While a relatively simple component, thrust reversers are an item of aircraft maintenance that cannot be forgotten. Their maintenance is performed on an on-condition basis, and intervals have been extended for the younger engine types. The global market and costs of shop visits are examined.

Thrust reverser repair & overhaul market

Thrust reversers are a specialist component that the majority of airlines outsource for repair and overhaul. The removal intervals for shop visits have now become extended to the point that few airlines have fleets large enough to generate a constant stream of thrust-reverser shop visits that would justify them having their own repair shops. The market for thrust-reverser repairs has therefore become consolidated to the point where it is now served by a smaller number of specialist providers.

Thrust-reverser units

There are two types of thrust reversers. The first is the clamshell reverser, which uses two moving clamshell pieces at the end of the cowling to completely close and re-direct the engine's thrust.

The second type is the cascade reverser. This is a system where the aft section of cowling outside the bypass duct on high-bypass ratio engines slides rearwards to expose openings and cascade vanes in the cowling wall, while blocker panels in the cowl deflect vertically to create a blocker door in the bypass duct. The air in the bypass duct is deflected through more than 90 degrees by the blocker door, and passes through the cascade vanes in the side of the engine cowl. The thrust from the engine core of most high-bypass engines remains unaffected, since there is no reversing mechanism.

The high-bypass and wide-intake fan designs of most engine types means that few engines have clamshell thrust reversers. Those that do are: the JT8D series; the Rolls-Royce Tay powering the Fokker 70 and 100; and the CFM56-5C powering the A340-200/-300. The CFM56-5C only uses clamshell reversers on the engine core. All other high-bypass engines have the cascade-design thrust reversers.

The main components of thrust reversers are actuation units, blocker doors and thrust deflectors, cascade vanes and the sliding cowl. These comprise three main parts of a thrust reverser: fixed or stationary parts; the actuation mechanism components; and the sliding engine cowl. The cascade vanes and the sliding cowl are solid parts with no complex or moving components, and are partly made with composite materials. The engine cowl also has heat blankets. The high cost items in thrust reversers are therefore screwjacks, composite materials, heat blankets and coatings.

Thrust-reverser maintenance

Maintenance of thrust reversers is now performed on an on-condition basis. Thrust reversers are constructed in two halves, and each half will be removed for a shop-visit input as required by its condition. The main removal causes for shop-visit work will be: reliability problems with the actuation units; foreign object damage (FOD) to the cowls and reverser flow cascades; delamination and corrosion of the cowls; and heat damage to the cowling and heat blankets. The extent of damage to, and deterioration of, thrust-reverser units will be related to the harshness of landings and treatment by the pilots, heat from the engine, and the environment in which the aircraft is being operated.

"There are no requirements to overhaul thrust reversers in aircraft maintenance manuals," says John Allen, project manager nacelles at SR Technics. "Only inspections are specified."

Shop-visit workscopes fall into three broad categories: basic, intermediate and overhaul. The condition of the removed unit will determine which level of workscope is required. A basic workscope will make the unit serviceable, ensuring in particular that the actuators are fully operational and reliable. In addition, repairs are made to wear strips, bushings, bearings and fasteners, and cowls and cascades, other functional checks are made, and any SBs are incorporated.

An intermediate shop visit will involve removing, refurbishing and replacing heat blankets. Repairs will be made to cascades due to FOD, and actuators will have more detailed workscopes. Some items will be replaced due to wear and tear.

An overhaul will involve deeper work that includes replacing hydraulic and pneumatic lines, re-skinning cowls, replacing blocker door components, and repairing composite materials. The unit will be completely disassembled, all parts inspected and repaired, and then reassembled.

"The overhaul on a CFM56-5C reverser will include a functional test and a clean, followed by a disassembly," explains Allen. "This is followed by visual and non-destructive test (NDT) inspections. Composites are inspected and repaired as required, and paint coatings are stripped from parts. Repairs are either minor structural ones or heavy according to condition. The unit is then reassembled, painted and tested. A lighter workscope results when there are fewer repairs because of fewer findings at inspection after disassembly."

Certain engines are still removed on a hard- or soft-time basis by some airlines. "We remove the reversers on the CFM56-5A/-5B at a 10-year and 24,000FC interval," says Allen. "Other engine types we repair reversers for include the CFM56-7B and -5C, PW4000-94 and the PW4000-100. We remove these on an on-

Shop visits for thrust reversers are performed on reverser halves to reduce the investment airlines have to make in spare units.

condition basis, and their removal intervals are mainly driven by accumulated FCs, corrosion and calendar time."

Joe Greenwood, vice president of sales and marketing at Triumph Airborne Structures comments that the fact that reversers are removed on-condition makes it hard to price shop visits to customers. "Intervals have gradually increased and are now long in many cases, so overhauls are usually required. In most cases engines are removed on-condition, although the operating environment has a big influence on the removal interval. In the past hard time intervals were 20,000-30,000FH, whereas now they are are 35,000-40,000FH in most cases.

"The variation in removal intervals means most workscopes are customised, and many are at a higher level," continues Greenwood. "A full overhaul will include a workscope on the actuation system. We also buy and use parts manufactured approval (PMA) parts and components. Airlines in the Asia Pacific, however, tend to prefer original equipment manufacturer (OEM) parts, while major US airlines generally accept the use of PMAs."

Some shops recommend removal intervals to airlines. "We find that a typical overhaul interval is about 30,000FH, followed by a second overhaul after a similar limit," says Jim Lickteig, senior manager of aftermarket customer support at Spirit Aerosystems. "The intervals are not always FC driven, and the interval driver depends on the operator. Some airlines even use calendar time as a removal interval driver. The FH:FC ratio is naturally a big driver, so reversers on the 777 stay on-wing longer than those on the 737s."

Removal intervals are similar across the industry. Air France Industries has a fixed interval of 42,000FH for CF6-80C2 reversers, which is similar to the 35,000FH that TAP Maintenance & Engineering typically achieves for the same engine and PW4000. Lufthansa Technik recommends intervals of 6,000FC for reversers used on long-haul aircraft, which will be equal to 35,000-50,000FH in most cases. It recommends intervals of 12,000FC for units used on short-haul aircraft. This is close to 15,000-24,000FH.

Air France Industries has calendar-based intervals for other engine types. "We have a removal about every five years for the CF6-50, eight to 10 years for the CF6-80E1, and have sampling at 10 and 12 years for the GE90," says Michel Bruet, vice president of aerostructures at Air France Industries. "If the condition of the unit is satisfactory then no maintenance is done, and it is possible that the unit could stay on-wing for as long as 15 years. Intervals for the CFM56 depend on the exact variant, so the -5A/-5B usually lasts eight to 10 years. There are also airworthiness directive (AD) inspection intervals of 12,000FC. Some types are reliable, while others require modifications and upgrades. Our objective with establishing soft times is to minimise the number of heavy repairs, such as autoclave repairs. We have therefore established soft times of 6,000FC for long-haul types."

Turn times depend on the workscope level. "A basic shop-visit workscope will typically have a turn time of about 10 days. This increases to 15-30 days for an intermediate or light workscope," says Lickteig. "Overhauls are about 30 days for a short-haul or narrowbody reverser on a CFM56, for example, and 45 days for a unit on large widebody engine." The turn times are similar for shops across the industry."

Providers

As described, thrust-reverser repair and overhaul is now a specialist activity, with fewer airline maintenance and engineering divisions being active. The business is divided between independent specialist shops, and airline maintenance and engineering divisions.

The average interval of six to seven years for narrowbodies, and seven to eight years for widebodies means that aircraft are having a reverser unit removed once every three to four years, depending on the number of installed engines. This implies the total market is for up to 5,000 reverser units or 10,000 reverser halves per year for the jetliner fleet. The market will be larger still when the volume of thrust-reverser shop visits for regional jets is taken into account.

Triumph Airborne Structures of the US is one of the largest providers, repairing 225 or more reversers per year. "We have a wide capability. In terms of narrowbodies, we cover the CFM56-3 and -7B series, all V2500 variants, the PW2000 and RB211-535. For widebodies, we have capability for the CF6-80C2 and PW4000. We can still do the JT8D and JT9D, but there is less work from these engines in the current market. We still have capability for the CF6-50 series, but the market rate for shop visits is too low to justify continuing with it. The CF6-80C2, however, accounts for the largest volume of activity."

Goodrich Aerostructures is the industry's largest provider of thrust-reverser repair and overhaul, with eight shops on six continents. Its two US shops are in Foley, Alabama and Chula Vista, California, while its European shops are in Prestwick, Scotland and Toulouse, France. The rest are in: Singapore; Dubai; United Arab Emirates; Tianjin, China; and Sao Carlos, Brazil.

Not only does Goodrich Aerostructures have an extensive capacity in terms of the number and size of

EXAMPLES OF THRUST REVERSER REPAIR & OVERHAUL PROVIDERS

Maintenance provider	Facility location	Engine types provided for
Triumph Airborne Structures	Hot Springs, Arkansas	CFM56-3, CFM56-7B, V2500, PW2000, RB211-535, CF6-80C2, PW4000
Goodrich Aerostructures	Foley, Alabama Chula Vista, California Prestwick, Scotland Toulouse, France Singapore Dubai, UAE Tianjin, China Sao Carlos, Brazil	All Airbus, all Boeing, E-190, 787, A350, MRJ & C Series
Spirit Aerosystems	Wichita, Kansas Prestwick, Scotland	JT8D, CFM56-3, CFM56-7B, PW2000, RB211-535, PW4000-94, CF6-80C2, PW4000-112, GE90
SR Technics	Zurich, Switzerland	CFM56-5A/-5B, CFM56-7B, PW4000-94
Lufthansa Technik	Hamburg, Germany	CFM56-3, CFM56-5A/-5B, CFM56-5C, CFM56-7B, V2500-A1/-A5, CF6-80C2, Trent 500, Trent 700
Air France KLM Engineering & Maintenance Group	Paris, France Amsterdam, Netherlands	CFM56 family, CF6 family, GE90 family
Aircelle	Dubai, UAE	Trent 500, Trent 700, Trent 800, CF34 family
American Composite	Miami, Florida	CFM56 family, V2500, CF6 family
Iberia Maintenance	Madrid, Spain	JT8D-200, CFM56-5A/-5B, CFM56-5C, RB211-535E4 CF6-80, Trent 500
TAP Maintenance & Engineering	Lisbon, Portugal	CFM56-5A/-5B, CFM56-C, CF6-80C2

facilities, but it also has the capability to repair and overhaul most commercial types of thrust reverser. It covers all Airbus and Boeing types, as well as the Embraer E-190. It uniquely also offers nacelle maintenance for several aircraft that are yet to enter service: the 787, A350, MRJ and Bombardier C Series.

Spirit Aerosystems has shops in Wichita, Kansas and Prestwick, Scotland. "We complete shop visits on more than 100 units each year across both shops," says Lickteig. "We also perform additional structural and composite repairs at our Prestwick facility. Our other activities include repairing nacelles, fan cowls and nose cowls. We have capability for reversers on engines powering the 737, 757, 747, 767 and 777 - that is, anything that we manufacture for Boeing at our Wichita facility."

SR Technics, now a fully independent maintenance provider in Europe, carries out about 50 reverser shop visits each year. "These are mainly CFM56-5A/-5B, the PW4460 and the CFM56-7B. There is a mandatory service bulletin (SB) recently issued on the -7B, which is forcing a lot of removals. In addition to all the types for which we have capability, we are considering adding capability for the Rolls-Royce Trent 500 and 700."

The majority of large airline maintenance and engineering departments that have thrust-reverser repair capability, and offer it as a third-party product, are in Europe. Lufthansa Technik is one of the largest of these providers, and its Hamburg facility carries out shop visits on about 150 reverser units annually.

Lufthansa Technik has one of the largest capabilities. For narrowbodies it can offer services for the CFM56-3, CFM56-5A/-5B, CFM56-7B and V2500-A1/-A5. For widebodies it has capability for the CF6-80C2, CFM56-5C, and Rolls-Royce Trent 500 and 700.

Air France Industries and KLM Maintenance & Engineering is another large provider. "We can provide services and repairs for all variants of the CF6 series, the CFM56 series, and all variants of the GE90 family," says Bruet. "We also have a joint venture partner, Aircelle, based in Dubai,which started serving the Middle East market in January 2010. Aircelle provides services for the Trent 500, 700 and 800 series, as well as the General Electric CF34 family. It has the capacity to perform shop visits on up to 150 halves or 75 reversers per year.

"In the Air France Industries and KLM Maintenance & Engineering facilities we have the capacity to perform shop visits on up to 300 halves or 150 reversers each year," says Bruet. "We also have a subsidiary AMG, which is a group of companies based in the US. One company in the group, AMC, repairs thrust reversers and structures, and it has a shop in Miami that has capability for the CFM56, V2500 and CF6."

Iberia Maintenance in Madrid, Spain has capability that matches most of its parent company's fleet. It can repair and overhaul the CFM56-5A/-5B, CFM56-5C, JT8D-200 and RB211-535E4 for narrowbody engines. Widebody engine types are the CF6-80 and Trent 500. Iberia Maintenance is also in the process of adding the V2500-A5. Its shop-visit activity is smaller than other European providers at about 60 reversers per year.

Another small provider is TAP Maintenance & Engineering. Like Iberia, TAP's capability is a reflection of its parent company's fleet. It has thrust reverser repair and overhaul capability for the CFM56-5A/-5B for narrowbody engines, and the CFM56-5C and CF6-80C2 for widebody engines.

Shop-visit economics

The cost of a shop-visit workscope is highly variable and depends on several factors, including: the condition of the reverser on entering the shop; the resulting workscope that is required; which modifications are required; the environment in which the aircraft has been flying; the pattern of operation; and the FH:FC ratio. The cost of the shop visit is also influenced by supply and demand, however. The large supply of shop capability and capacity for older and more popular types has depressed market rates. Rates for reverser halves for the CF6-80C2 are $90,000-150,000. The cost for a full reverser is therefore $180,000-300,000, which is relatively low for a unit of its size.

Rates for reversers for narrowbody engines are about $200,000 for a V2500, and mature rates for the CFM56-5B and -7B will be similar. Rates for the -7B are lower because the first workscopes of

Removal intervals for reversers from modern engine types are in the region of 12,000FC for short-haul types and 6,000FC for long-haul types. Actual shop visit workscopes will depend on removal interval and the unit's condition on initial inspection.

many reversers are relatively light; as low as $100,000 in some cases.

Shop-visit costs for reversers from widebody engines are $300,000-400,000 for smaller types like the PW4000-94. Many widebody engines are larger and rates for the PW4000-100 are higher at $450,000-600,000, while they vary widely at $500,000-1,000,000 for the similarly-sized Trent 700.

These shop-visit costs translate into reserves per FC or per FH; whichever way an operator considers appropriate.

Intervals for reversers of modern narrowbody types are generally 12,000-20,000FC in most cases, equal to intervals of 18,000-30,000FH. Types like the CFM56-5B, CFM56-7B and V2500 will have mature shop-visit costs of about $200,000. The range of shop-visit costs will be $200,000-300,000 depending on the removal interval and subsequent workscope required. The reserves for a thrust-reverser unit will therefore be $15-17 per FC, or $10-11 per FH.

Intervals for older types, like the CFM56-3, will be shorter than those for modern types, but shop-visit costs will also be lower. Reserves will therefore be similar to those for the CFM56-5B and other modern engines. The large number of parked and stored older generation aircraft means there is a large supply of thrust-reverser units for the JT8D and CFM56-3 on the aftermarket. Airlines may be able to buy time-continued units on the used market for less than the cost of a shop visit. Allen estimates the market value for a CFM56-3 reverser unit to be $150,000-200,000.

Intervals for smaller widebody engines like the CF6-80C2 and PW4000-94 are 6,000-8,000FC, which is equal to 35,000-60,000FH. The range of shop-visit costs for the reversers on these engines is $300,000-400,000. The resulting reserves for each thrust-reverser unit is therefore about $50 per FC, or $7-9 per FH.

Similar intervals are achieved for larger types like the CF6-80E1 and Trent 700, although the higher shop-visit costs of reverser units results in higher reserves of $12.50-$14.00 per FH for the CF6-80E1, and $14-22 per FH for the Trent 700. The reserve for the Trent is so high, because it suffers both from higher shop-visit costs and shorter intervals due to technical problems.

Spare reversers

Although the reserves for thrust reversers are analysed here as for reverser units for a whole engine, maintenance on thrust reversers is carried out on halves. "Many airlines remove thrust reversers in halves to limit the investment in sets of spare reversers," says Bruet. "The on-condition maintenance policy means the timing of removals is flexible, so removals can be staggered and delayed to allow halves to be removed and repaired in turn."

Airlines have several options when it comes to sourcing spare reversers. The main two choices are between owning spare reverser units, and paying reverser repair and maintenance shops to provide spare units as part of a support package.

Market values of spare units are the first consideration. "Typical values for units on the CFM56-5B are $1.5-2.0 million, and similar at about $1.8 million for the -7B, and $1.8-2.5 million for the -5C. Values for the older CFM56-3 are down to $150,000-200,000. Values are the highest for the V2500, which are in short supply. These are as high as $3.0-3.5 million.

The effect of supply on market values is reflected by the PW4000-94, whose reversers cost $1.2-1.6 million. Values for the Trent 700, which is relatively young and in short supply, are $3.8-4.0 million.

"There are various ways we can support airline customers with spare sets," says Lickteig. "This includes offering exchange reverser units, or units on short- and long-term lease programmes. We can also supply spare units if a reverser's shop visit runs over its guaranteed turn time."

Some suppliers can supply customers from large pools of spare reverser units. Lufthansa Technik, for example, has a pool of about 150 reverser halves.

In addition to providing spare reverser units to airlines to provide coverage during repair and overhaul, repair agencies offer a range of engineering and support services. An example is Spirit Aerosystems. "We offer total maintenance, spare unit provisioning and overall full support contracts," says Lickteig. "We do not offer power-by-the-hour (PBH) contracts, but we do provide the choice of flat-rate repair pricing as well as time and material deals."

Long-term contracts typically offer fixed-price repair and shop visits, as well as provisioning of spare sets. "We provide these services, as well as a few time and material contracts, or fixed-price contracts which are good for budgeting. Time and material contracts are most suited to on-condition maintenance, when removal intervals and shop visit workscopes are hard to predict," says Greenwood.

Besides pricing systems, repair providers can also provide a range of other support products. "We offer pool access for complete units or spare parts, logistics and aircraft-on-ground (AOG) support, and asset management," says Bruet. "We also design repairs and have a design approval certification. In addition to main shop visits, we can also provide smaller on-wing repairs, depending on on-wing limits. Airlines prefer this since it prevents removals. AC