other causes of premature removals include engine overheats and engine blade failure."

"ADs and SBs can result in premature removals, as can premature delamination and disbonding, large areas of corrosion, failures of actuation systems, FOD and ingestion, damage from ramp vehicles, and damage from interference with slats," says LaChance. Other issues are damage to the inner wall of the C-duct, which can result from the high temperature of the engine core destroying bonded structures, and damage discovered during line maintenance that is beyond the scope of line maintenance.

One of the major issues of thrust reverser repair is delamination of composite material that is bonded to metal structure. This is caused by moisture freezing at altitude, causing disbonding. The degree of delamination increases exponentially with time on-wing.

Similarly, compliance with ADs and SBs can cause planned removals. Many airlines had planned or soft removal intervals in the past, especially with older thrust reverser types.

Actual removal intervals are varied. Older engine types generally have shorter intervals. Engine types like the CF6-80C2 and PW4000 have intervals of 6,000FC, and 35,000-40,000FH. This will be equal to about eight years in the case of typical long-haul operations for the 767 and 747-400 aircraft they are powering.

Similar intervals are achieved for reversers on modern engine types, such as those powering the A330/340 and the 777. "We have seen first removal intervals of 40,000-50,000FH," says Brugman, "and an average of 30,000-40,000FH. This is in the case of reversers for all three engine types powering the 777, and the CFM56-7B. We have not actually seen any second removals for these types yet."

The original equipment manufacturer's (OEM's) recommendation for types such as the Trent 700 and 800 is every seven to 10 years. This is equal to 31,000-45,000FH.

Repair process

"There is no defined shop visit repair or overhaul process in the structural repair manual (SRM) or component maintenance manual (CMM)," says Campion. "This means that the workscopes and subsequent costs and quotes will be highly variable."

The implications are that an airline's engineering department or the repair shop has to define the shop visit workscope. "As a result of this, OEMs and repair shops have developed a lot of unique or special repairs, which are not in the SRM or CMM," says Campion.

There are several levels of shop-visit workscope. The different levels, however, are defined by the individual shops. Aykut describes the smallest as an on-wing repair, needing no disassembly. "This could be an outer surface repair, or a composite repair," says Aykut.

Aykut categorises the next highest as a light shop visit, requiring a removal and then a small degree of disassembly. This can be the removal of a sleeve, a blocker door, or a pivoting door.

LaChance says that Delta TechOps only disassembles a reverser to the extent required to perform the required visual inspections and maintenance. Once disassembled, a tap test is performed on all honeycomb and bonded parts for evidence of delamination, internal moisture, scratches and contour defects. Visual inspections are also made of the doors, fairings, seals, electrical harnesses, sensors, blocker doors, cascades, sliders, draglinks, springs, and hinge fittings.

Reference is made to the SRM for allowable damage and repair data. The CMM will specify which parts and components require a non-destructive test (NDT). Insulation blankets should also be removed and visually inspected. The unit can then be reassembled and tested.

The next level is a full overhaul, where the unit is completely disassembled. All components are inspected and repaired or replaced, as required.

An overhaul starts with an incoming inspection. "This is followed by a disassembly, and then a general visual inspection of all the sub-components," says Aykut. For example, LaChance says that actuators and sync locks should be removed, and have a general visual inspection in accordance with the CMM.

A full overhaul will be similar in many ways to a light shop visit, but it will have some additional elements and procedures. LaChance says the main addition is the removal of the actuators and the sync locks, followed by a visual inspection as specified in the CMM.

"Removed components and sub-components are then sent to the relevant repair shop," says Aykut. "The structural components have a detailed inspection, followed by either a repair or a replacement as necessary. The most complex parts are the electrical and pneumatic actuators. Some parts are life-limited, and all have to be checked and sent to the relevant shops. Parts that are life-limited, and cannot be replaced on-wing, would force the removal of the complete thrust reverser unit."

The most frequently replaced parts are: the locking actuators, which are life-limited; the blocker doors; the central drive unit, which powers the actuator; the outlet cascades, if they are damaged by FOD; and the silicon seal on the inner wall of the main structure.

Brugman adds that other frequently replaced parts are bushings, bearings, wear pads on blocker doors, seals and insulation blankets. He adds that in 99% of cases, delaminated composites can be repaired. "These are actually the most expensive and complex repairs, since they may require a bonding tool and subsequent treatment in an autoclave," explains Brugman. "The other complex repairs are structural repairs. Many airlines may seek the advice of the OEM when they experience complex repairs."

Once all parts have been repaired, the sub-components and components are reassembled, and shop reports are made. The reversing mechanism is then manually tested.

The components most frequently repaired and replaced are the seals, hydraulic components, switches, blocker doors, and bushings and bearings. LaChance comments that the removal and repair of the inner wall of the main structure is the most complex and expensive repair.

"Delamination makes the repairs of the main C-duct sleeves expensive," says Aykut. "It involves a full disassembly and NDT inspection, and requires a large backplate tool to maintain the shape of

Many airlines have divested their inventories of thrust reverser shipsets. Airlines are offered exchange or loan shipsets by repair shops when their own reversers are in the repair facility.

the duct. In many engine types it is also a composite structure, and so requires the use of an autoclave to complete the high temperature repair."

Repair costs & economics

Kornberg comments that the small repair workscopes cost $15,000-20,000.

Lighter shop visits will typically cost $100,000 per shipset for smaller engines, and up to $150,000 for larger engines.

The larger shop visits or overhauls for a shipset can cost up to $250,000 for the larger types, or $150,000 for narrowbody engines and the CFM56-5C.

The average shipset shop visit cost for a CFM56 and V2500 family member will therefore be $125,000. Narrowbodies will therefore have a total cost of $250,000 for both engines. Amortised over an average interval of 35,000FH equals a reserve of up to $10 per FH.

The average shop visit cost for widebodies, such as the A330 and 777, will be $200,000 per shipset, and so $400,000 for both sets on the aircraft. Over a similar removal interval of 35,000FH, this equals a reserve of $10-15 per FH.

These reserves compare favourably with older types of reversers. This is mainly due to shorter intervals of 10,000-15,000FH. Shop-visit costs were similar to those of younger types.

Reverser inventories

Consideration also has to be given to the acquisition of spare units while removed reversers are in the repair shops.

The turn time for a thrust reverser shipset shop visit ranges from 10 to 45 days. "Ten days is typical for smaller repairs, while a light shop visit needs 20-25 days, and a heavy shop visit or overhaul needs 30-45 days," says Brugman.

Fewer airlines now own inventories of spare reverser shipsets. Most of the larger shops provide spare units while the airline's unit is in repair. Spares can be provided in two ways: either by an exchange or via a loan.

"Sabena Technics has spare thrust reverser units, fresh from an overhaul and in a serviceable condition, which means the unit is in a time-continued condition and has accumulated FH and FC on-wing," explains Campion. "We suggest that the customer uses an exchange for an overhauled unit, while it is better for the customer to take a serviceable unit for an exchange or a loan.

"An exchange works by us supplying the airline with a spare, overhauled unit to replace its unit that needs a shop visit. This way the airline ends up with a different thrust reverser to its original," continues Campion. "The airline pays a swap or exchange fee to cover the capital cost of the spare reverser, plus the cost of the shop visit. In the case of a loan, we lend the airline a thrust reverser while its own unit is in the shop, and this loan is charged at a daily rate, in addition to the cost of the shop visit. The airline then returns the loaned reverser when its own has completed its shop visit. The airline gets its original reverser back, but has to perform removals and installations. Lease contracts greatly influence whether an exchange or a loan programme is used."

Sabena Technics has capability for all members of the CFM56 family, the V2500, the PW4000-94, PW4000-100, and the CF6 family.

Turkish Technic provides maintenance and repair for reversers on the CFM56-7B, V2500, CF6-80E2, GE90 and Trent 700 engines. It also offers spare reversers through an exchange programme.

Air France Industries KLM Engineering & Maintenance (AFI KLM E&M) provides repair and maintenance for thrust reversers on the CF6-80C2/-80-E1 family, GE90 family, and all CFM56 family members. Its new nacelles repair facility, which is opening in Paris in 2015, will include capability for reversers on the 787, and will offer loans and exchanges.

Delta TechOps provides repair and maintenance for reversers of the CFM56-7B, PW4000-94, PW2000, and CF6-80A. It also has Federal Aviation Administration approval for the CFM56-5A/-5B.

Spirit Aerosystems has an extensive pool of spare reversers for the 737NG and 777 engine types. It usually provides these on an exchange fee basis, although Brugman adds that some airlines do not have an exchange fee if they have long-term maintenance agreements.

The alternative for airlines is to own their shipsets of spare thrust reversers. This can be economical for larger fleets where spare units are constantly required. The investment, however, will be large, and many airlines have chosen to divest a large percentage of their component and spare engine inventories.

An average shop visit turn time of 45 days means that a single production or repair line will be kept busy all through the year with about eight shop visits. A fleet of 30 twin-engined aircraft with an average removal interval of eight years will therefore keep a single thrust reverser repair line busy. Many smaller fleets will therefore result in gaps of activity between thrust reverser repairs.

The capital cost of spare reverser units is as low as $100,000-200,000 for older types like the CFM56-3, and $1.2 million for the CF6-80 family, which now have a glut of spare units in the market.

The reversers of more modern types have higher market values and list prices. This is $1.0-1.3 million for the V2500-A and CFM56-7B, and $3.0 million for types like the Trent 700, and up to $5.0 million for the GE90.

Many airlines therefore prefer to avoid investing in spare units, and use loan or exchange programmes instead.