THE ENGINE YEARBOOK

Aircraft Technology's annual publication for the aero-engine professional

2011

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Engine MRO outlook

Engine MRO represents the biggest part of MRO spend and the engine fleet is expected to grow at 2.5 per cent a year over the next decade. *David Stewart* of industry consultancy *AeroStrategy* looks at the facts and figures.

In 2009, there were approximately 20,500 active air transport aircraft with 45,000 jet engines. This fleet flew about 114 million engine flying hours, and generated $15.3bn in engine overhaul spend.

By these measures and many others, the air transport engine market is thus one of great significance. Engine OEMs and MROs are together responsible for the performance of an asset which is a prerequisite to airline reliability and aircraft availability and a driver of fuel costs. It also represents the largest share of MRO spend (see below).

This article provides the numbers behind this engine market. It also highlights some of the key trends and challenges for the engine MRO supply chain, not only today in the recession but also in the coming years when the next aerospace cycle moves into an upswing. The reduced spend and the timing of this recovery is, of course, one of the aforementioned short-term challenges!

Engine fleet

AeroStrategy and UBM Aviation together produce an independent forecast of the aircraft and engine fleet, and associated MRO spend, over the period 2009-2019. Based on this forecast, the engine fleet is expected to grow at 2.5 per cent per annum, from 45,000 to 57,500 over the next decade.

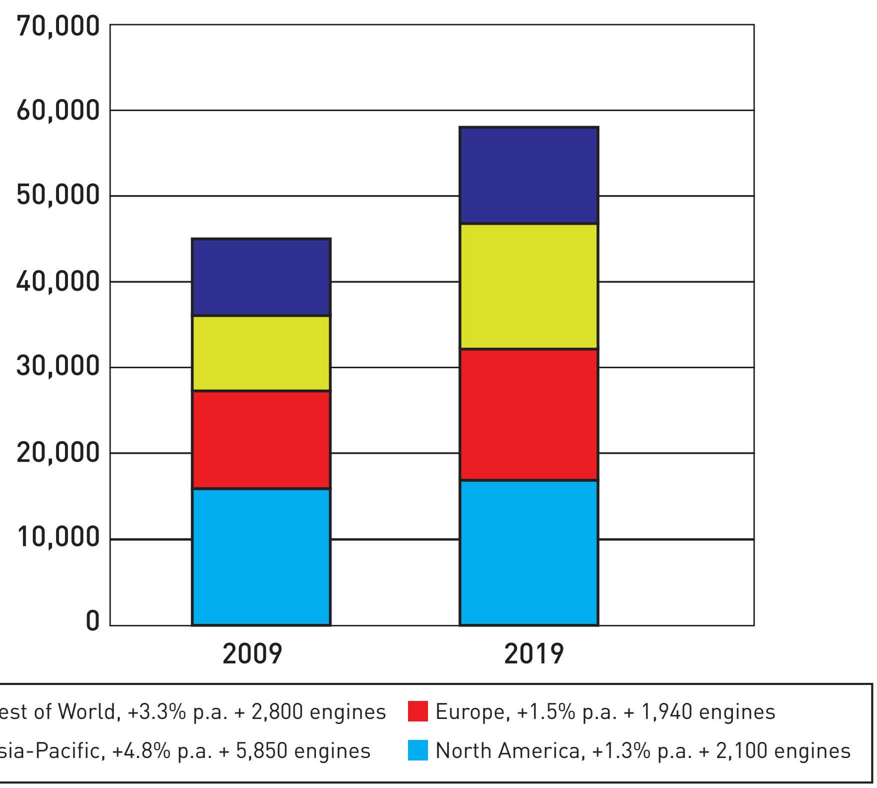
This fleet can be segmented in a number of different ways that can inform supplier strategies and focus in the coming years. For exam-

Table 1

Engine OEM	Fleet Size 2009	Fleet Size 2019	CAGR (%)	Fleet Share 2009 (%)	Fleet Share 2019 (%)
CFMI	15,200	23,000	4%	34%	40%
GE	9,800	13,100	3%	22%	23%
P&W	8,570	4,730	-6%	19%	8%
Rolls-Royce	6,460	8,110	2%	14%	14%
IAE	3,590	7,050	7%	8%	12%
Other	1,150	1,420	-4%	2%	1%

ple, the regional analysis of the fleets in 2009 and 2019 (see Graph below) highlights some obvious yet dramatic conclusions. Everyone knows that the growth rates in Asia (especially China and India) will be relatively high. But what does that mean in absolute terms? The active jet engine fleet in Asia Pacific (including China and India) will grow from 9,650 in 2009 to 15,500 in 2019 — that's an additional 5,850 engines to support and maintain. At 4,040 engines, this is larger than the absolute engine fleet growth in North America and Europe combined. It is clear that engine MRO suppliers and others in the related supply chain who have not already developed corporate, capacity, customer support and logistics strategies for the Asia region risk losing out in a significant way.

Engine fleet growth by region 2009-2010 (region, CAGR and absolute increase)



A second way of segmenting the fleet is by engine OEM. Table 1 (*above*) provides the associated information.

This demonstrates (amongst other things) the huge growth in the narrowbody engine fleet (CFMI and IAE), the growing share of the fleet represented by GE (including its share of CFMI engines), and the significant decline in the Pratt and Whitney fleet (excluding their share in IAE).

This table does not address one clarion issue: "What about the potential re-engining of the A320 and the 737?" This subject that might have greater clarity by the time this article is published and read. The data assumes that re-engining does NOT occur, and by so doing, shows how massively significant for some OEMs this re-engining decision is. For example, if the A320 family is re-engined with a Pratt & Whitney GTF (geared turbofan) and a CFMI alternative option (an outcome that seems increasingly likely at this time), how different would the above table look for Pratt & Whitney and IAE? Very different is the answer.

A third important segmentation approach is by maturity of the engine. Using the following categories: in production (e.g., CFM56-5B, CFM56-7, CF6-80E, GE90); future (e.g., GENX, Trent XWB, SAM146); mature (e.g., CF6-80C2, PW2000, RB211-535); and old (e.g., JT8D, CF6-50, RB211-524). Graph 2 (p6) shows the emphatic switch in the engine fleet towards the "in-production" and "future" categories. In 2009, these represented 50 per cent of the fleet, and in 2019 this share grows to 78 per cent. The old fleet declines at 10 per cent per annum, the mature fleet at four per cent per annum. What's the implication for the supply chain? For those suppliers with a portfolio focused on mature and old engine types, it's clear that the challenge of how to get capability on and access to newer engine types is now looming very large.

MRO spend outlook

The 45,000 engines and 20,500 air transport aircraft generated an MRO market in 2009 worth $42.7bn, a decrease from the 2007 peak year of spend of about $45bn. This decline was driven primarily by the permanent parking of aircraft resulting from the high fuel price and airline failures in 2008 and from the recessionary pressures of 2008 and 2009 that resulted in declining fleet-wide aircraft utilisation.

How does this MRO spend break down? The largest segment is engine overhaul at $15.3bn (36 per cent), followed by component overhaul ($9.4bn, 22 per cent), line maintenance ($8.7bn, 20 per cent), airframe heavy maintenance ($6.3bn, 15 per cent) and modifications ($3bn, seven per cent). That is, engine overhaul, defined as off-wing engine maintenance activity only (i.e., excluding engine management and on-wing activity) is the biggest driver of airline MRO spend.

What are the expectations for growth? Whilst the total MRO market will grow to $58bn in 2019 at 3.2 per cent per annum (in constant 2009 $ terms), engine overhaul is forecast to grow at above this rate, at four per cent per annum, to $22.5bn in 2019. This growth rate is higher than that for the engine fleet (2.5 per cent per annum) because average aircraft utilisation is expected to increase as airlines seek to improve asset utilisation and reduce unit cost. The associated forecast shows annual engine utilisation growing from 114 million hours to 174 million (4.3 per cent per annum).

Once again, the engine-related MRO spend information can be usefully segmented to illustrate or re-emphasise the challenges for the engine MRO supply chain.

The MRO spend regional analysis (Table 2) reinforces and exacerbates the previous

Table 2

Region	Engine MRO Market 2009 ($B)	Engine MRO Market 2019 ($B)	Absolute Growth ($B)
North America	5.3	6.0	0.8
Europe	4.5	6.0	1.4
Asia-Pacific	3.4	6.9	3.5
Middle East	0.8	1.7	0.9
Rest of World	1.4	2.0	0.6
TOTAL	15.3	22.5	7.2

Share of engine fleet by engine maturity, 2009 and 2019

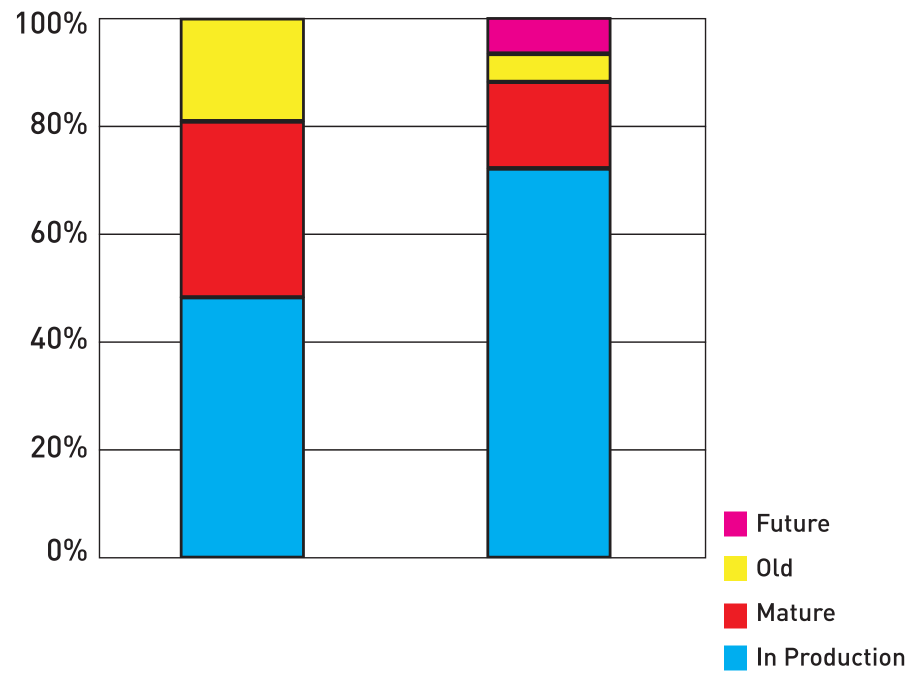


Table 3

Measure	1995	2009
Market Size ($B)	6.5	15.3
In-House Share	54%	23%
OEM Share	13%	43%
Independent Share	14%	19%
Airline Third Party Share	19%	15%
Outsourced Market ($B)	3.0	11.8

observation on the importance of Asia in the future.

Asia Pacific accounts for almost 50 per cent of the absolute growth in engine MRO spend and the region will be a larger engine MRO market than North America and Europe in 2019. This is driven not just by the fleet growth, but also by the age demographics of the fleet already in operation.

A different segmentation is by aircraft category: regional jet engine (e.g. CF34, AE3007), single-aisle (e.g., CFM56-7, V2500) and twin-aisle (GE90, PW4000, Trent family). Whilst twin-aisle engines account for 27 per cent of the fleet, such engines generate some 45 per cent of the engine MRO spend, simply because they are larger and more expensive to maintain. Regional jet engines represent 14 per cent and six per cent of the fleet and spend respectively, whilst for single-aisle, the numbers are 59 per cent and 49 per cent. This is of particular importance to airlines because, unsurprisingly, there is less supplier choice on the larger engines and therefore typically less competition.

It was pointed out in the earlier fleet analysis that “in-production” and “future” engines will account for 78 per cent of the fleet in 2019. The same is roughly true for engine MRO spend. And on newer engine models, it is also valid to say that engine OEMs have a competitive advantage over other third-party suppliers. OEMs have the ability to sell long-term MRO support deals at the point of aircraft purchase and they control access to technical data, documentation and many parts. They can also be more flexible on material pricing within their MRO offers, should they choose to do so. As evidence of the market strength of OEMs, one just has to observe the market penetration of the Rolls-Royce TotalCare offer on their own engine models, especially the Trent family.

So the 2019 information from this segmentation analysis (by engine maturity) raises an important challenge for airlines - they need to develop strategies that enhance competition and/or help protect/reduce costs, especially on the larger, newer engines where OEMs tend to have a stronger market position. The ability of the engine OEMs to raise/escalate their prices even in the midst of the current recession remains an open and regular complaint of many airlines.

One segmentation approach obviously not yet discussed is by engine type. In 2009, there were five engine families that generated more than $1bn in demand (in descending order of market size): CF6-80C2, V2500, CFM56-3, PW4000 (all versions), and CFM56-7. In 2019, there are seven engine families with MRO demand greater than $1bn (in descending order of market size): V2500, CFM56-7, CFM56-5B, GE90, PW4000, CF6-80C2 and the CF34.

It is staggering to note that the largest three engine markets, those that power the A320 and 737NG, will alone generate a combined 2019 market size of over $9bn! This is a huge potential market, and this once again highlights the dramatic impact that a re-engining decision of the A320 and 737NG (with a discussed entry into service of about 2014/2015) will have on the future breakdown of the market.

Engine MRO supply

There are four main categories of supplier in engine MRO — the OEMs, in-house airline shops, airline third-party providers (e.g., Delta Tech Ops, LH Technik, Iberia) and independents (e.g., MTU, Standard Aero and ST Aerospace).

In 2009, engine OEMs held a 43 per cent share of supply. This includes OEM-based joint venture suppliers such as TAESL, SAESL and HAESL. Some 23 per cent of engine MRO is conducted in-house, 19 per cent by independents and 16 per cent by airline third parties. Note that in this calculation, where, for example, LH Technik overhauls engines for Lufthansa, this is considered in-house.

There has been a significant shift in this supply breakdown over the last 15 years (see Table 3).

Since 1995, OEMs have increased their share of the market by 30 percentage points, primarily by taking work from "in-house" supply, the proportion of which has dropped by 31 percentage points. Interestingly, the combined share held by airline third parties and independents remains virtually unchanged at 33-34 per cent. As a result of this change in purchasing behaviour by airlines, the "available" or outsourced market has grown at just over 10 per cent per annum over this period, to $11.8bn in 2009.

This outsourcing trend will likely continue into the future, albeit not at such a fast rate as historically. The reasons for this are threefold. First, as airlines move into new aircraft, the associated new engines are becoming increasingly reliable and the cost to establish overhaul capability is getting higher. These two factors make the business case for in-house capability more and more difficult to justify. Second, airlines today are focusing more on their "core business" of flying passengers. And engine maintenance to most airlines is non-core. Third, a viable supply base exists for many engine types, so airlines can and should leverage this opportunity.

Engine MRO market in recession

The recent recession has obviously impacted spend on engine MRO. Airlines have parked many of the old maintenance intensive aircraft such as the 737 Classic and they have reduced overall aircraft utilisation to better match capacity with demand.

Given the imperative to reduce costs, airlines have sought many other ways to reduce their engine MRO spend as well. Examples include: a reduction in workscope for shop visits; where possible, more repairs and less replacement of expensive parts; deferment of the replacement of the very expensive life-limited parts and use of short-stub engines; greater leverage of spare or surplus engines in lieu of an overhaul; and of course, some airlines have sought to renegotiate their MRO contracts.

All these changes in behaviour have meant that engine overhaul suppliers, depending on their engine and customer portfolio, have seen revenues decline on average by 10-15 per cent.

When will recovery occur? This is ultimately driven by the financial health of the airline industry, which in turn is very dependent on

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economic growth and fuel prices. The current outlook is for relatively slow global economic (GDP) recovery in the order of two to three per cent per annum, with fuel prices being quite high at over $80/barrel. In this case, 2010 will likely be a year of low single digit percentage growth, with recovery really taking hold in 2011.

However, a worst case scenario would be another drop in economic growth and continuing high fuel prices. In this event, the engine MRO market is likely to remain depressed for a while longer. In an upside scenario, where the expected slow economic growth continues, and the fuel prices drop below $80, the market would probably see a quicker and more "V-shaped" recovery.

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Trends, challenges and opportunities in engine MRO

No engine MRO market review would be complete without a comment on the status and development of PMA. The recession has seen the use of PMA decline by some 17 per cent since the 2007 peak. There are a number of reasons for this, including: airline use of buffer stock rather than buying of inventory; more repairs rather than replacement of parts; parking and cannibalisation of the mature aircraft fleets where PMA had a higher penetration of material content; reduced airline resources available to the PMA approval process; and last but not least, OEM defensive measures. This latter point can be illustrated by GE/CFMI's agreements with potential adopters/users of PMA, the independent suppliers such as AVEOS and ST Aerospace. This has successfully given GE/CFMI greater influence over the parts/material supply chain.

Despite this, PMA remains a strategic tool for airlines to use in the face of increasing prices or poor parts availability from OEMs. Therefore, it is expected that adoption of PMA will recover and increase, especially in the airframe components and interior parts of the aircraft.

A number of key challenges have already been raised. In particular, there is the growing importance of the Asia Pacific market and the perceived threat (to costs) of more limited sources of supply on the new larger engines coming into service in the next decade. In addition, the size and growth of the single-aisle engine MRO market (A320/737NG) will have been an expected foundation for many suppliers' revenue prospects over the next decade. A decision to re-engine the A320 and the 737NG would change the long-term outlook for the current engines significantly.

Opportunity obviously also exists. Market recovery is expected in the not too distant future and robust growth of four per cent per annum (in constant $) is forecast. This combined with an increase in outsourcing means an even higher growth rate in the available market will occur. However, this higher market "availability" will only be realisable and accessible to airline third-party and independent MROs if they develop counter-strategies to the threat of OEM-based long-term MRO contracts signed at aircraft delivery.

Engine MRO is a large, global, competitive, technologically and service demanding market. The critical long-term threats and opportunities are evident for all to see. The winners will be those who take action, develop the appropriate strategies and build the right capabilities, partnerships and portfolio to succeed.

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An aero engine's life cycle can be divided into three main stages: the financial, management and trading phases. Careful and far-sighted management is necessary to balance maintenance cost against operational risks whilst maintaining maximum asset value as the engine progresses through these different periods.

Managing engines wisely

Everything is rosy during the 'honeymoon period', the first years of an aero engine's life cycle and main part of the initial financial phase. The power plant has been freshly delivered from the OEM and mated with its original operator who will generally be able to enjoy its daily faithful, revenue-creating service without worrying much about prolonged and expensive maintenance. Premature engine removals for component deterioration should be covered by the OEM as part of its product warranty, and even foreign object damage (FOD) events might fall under a separate insurance policy. Typically, the OEM will also make guarantees for fuel consumption, piece-part life and reliability, especially on new-generation equipment, and possibly even commit to cost per flight hour and/or flight cycle. Apart from ensuring compliance with the regulatory requirements and keeping a moderate level of technical oversight (to make sure the required maintenance and operational processes are safely and adequately working), the operator has no more engine management responsibility.

But this sweet, uncomplicated life typically comes to an end after approximately seven years; although this does depend on the type of aircraft and its utilisation. At this point the engine is taken off wing for its first scheduled maintenance shop visit. The OEM's warranty begins to expire in individual areas, and its financial support starts to dwindle. The engine becomes 'adolescent', as David Garrison, MD engine and component maintenance at Delta TechOps in Atlanta, US, puts it. For him, the operator has to take on more responsibility for the power plant's maintenance planning in this second part of the financial phase. Garrison states: "During this phase one will be actively managing the unscheduled engine causes and determining the engine's true capabilities based on the current design and the owner's [airline or lessor] operating parameters. During this phase one is also analysing the best life-limited part (LLP) management philosophy."

Power-by-the-hour

A power-by-the-hour (PBH) or total support agreement with the OEM or an MRO provider is one option for the operator. This would allow continued flying without assuming the responsibility of balancing maintenance costs against operational risks and determining the maintenance planning. Normally, the engines stay in the service of the initial operator as there is only limited aircraft remarketing taking place at this point in time. The operator can pay the OEM/MRO an individually arranged, flight hour-based rate for their technical support services and concentrate on its main business of providing air transport. For example, Delta TechOps's PBH contracts usually include fleet removal forecasting, service bulletin modification and inspection recommendations, on-wing engine condition monitoring, and the development of a maintenance programme, according to Garrison.

During the initial 'honeymoon' period of an engine's life cycle, its maintenance is largely determined by the OEM's product warranty policy and guarantees, and the operator/owner does not need to manage an engine plan.

However, even apparently comprehensive packages do not necessarily cover all eventualities that might concern an aircraft operator or owner. "One comment about total support is that all too often it is not really total support," remarks Karl Gibson, operations director of TES Aviation, an aero engine management company based in the UK. He highlights that total support and PBH agreements always carry exclusions and might not cover certain work; FOD removal as an example. These extra-contractual maintenance events have then to be accomplished on the basis of their individual (man hour) time and material cost requirements. In that case the operator incurs both the cost of the regular PBH/total support payments, whether any regular maintenance work has actually been done or not, as well as the individual time and material-based payments for the additional work. Hence Gibson argues that, in order to forecast the entire MRO expenditure for an engine over a given period of time, the operator has to make an analysis of likely time and materials cost in the first place, irrespective of whether the company then decides to sign a PBH/total support contract or not.

This does not mean that a PBH/total support agreement won't still be the best option. "We look at what is best for our customer's requirements and do studies across a number of maintenance cost per flight hour agreements," explains Steve Froggatt, engineering manager at TES Aviation. "We won't always go for time and material if the power-by-the-hour contract makes more sense. It all depends on the engine, operator, any specifically harsh operating area or condition."

For Abdol Moabery, CEO and president of GA Telesis, an aircraft asset management firm, component supplier and maintenance provider in Fort Lauderdale, Florida, the issue comes down to whether the operator wants to make regular payments to a PBH/total support provider for the maintenance in advance or pay for the individual events as they come along. "The provider of that [PBH/total support] service is accumulating cash for a 10 or 15-year programme. Some airlines view that cash as important to their business [now]. So they don't want to pay up front and would rather just do it as time goes by."

Whatever decision is eventually made, it is of fundamental importance to get a clear understanding of the full maintenance cost that is likely to be encountered throughout the proposed service period for the engine. Although these expenditures can vary substantially between different operators and equipment, they can nevertheless be predicted with great precision over long periods of time. Analysing an engine's remaining life cycle in light of its operational requirements and the financial objectives of its owner, if it is a leased engine, is the first step for any technical management team before determining the future maintenance plan.

Management phase

This becomes increasingly important as the engine progresses from the financial phase into the management phase. By then the powerplant is between 12 and 15 years old, may have transitioned from one operator to the next, its PBH/total support contract may be expiring, and it will need to come off-wing for its second, third or fourth shop visit. All product warranty and guarantees have finally expired, and the maintenance plan is no longer governed by the OEM's product and repair developments. There will be a range of alternative PMA parts and DER repairs available on the market, which will give the operator/owner some choice to tailor the future maintenance plan to its individual needs. "The management phase is where most change is going to take place within an engine and its value," states Froggatt. "The management decisions one makes at that particular point, for a number of shop visits, is going to dictate the residual value when one gets towards the trading phase [when the engine will eventually be disassembled to serve as a parts source]. As the lessor, one is looking more into the asset value,

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Trading phase: when the value of the individual parts and components exceed the book value of a complete engine, it is teardown time and the asset will serve as a spare part source.

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> **— Abdol Moabery, CEO and president, GA Telesis**

because one is looking at the end and what one wants to do with the asset. The operator, specifically, is looking at the cost per hour, because that's what it is all about to turn a profit."

The main factors in the assessment of an engine's remaining life cycle, which will indicate how long the engine may be able to stay on-wing until the next shop visit, are aircraft utilisation, the status of the LLPs and their remaining flight hours/cycles, the maintenance history, and the airworthiness directive (AD) status. If the analysis is performed from an operator's perspective who has leased the engine, the length of the proposed service period is another major determinant. External engine management consultants are typically engaged in contracts over three or five years. Engine trend monitoring data at different power settings (usually idle, take-off and cruise) will provide a clear picture of the power plant's current performance and what deterioration can be expected in terms of both extent and rate. Establishing the fuel flow and exhaust gas temperature (EGT) parameters will allow the management team to outline an initial overhaul strategy, according to Moabery. "As turbine blades get older, the wear starts to cause EGT margin degradation, and the engine will very quickly move from a strong performing engine to one that operates with no EGT margin."

Once all these parameters have been determined, it becomes possible to predict which maintenance tasks will be necessary in the future, what this will cost, what options the operator will have to control its spending, and how this might be affected by additional, unscheduled maintenance. "We run those engines forward on our system which allows us to forecast all the events. We would work-scope each engine individually as a paper exercise and identify what the costs were against the critical elements within that work scope, what the material costs would be based on the material standard that is in there [the engine]," explains Gibson. "We would include all the unscheduled events that could potentially happen, lease costs, everything ... and we would give them effectively what the cost per hour of their operation would be."

If it is a leased engine, the interests between the operator and owner are likely to diverge as indicated above. The airline might only be contractually obliged to release the engine with a certain life left on it at the end of the lease agreement. This would allow the company to minimise the workscope accordingly to reduce its costs during the lease period. On the other hand, however, the lessor will be looking at the cost of operation over the entire ownership period, which might go long beyond the original operator's lease agreement. The lessor will want to enhance the workscope as much as possible in order to maintain a high asset value. This would make it more attractive and marketable to other operators who might lease the engine in the future. The two parties have then to find some common ground to keep the cost per hour of the engine at a level that is acceptable for both. If the lessor demands a technical standard that is significantly higher than what is necessary to the operator, one solution could be that the lessor makes a contribution to the maintenance cost.

The use of PMA parts and DER repairs, instead of the standard OEM material and processes, is clearly one, if not the, most important and powerful means to reduce engine maintenance costs. However, while their use has been widely established throughout Western Europe and North America, this is not necessarily the case in all other regions. PMA parts

The use of PMA parts and DER repairs instead of the standard OEM material and processes is one of the central questions when an engine enters the management phase and the future value strategy is determined.

can become an obstacle when trying to find a lessee for an overhauled engine, for example, in China and India — two future growth markets.

But even within the boundaries of jurisdiction of the FAA and EASA, the cheaper alternative repair materials and processes might not always pay off either. In light of the increased operational risk of using PMA parts and DER repairs, the potential cost savings might be considered much less tempting for an airline with, for example, 10 aircraft than a carrier with a fleet of 100 aircraft. "The risks of operating PMA parts are vast," believes Moabery. "The risks are calculated over a fleet of engines. So in the case of an airline with a large fleet, one can look at that risk and decide it is worth doing. But the small operator may look at it and say, 'for the cost savings that I save, it's not worth it'. If I have a major engine failure or a catastrophic event, then all of those savings are wiped out by one event."

Trading phase

At approximately 20 years of age, the engine enters into the trading phase, the final part of its life cycle. By this time, the value of the entire aircraft is mainly driven by the engine value. Ironically, however, the book value of the power plant in itself is coming down so far at this point that it no longer warrants the cost for an overhaul. The engine's technical standard and performance has been surpassed by its younger counterparts in the fleet, and possibly even by new-generation equipment that has emerged in the meantime. Furthermore, there will be an increased number of other engines of the same type and similar age on the market, which have been phased out by other operators and have consequently brought down engine lease rates and spare part prices. Not only does it then become cheaper for the operator to swop an engine against a leased one rather than to repair or overhaul it, indeed there comes the point where the value of the individual parts and components exceed the book value of the complete engine. It is teardown time at this point and the engine will serve as a source for spare parts.

The dynamics of the trading phase are subject to the economic conditions at the time. In periods of growth, when queues before airline check-in desks and OEM sales offices are long, the service lives of older aircraft are stretched too, and consequently lease prices for older engines with some residual 'green-time' are stable. 'Green-time' is the available period during which an older engine can remain in service until its last maintenance records expire and it will be torn down. Conversely, when the industry goes into a downturn and airlines are cutting capacity, the older, less efficient aircraft are the first ones to stay on the ground. "A good example right now is the CFM56-3 model [for 737 Classics], where there are so many spare engines available in the market that an operator may decide to run off 'green-time' on a leased engine as opposed to putting in $2-3m to repair the original engine," reports Moabery.

While the deferral of maintenance and using-up of surplus engines will help to drive older equipment permanently out of the market, it would be a short-sighted waste of material and finances to take advantage of aircraft capacity cuts in the current economic climate and apply the practice to younger equipment too. Garrison warns: "In the airline industry, economic cycles are a way of life and have a significant impact on an airline's budget sensitivities. The airline industry is a cash hungry business and during an economic downturn, airlines work hard to preserve cash. This stance can make engine management very difficult, because you will need to invest in your fleet during the shop visit to make sure that you build in the goodness to obtain your engine run time and reliability plan. Airline customers who do not maintain the investment discipline during the economic downturns can expect their cost per hour and total cost to increase in future years."

Spare engine financing

Just as the aviation industry was showing signs of economic recovery the ash cloud descended and traffic figures slumped. It is hardly surprising that there is a reluctance to invest but there are, as *Jon Sharp,* president and CEO of *Engine Lease Finance Corporation*, writes, some reasons for optimism.

To say that the second quarter of 2010 did not present a great outlook for aviation finance is an understatement. Last year saw the largest decline in air traffic since WWII. That was already on top of a massive traffic decline in 2008. Record losses were sustained, according to IATA, and prospects remain poor for this year. Airlines reacted quickly by cutting capacity: routes were culled and frequencies reduced; new aircraft deliveries, where possible, were delayed or even cancelled; and large quantities of existing aircraft were parked in the desert, with the emphasis on parking the less efficient aircraft and an obvious attendant downwards impact on their values. Reduced flying means less MRO work and less demand for spare engines; all the engine lessors have equipment available for immediate lease and rentals have dipped accordingly.

Longer-term, the leasing companies have had to accept that certain aircraft and associated engine types have suffered a permanent reduction in value, which demands a write-down on their balance sheets. However, new aircraft types are overrunning on costs and timescales, which prolongs the valuable life of some older aircraft types, at the same time as introducing more uncertainty into residual value prediction. As if that was not enough, oil prices remain

Lessors like to receive maintenance reserves as the airline burns value off the engine asset

> ***Leasing companies have had to accept that certain aircraft and associated engine types have suffered a permanent reduction in value, which demands a write-down on their balance sheets. However, new aircraft types are overrunning on costs and timescales, which prolongs the valuable life of some older aircraft types, at the same time introducing more uncertainty into residual value prediction.***

volatile thereby introducing yet more uncertainty into residual values in the shorter term (and airlines face the risk of making losses solely from backing the wrong hedging policy, which does not help them or their lessor partners).

Through capacity cuts, load factors were maintained in a reasonable range, but yields suffered badly; the special offers made by the air carriers to attract the flying public back into their seats meant that prices were slashed and revenues suffered, although there is now evidence that fares are creeping back up to sustainable levels on key routes such as the North Atlantic. The airlines need these revenues and their suppliers — the leasing companies — are relieved to see it happening; the airlines in the Northern hemisphere at least need to earn substantial surpluses in the summer months to see themselves through the lean winter months. It is during the winter that defaults on rental payments are most frequent, due to cash shortages. Most leasing companies are having to deal with delinquencies and even defaults or bankruptcies — as such, being between the banks and the airlines, they provide to the industry an essential mid- supply chain buffer that helps modulate the peaks and cycles of the economy, both at regional and global level, by absorbing some of the pain when times are bad.

Air finance and engines

Small wonder then, there has been a flight of capital from the air finance industry with only a few of the cannier banks hanging on in there. Even now, with signs of global economic recovery quietly but steadily emerging , the upturn for the airline industry has been confounded by the ash cloud hanging over much of Europe; the scientists tell us that the eruption may go on for many months and we are in for a period of randomly disrupted air travel. In the second half of 2010 we are faced with a crisis in the euro zone and the concern that Greece's economic problems will become contagious, leading ultimately to a double dip world-wide economic recession. The industry continues to stagger through these and similar problems and reluctance to invest continues.

The real problems with air finance have been largely disguised by the continuance of very low interest rates thanks to the intervention of various governments following the global credit crunch. The banks that have funded the industry have done so because they can charge high margins as a result of low underlying interest rates; low base rates will not last forever, however, and without a structural overhaul of the financial system, the industry will only struggle on. Some banks have now returned to the fray and some strongly funded leasing companies are still writing new business, but there remains a funding gap for new deliveries of aircraft and engines. There is also the small matter of several very large leasing companies looking for a buyer.

The banks, not surprisingly, favour loans guaranteed by the Export Credit Agencies (ECAs), who have hugely increased their participation in the last year or two (ECGD [UK export credit agency] will probably guarantee twice as much in 2010 as they have in previous years) but the ECAs cannot alone sustain this gap in aircraft and engine financing markets, nor can the Original Equipment Manufacturers (OEMs). The leasing companies are next most attractive to banks, who by lending to a lessor against a specific asset will have a clear mortgage on an identifiable piece of metal that is being managed by the lessor to maximise its future value. Thus the lessor is an essential part of the system, yet current OEM behaviour is actually discouraging to this form of external finance right at the time when the market needs it most.

OEMs muscle in on the aftermarket

To explain: the OEMs spend vast amounts of R & D in developing a new engine and need to recover those costs not just from new sales, but from the lifetime spares sales and MRO services. They are understandably getting more and more possessive about their aftermarkets, and preventing the use of non-OEM parts and repairs (PMA and DER) whilst squeezing those leasing companies and MROs (Maintenance and Repair Organisations) and parts suppliers who are not owned or part-owned by them. Fair enough. Unfortunately the increasingly common OEM inclusive maintenance packages are not friendly to non-OEM owned leasing companies and so reduce the amount of finance available from them. The problems leasing companies have with OEM 'Inclusive Care'-type maintenance packages fall into three categories:

The first is the matter of security. The lessor likes to receive maintenance reserves as the airline burns value off the lessor's asset, to offset credit risk. With an inclusive maintenance package, the OEM and not the lessor, receives the reserves and holds them in a fund, so the lessor's security is at least diminished or even becomes non-existent. Also the lessor is exchanging airline risk for OEM risk, admittedly in some cases a better credit, but it is the concentration of such risk in one MRO provider which is worrying to credit committees

Manufacturers such as Rolls-Royce are becoming increasingly concerned with aftermarket support.

who now have to review OEM risk as well as airline balance sheet risk.

Secondly, there are concerns about the portability of the fund. When Airline A has finished his lease, does the OEM pay the total remaining amount of the fund to the lessor and can the lessor transfer the benefit to his next customer, Airline B? Possibly not, but even if so, is the amount collected enough, given that (a) the hourly and cyclic rates will probably have been set at a concessionary level to win a sales campaign, (b) with respect to engines at least, depending on the package structure, the level of payments may refer to a first run and so not reflect true averaged lifetime cost and (c) the two airlines A and B may have very different operational profiles meaning that rate may not be enough overall and Airline B would have to pay 'catch-up'. Some aircraft inclusive maintenance agreements do not even separate out the rate for engines from the total.

Thirdly, there is the choice of MRO provider. With an OEM maintenance package, there is no choice and the asset has to go back to the OEM or its nominated service provider. Airline B who wants the available aircraft/engine from the lessor but is already locked in to a long-term maintenance programme with a third-party provider will find his choice of equipment restricted and the

> **"** ***Lower labour costs available in Asia Pacific and South America make them attractive regions to develop MRO facilities with all the associated infrastructure. China, Japan, Brazil, Russia and other countries with aspirations to develop commercial aircraft and engine manufacturing have an opportunity for a fresh start and should take note and think about the structure of their industry and how they interface with the financial community.***

> *"The ECAs cannot alone sustain the gap in aircraft and engine financing markets, nor can the OEMs. The leasing companies are attractive to banks, who by lending to a lessor against a specific asset will have a clear mortgage on an identifiable piece of metal that is being managed by the lessor to maximise its future value. Thus the lessor is an essential part of the system, yet current OEM behaviour is actually discouraging this form of external finance right at the time when the market needs it most.*

lessor simultaneously find his re-marketing options restricted.

So the OEMs (engine OEMs in particular), by increasing their efforts to sell inclusive maintenance packages are driving away the remaining independent sources of finance for their products; does this mean they are moving to a model where they keep the engines they produce on their own balance sheets? Is this really desirable? The trend is certainly growing and some OEMs are talking about selling 'power only' for the next generation of engines. These new engines will be designed to have a fixed life with all LLPs at the same limit as the expected power restoration interval and an airline would pay a fixed amount for the engine for that period of operation, before exchanging it for another one, upon payment of another fixed amount. So there is never the matter of the ownership of the engine passing from the OEM. Nothing for a bank to have security over and nothing for a lessor to own. I also wonder how an ECA can participate in such a structure.

The inevitable conclusion is that new style relationships between OEMs, the financial community and MRO organisations are essential, not just for the benefit of those three parties, but also for their customers, the airlines.

Whatever signs of economic recovery in the aviation industry there are have been led by the Middle East traffic growth, albeit from a relatively small base, and in the Asia Pacific region, with growth in China continuing but at a slightly less frenetic level (which does give more confidence of avoiding a nasty bubble). There is much press about the new aircraft types coming out of the Asia Pacific region. Abu Dhabi is investing heavily in the MRO sector not only in the Middle East but also in the West. Lower labour costs available in Asia Pacific and South America make them attractive regions to develop MRO facilities with all the associated infrastructure. China, Japan, Brazil, Russia and other countries with aspirations to develop commercial aircraft and engine manufacturing have an opportunity for a fresh start and should take note and think about the structure of their industry and how they interface with the financial community. The Chinese and Middle East airfinance markets may well be largely be captive to their own banks and Sovereign Wealth Funds, but what the Western leasing companies do have is a wealth of expertise and it is that which can be allied with the new wealth to create new, successful partnerships.

So, a new business model is needed. A simple conclusion is the airfinance industry needs new, fresh thinking alliances between the airlines, lessors, OEMs and MROs on the one hand and new alliances of old expertise and new money on the other. A really enlightened approach would be to combine the two. Somebody has to make this happen.

The evolution of low-emissions combustion chambers in commercial aircraft engines, 1990 – 2010

During the 1990s the aerospace industry was forced to confront the world's growing environmental awareness, which manifested itself in tougher certification requirements for aircraft engines and the introduction of local environmental regulations, particularly in Europe. *David Cook,* President of *ASM Consulting,* was sales director at CFM International from 1989 to 2001 with account responsibility for Northern Europe. Through sales campaigns at Austrian Airlines, Swissair, SAS and Finnair he saw firsthand how the aero-engine industry responded to demands for cleaner engines which, in turn, explains why the industry is so well-equipped to meet the challenges facing a new generation of commercial aircraft engines.

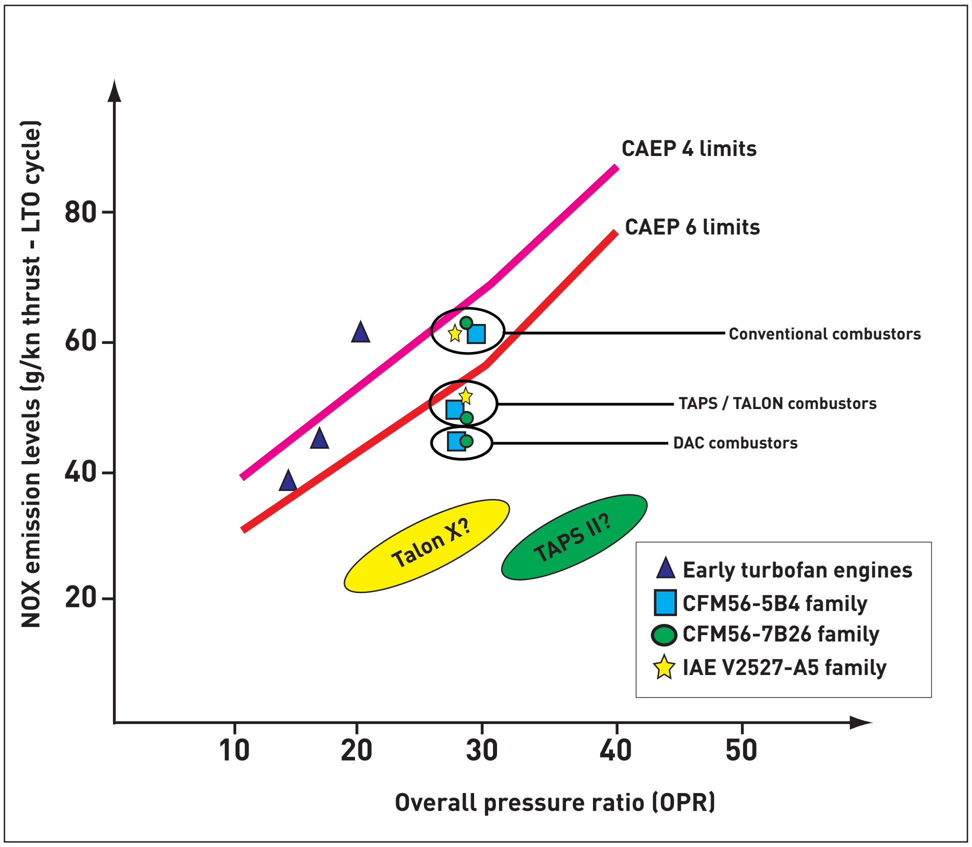
As mass air travel started to develop in the 1970s the public, particularly those living around airports, became more and more vocal in their concerns about aircraft noise and atmospheric pollution. Images of earlier generation four-engined jets heading for distant destinations with engines bellowing long plumes of smoke are emblematic of this period. By the late 1970s the International Civil Aviation Organisation (ICAO) decided to act by bringing in limits for aircraft engine noise and polluting emissions, defining certification standards for Nitrous Oxides (NOx), Unburned Hydrocarbons (UHCs) and Carbon Monoxide (CO). These standards were put under the responsibility of the Committee for Aviation Environmental Protection (CAEP), established in 1983, which published its first set of regulations (CAEP 1) in 1988.

After training and serving as a technician in the Royal Air Force, followed by a number of years with a British regional aircraft manufacturer, I was recruited by Snecma to join the CFM sales team with specific responsibility for Scandinavia. It quickly became apparent that environmental issues were a principle concern for my new customers, one clue being that the president of the one-time Swedish domestic airline Linjeflyg had his environmental advisor located in the office next to his! Meeting people at airlines such as SAS, Braathens SAFE, Finnair and Icelandair, I came to understand the fragile nature of the Scandinavian environment and how much it is under threat from external sources of pollution such as large power stations in other parts of Europe. While they could not do much about external sources they were determined to protect themselves from internal sources, developing the 'bubble' concept whereby any new industrial project was required to account for all emissions generated by its activity. It was as a result of this philosophy that the world's first local emissions legislation was applied to Swedish airports in 1990, limiting NOx emissions emanating from all aspects of the airport's activities and initiating charges for aircraft movements dependent on the aircraft engine's certified NOx emission levels. While ground vehicle activity, in particular private cars, was clearly the main source of airport NOx emissions this concept was also aimed at curtailing, or at least penalising, movements of aircraft with high NOx emitting engines.

At around about the same time Austrian Airlines and Swissair launched an evaluation to replace their ageing DC-9 fleets, finally selecting the Airbus A320-family as their preferred airframe. This gave them an opportunity to evaluate both CFM56-5B and IAE V2500-A1 engines in a competitive selection process. As Switzerland had recently followed Sweden's example by introducing airport NOx emissions taxes the message from the airlines was clear — all other things being equal, they would select the engine with the lowest certified NOx emissions. The gauntlet had clearly been thrown down and it was up to the aero-engine industry to respond.

Controlling aircraft emissions

It is perhaps worth reminding ourselves what emissions are produced by an aircraft engine and how they may be controlled. As previously mentioned, those emissions controlled by the engine's certification process are NOx, UHCs, CO and smoke. Limits for these emissions are defined by ICAO dependant on the engine's overall pressure ratio (OPR) and measured through what is called the landing and takeoff cycle (LTO) ie: the sequence of events beginning with start-up and taxi out to the end of the runway, engine acceleration to takeoff thrust, through the takeoff run, up to 3,000 feet on the climb-out, then from 3,000 feet on the descent to touchdown on the runway threshold, the landing run, taxi in and shutdown. Visible smoke consists of small soot particles in the jet exhaust and is created by inefficiencies in the combustion process. Similarly, UHCs and CO are produced by inefficient combustion, particularly at low engine rpm. The most important pollutant in terms of amounts produced and potential environmental impact is NOx. This is produced by an engine when air (consisting of oxygen and nitrogen) is subjected to high temperatures, particularly during the combustion process, and decomposes. It plays many different roles in terms of its environmental impact: it is a recognised human health risk, promoting asthma and a wide range of respiratory diseases and, in the presence of sunlight, NOx creates ozone at low altitudes thus contributing to the greenhouse effect. NOx is also very persistent, remaining in the atmosphere for many years after other pollutants have either dispersed or decomposed.



As is often the case with anything to do with aircraft engines, the combustion chamber designer is faced with a multitude of conflicting priorities. He must make sure that maximum thrust is produced at takeoff, that maximum fuel economy is achieved at cruise, that the flame does not go out at high altitude or in heavy rain ... and, of course, that the engine meets its environmental certification requirements. In order to minimise UHC and CO production the combustion chamber needs to avoid producing these compounds by a highly efficient combustion process, or be able to burn off the by-products of inefficient, low-rpm, combustion. In order to minimise NOx production the combustion chamber needs to reduce as much as possible the amount of air subjected to the elevated temperatures of high-rpm operation. This is achieved by either limiting the volume of air subjected to high temperatures or by reducing combustion temperatures. The problem facing CFM and IAE back in the early 1990s was how to resolve these two conflicting design requirements to meet the Austrian/Swissair challenge.

Obviously, I was not privy to IAE's proposal but we at CFM were led to believe that their solution revolved around modifications to an existing combustion chamber design. Conventional chambers function on the basis of what is called the Rich Quench Lean (RQL) process. The fuel mixture at the nozzle is relatively rich, providing high power and good fuel economy but generating large amounts of UHC and CO at low power settings. These pollutants would be burned off as they moved into a relatively lean combustion environment when additional air was introduced further down the combustion chamber. At high power settings the NOx produced in this rich burn process would be limited by quickly cooling, or 'quenching', the combustion gases by introducing large volumes of cooling air just downstream of the burner flame. It is my understanding that the work done IAE/Pratt and Whitney at this stage made a significant contribution to the development of their TALON (Technology for Advanced Low NOx) combustion chambers which later equipped the IAE V2500 and PW4000 series engines.

The CFM solution was to draw on a radically new combustion chamber design already in the prototype stage at GE (GE have design responsibility for the CFM56 engine core). Called the double annular combustor, or DAC, it effectively split the combustion chamber in two, each sub-chamber having its own fuel nozzle. The outer chamber was relatively long and operated at the lower thrust levels. This long chamber provided the time in the combustion process to burn off UHCs and, together with a leaner fuel/air ratio, reduced CO. At high thrust levels both chambers were lit, providing the required levels of thrust but with a relatively shorter

The author at the delivery of the first SAS 737-600 equipped with CFM56-7B20 DAC engines, September 1998. The green flower logo was used by SAS to promote its environmental strategy.

chamber compared to the equivalent conventional chamber, thus reducing the time at which air was exposed to the high combustion chamber temperatures (residence time) and so reducing NOx. The design was complex and could only be controlled by the use of an electronic fuel control system, or FADEC, in order to correctly manage the staging of the two sets of fuel nozzles throughout the flight regime. However, with its promise of over 30 per cent NOx reduction compared to its equivalent single annular combustion design, and the fact that this programme had more credibility due to its advanced prototype testing, this was the solution selected by Austrian and Swissair. In March 1995 the first CFM56-5B DAC-powered A321 entered service with Swissair, the first of a total of 375 DAC engines to go into airline service.

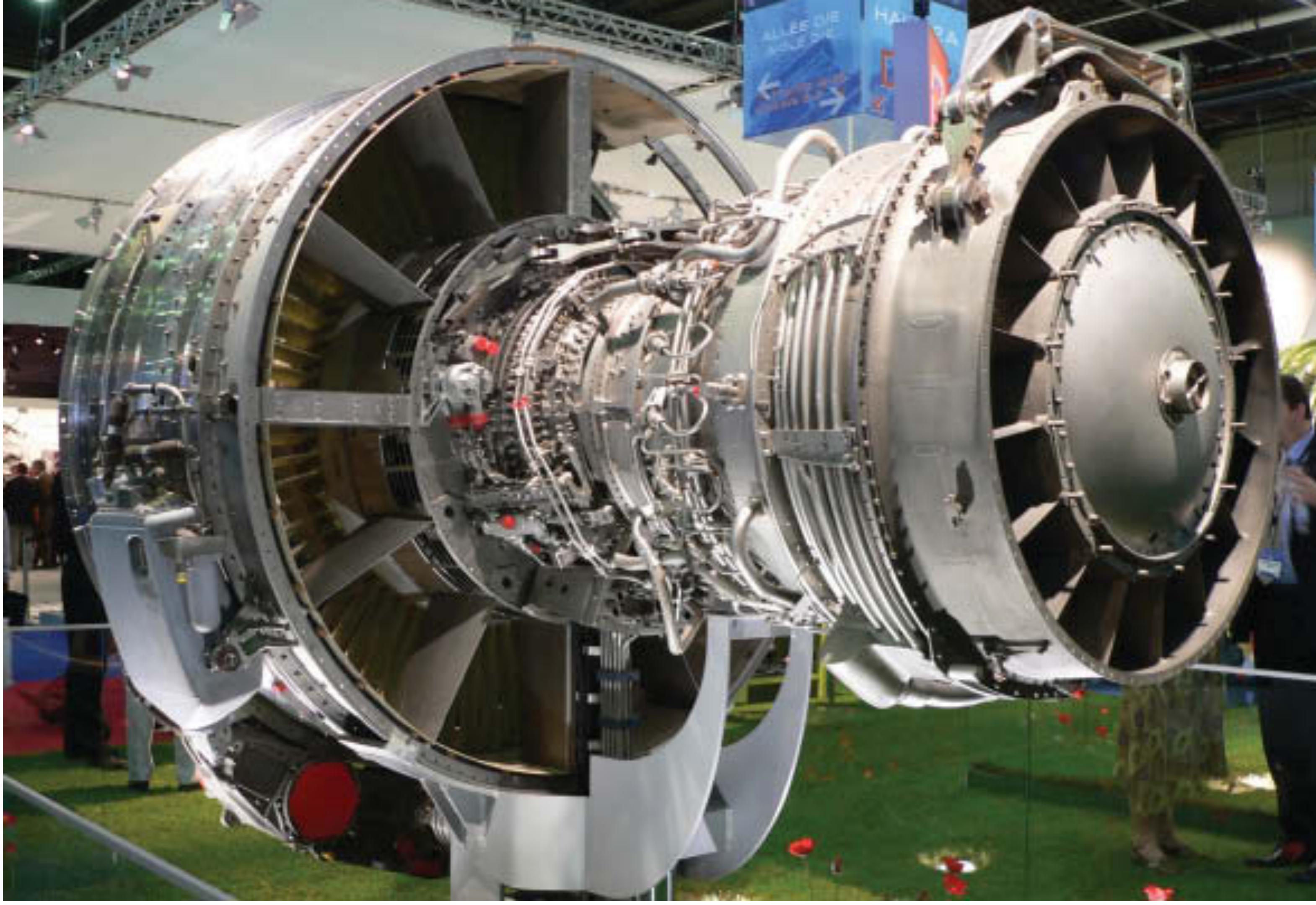
While Austrian and Swissair were the first airlines to specify low-emission engines for their aircraft they were not the only ones interested in the subject. During the 1990s there were a number of attempts to create close alliances between Austrian, Swissair, SAS and Lufthansa. While these early negotiations did not reach a definitive conclusion they were to lead to what is now known as the Star Alliance. Much of the discussion focused on fleet commonality but, despite the fact that these airlines operated large numbers of Douglas DC-9 and MD-80 series aircraft, it was extremely difficult for them to agree on a replacement airframe. As mentioned earlier, Sweden had already introduced emissions taxes at its airports and so SAS took a great deal of interest in the Austrian/Swissair engine selection process. It was therefore inevitable that, once SAS had decided to replace its DC-9 fleet with the 737-600 aircraft, they too should specify the DAC for their CFM56-7B engines.

Finnair was another airline which later selected the DAC engine. While not subjected to specific airport emissions taxes themselves, Sweden was an important market and they did not want to be at a competitive disadvantage with SAS. Having selected the Airbus A320-family to replace their DC-9s the decision was, to some extent easier for Finnair as the CFM56-5B DAC engine had already been in service with its launch customers for a couple of years. The first Finnair A321 with CFM56-5B DAC engines entered commercial service on February 5, 1999.

Teething problems

With such a complex combustion chamber design, and the requirement to optimise the staging of the two sets of fuel nozzles, it was inevitable that there would be some teething problems. From the start of the DAC programme CFM recognised that this new chamber would generate additional maintenance costs due to erosion of the centre body which separated the two parts of the chamber. To their credit the airlines who selected the DAC accepted this additional maintenance cost burden, as well as a healthy supplement to the engine list price, believing it to be a fair price to pay to demonstrate their environmental credentials. In retrospect, it would probably be fair to say that the -5B engine entered service with relatively few problems: some hot starts, some over-temping during taxiing, but no major difficulties as far as I recall. As the -7B used the same core (HP compressor, combustion chamber, HP turbine) as the -5B CFM believed that they could confidently offer a -7B DAC to SAS which would build on the Austrian/Swissair experience and provide a 'low risk' entry into service. This was not the case.

Problems began even during initial engine testing. Austrian and Swissair were using their -5B engines on A320 and A321 aircraft at thrusts ranging from 25,000lb up to 31,000lb. SAS had selected the 737-600 aircraft for their domestic and intra-Scandinavian routes and, as such, the aircraft were expected to operate with very light fuel loads, little baggage and in a relatively cool operating environment. They only required the -7B engine at its minimum certified thrust of 18,000lb and, even then, expected to operate with a significant derate. Despite the fact that the -7B core was the same as for the-5B, this lower thrust proved troublesome for DAC development. No matter



The CFM56-5B entered service with relatively few problems.

how they tried the GE engineers just could not get the -7B DAC to work correctly at 18,000lb thrust. Get the NOx right and the CO would go off the scale. Get the NOx and the CO right then the smoke would be uncontrollable. In the end CFM were forced to accept that the -7B18 DAC engine was not certifiable and agreed to provide SAS with a -7B20 engine, 20,000lb thrust being the minimum thrust level at which they could get the DAC to work effectively. The engine was duly certified, the aircraft delivered and the first scheduled flight of an SAS 737-600 equipped with CFM56-7B DAC technology took place on October 31, 1988 - ironically enough, on an early morning rotation between Stockholm and Paris Charles de Gaulle.

The -7B DAC quickly settled into service and seemed to bear out CFM's claims of a reliable, derivative engine. However, during the long, dark winter of 2000, worrying stories began to emerge from the SAS flight line. An engine was showing signs of high vibration and borescope inspection revealed that it had lost a low-pressure turbine (LPT) blade, sheared off cleanly at the blade root. A few days later another engine exhibited the same symptoms and, within a matter of weeks, SAS had lost five engines. This was clearly a serious problem and the full weight of CFM customer support swung behind the effort to help this major customer. Engines were replaced, unserviceable engines stripped down, turbine blades and disks rushed into the laboratories for analysis. The problem was obviously related to LPT blade fatigue but what was the cause, and why had the other DAC operators not experienced the same problem? The answer came from a careful analysis of SAS flight data and an understanding of the way they operated their 737 aircraft. DAC FADEC software was programmed to schedule a fairly clear 'switch' from single, outer burner operation at low rpm to double burner operation at high rpm. What in fact was happening was that, in operating their aircraft into congested European airports, SAS were forced to fly long landing approaches at intermediate altitudes, stepping down into the landing pattern. This forced the FADEC to keep switching the DAC from single burner operation to double burner operation during the landing approach, thus inducing a resonance in the LPT disk which weakened the LPT blade root. After more than 1,000 cycles or so blades started to break.

Alternative operating procedures were rushed in to avoid 'long, low' approaches, LPT disks were re-designed and, over a period of almost two years, engines were modified. This was a major challenge to both CFM and the airline but again, their willingness to resolve the problem and keep the DAC engine flying was a

> ***"The combustion chamber designer is faced with a multitude of conflicting priorities. He must make sure that maximum thrust is produced at takeoff, that maximum fuel economy is achieved at cruise, that the flame does not go out at high altitude or in heavy rain ... and, of course, that the engine meets its environmental certification requirements.***

CFM56-7B engines underwent extensive modification following a bumpy start with SAS.

potent demonstration to their joint commitment to the environmental challenges facing the industry.

Learning from the DAC experience

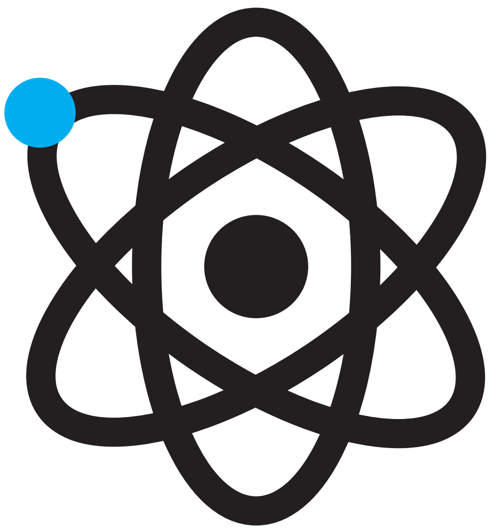
After the initial problems the DAC has continued to operate well although anecdotal evidence suggests that the maintenance cost penalty of the split chamber design is rather higher than initially indicated. A number of airlines who have 'inherited' DAC engines from leasing companies following the break-up of Swissair and Sabena in 2002 regret the high maintenance costs of these engines and the problems of intermix without necessarily understanding (nor being sympathetic to) the important role they played in our industry's battle with the environmentalists. Let us not forget either that the GE90 engine, powering over 500 777 aircraft with various airlines around the world, is also fitted with a DAC which has operated impeccably. However, GE maintains that their choice of this technology was aimed primarily at taking advantage of its short length to reduce engine weight rather than any specific environmental advantages. GE and CFM did, none the less, learn a lot from the DAC experience and, as their understanding of the complex issues relating to combustion chamber thermodynamics evolved, they were able to propose an alternative to the split chamber design. By effectively resolving the contradictions of NOx, UHCs and CO at the burner nozzle, rather than in the body of the combustion chamber, they were able to revert to a more conventional RQL chamber design but with a highly sophisticated staged nozzle concept called TAPS — Twin Annular Premixing Swirler. TAPS was initially conceived as part of the Tech56 technology acquisition programme aimed at developing technologies to be incorporated into a new generation of engines to be introduced in the 2012-2013 timeframe when Boeing and Airbus were originally expected to launch their next generation single-aisle aircraft. However, as these new aircraft programmes began to slide further into the decade CFM took the decision to commercialise the Tech56 technology by launching a major product update of both its -5B and -7B family of engines. The Tech Insertion (TI) programme provides for important improvements in the engine core, with TAPS technology leading to a 28 per cent reduction in NOx compared to an engine with the original standard combustion chamber without the DAC complexity, as well as reductions in fuel burn and maintenance costs. While initially introduced as an upgrade kit the TI hardware is now standard build configuration for all CFM engines.

CAEP continues to reduce NOx levels

During this time the industry has continued to come under both political and social pressure from national governments and environmental groups. However, much to the frustration of those airlines who had invested in DAC technology, there was not, as feared, a widespread proliferation of airport environmental taxes. None the less CAEP continues to challenge engine manufacturers to lower certified emission levels of new engines: CAEP 2, introduced in 1996, reduced NOx emission certification limits by 20 per cent compared to the original levels. CAEP 4, in 2004, reduced NOx levels by another 16 per cent and CAEP 6 (2008) by a further 12 per cent. Emission limits have been tightened to such an extent that no engine can be offered to the market today without a low emissions combustor and all engine manufacturers have their low emissions technology programmes. IAE and Pratt & Whitney have continued to develop their TALON combustor such that the new geared turbofan series of engines, due to enter service in 2013, will incorporate the latest TALON X technology offering NOx emission levels 55 per cent below current CAEP 6 certification limits. The Rolls-Royce Trent series of engines are equipped with the 'Phase 5' combustor, providing margin relative to CAEP 6, but the 'Phase 6' combustor programme currently under development has even more ambitious NOx objectives.

The aerospace industry, and in particular commercial air transport, continues to come under close scrutiny and, as mass air travel develops, will continue to be asked to make even greater reductions to its environmental impact. The CAEP 8 meeting which took place in Montreal this February proposed a further 6-15 per cent reduction in certified NOx emissions for new aircraft engines from 2014, and also 'committed to a timetable for the development of a new Carbon Dioxide (CO2) standard by the time of the next CAEP meeting (CAEP 9) in 2013' (ICAO press release). Whilst competitive commercial pressure has brought about substantial reductions in fuel burn — and hence CO2 emissions — over the years it has, until now, escaped the concept of certifiable limits. Now, as a direct result of the recent Copenhagen Environmental Summit, the industry will be subjected to even further scrutiny.

I am convinced that, as a result of its experience over the last 20 years, the aero engine manufacturing industry is well placed to meet those challenges and, while the DAC may soon be consigned to the top shelf of history, I believe it has played a vital role in helping the industry to understand the infinite complexities of combustion chamber thermodynamics and the operation of low emission combustors in scheduled airline service.



Gearing Up for the GTF

Pratt & Whitney's new PurePower PW1000G geared turbofan has already been chosen for three new narrowbody programmes. Speculation is growing that the GTF could feature on a re-engined A320 or 737, and even on a future widebody. *Chris Kjelgaard* looks at its prospects.

There's little question that Pratt & Whitney's new PurePower PW1000G family of geared turbofan engines represents a remarkable technological achievement and many pundits are touting its potential as a major contender in tomorrow's narrowbody-propulsion market.

The PW1000G has already been chosen to power the Bombardier CSeries, Mitsubishi MRJ and Irkut MC-21 narrowbodies, and — as rumours proliferate that Bombardier intends to stretch the CSeries into a 150-seat design — analysts see the PW1000G as a strong candidate to power any re-engined A320 or 737 that Airbus or Boeing might respectively offer.

However, few observers have noted that the geared turbofan (GTF) concept is already highly proven in the civil aviation market — albeit in the form of engines rather less powerful than Pratt & Whitney's new offering. As do all GTFs, these engines employ planetary gearboxes — driven by the low-pressure spool — to de-couple the low-pressure turbine (and low-pressure compressor) from the fan. This allows both the fan and the low-pressure spool to revolve at their optimal rates — fast for the low-pressure spool, quite slowly for the fan.

Geared turbofans already in service

Both the LF502/LF507 and the TFE731 engine families (now made by Honeywell, but originally developed by Avco Lycoming and Garrett respectively) are geared turbofans that have clocked up many millions of hours of flight time — and new versions of the TFE731 in particular continue to sell well, according to Bill Storey, founder and president of aerospace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Final assembly of a PW1000G demonstrator engine.

> *We think we have the most durable blades, in combination with [operating] temperatures more conservative than the competition. The PW1000G will run at lower temperatures than we think the competitors are going to run at.*
> —Paul Adams, senior vice president of engineering, Pratt & Whitney

research firm Teal Group. While the LF502 suffered serious reliability problems — which led to the development of the LF507 — these weren't to do with its geared fan, says Storey, and the GTF concept has proved reliable in service.

So why all the fuss about the PW1000G? The answer is that it's a much bigger, more powerful GTF than any previously designed. Storey says that where Pratt & Whitney (P&W) has made a breakthrough in bringing to market a new GTF family is in managing "to get the weight of the gearbox down to a scale where it makes the concept viable" for large-aircraft applications. P&W duly patented this new gearbox technology, "so competitors can't jump on it," he notes.

The PW1000G's fan and core

In pursuing the narrowbody propulsion market, P&W chose to develop a GTF rather than a more conventional turbofan because it believed its GTF design could offer the best "value proposition" in two ways, says Paul Adams, P&W's senior vice president of engineering.

First, because the PW1000G's fan rotates 30 per cent more slowly than that of a conventional turbofan, P&W could make the engine's 18-blade fan diameter very large without running into the blade-tip shockwave problems that destroy a conventional engine's efficiency above about 80 per cent of maximum thrust. The large fan diameter allows a much higher bypass ratio than would be possible with a conventional turbofan, increasing the PW1000G's propulsive efficiency. The slower-turning fan also minimises the chances of blade damage from bird ingestion, since most ingestion damage is caused by the speed at which the fan is turning, not the speed at which the bird is flying.

In developing the PW1000G, P&W also designed in a new, very durable core — based on a core it developed with MTU, one of P&W's partners in A320 supplier International Aero Engines — optimised for the high-cycle narrowbody operating environment. Because the low-pressure spool in the GTF can run at its optimal speed without effecting the propulsive efficiency of the fan, P&W was able to remove several low-pressure turbine (LPT) stages: The

PW1000G has three, rather than the six or seven normally needed. Similarly, P&W could do away with two low-pressure compressor (LPC) stages, using three in the PW1000G rather than the conventional five.

Dropping five or six LPC/LPT stages produced an engine with less than 50 per cent of the low-pressure stages in a conventional turbofan, and 1,500 fewer blades, says Adams. At the same time, P&W introduced into the PW1000G a new eight-stage high pressure compressor, each stage of which is a single-piece, integrally bladed rotor (or "blisk").

The PW1000G's core also has an advanced combustor based on P&W's low-emissions TALON-X design. This features a "floatwall" of inner-lining panels — which can expand and contract independently, reducing lining wear — as well as a rich-quench-lean combustion cycle to prevent nitrogen oxides forming. Behind the combustor, P&W has employed new turbine cooling technologies, including advanced thermal-barrier coatings, powder-metal blade alloys, new cooling-air-path geometries within blades, and turbine-casing active clearance control.

"We do think we have the most advanced combination [of cooling technologies]," says Adams. "And we think we have the most durable blades, in combination with [operating] temperatures more conservative than the competition. The PW1000G will run at lower temperatures than we think the competitors are going to run at."

Other key technologies

Two other technologies are important in the PW1000G, says Adams. One is the composition of the engine's fan blades, still largely secret. Adams says the PW1000G has "a hybrid metallic fan blade" that P&W has developed over the past two years. "It is actually lighter and higher-efficiency than a composite fan blade" the same size would be, he claims. "We think we have got a concept that meets all structural criteria and is significantly better than a composite fan blade. We have done full-scale, full-speed birdshots and we're in extremely good shape. We don't see any significant risks with the fan blade."

Another key technology is the PW1000G's gearbox. P&W expects the gearbox, which is made of high-strength gear steels, to be "very low-maintenance", says Adams. "We're expecting the gear will be less than two per cent of the maintenance cost of the product. It's designed to be full-life without any additional maintenance outside normal maintenance periods."

Combining "a very efficient core designed specifically for the high-cyclic narrowbody market" with the propulsive efficiency created by the PW1000G's large fan and its high-strength gearbox will create "a step change" which will provide "the best value proposition" for the market, he says.

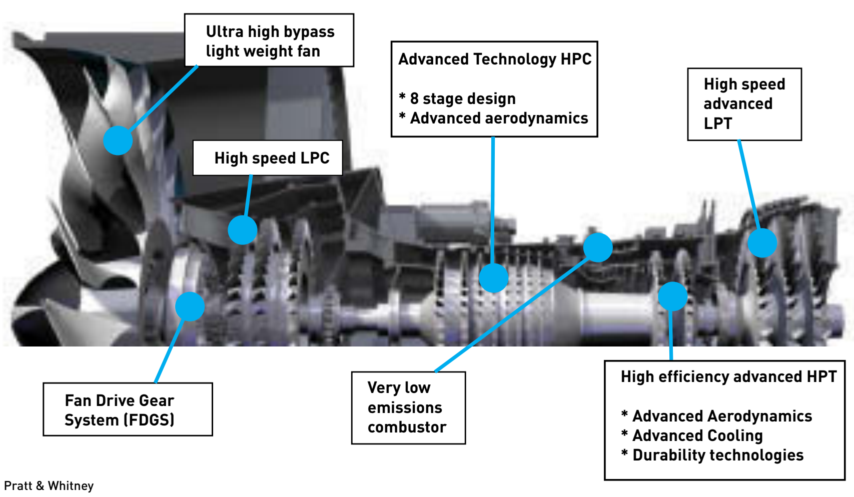
That market includes aircraft "up to the A321 or the large-737 class". P&W has already run demonstrator GTF engines at 30,000lbf, is developing a 30,000lbf PW1000G for the Irkut MC-21 — with a 12:1 bypass ratio, like the CSeries powerplant — and Adams says P&W sees the PW1000G's competitors as being engines offering "more than 30,000lb".

The company has been running a full PW1000G core since late 2009, and reportedly has scheduled the first CSeries engine to run in August and the first MRJ engine in October. With the CSeries expected to enter service in 2013, P&W will bring the PW1000G to market significantly before 2016, when CFM has said its LEAP-X will be ready for its first application, China's COMAC C919 mainline narrowbody.

The PW1000G's market and its competition

This could help P&W in winning a position on a re-engined 737 — and a re-engined A320. "Whether or not it proves to be a competitive

PurePower™ PW1000G advanced technologies



source: Pratt & Whitney

Above: Pratt & Whitney is hoping that should either a re-engined A320 or 737 appear, the PW100G would be selected to power it.

advantage, it gives [P&W] good reason to think they have a head start on the single-aisle war," says Storey. "They may even stumble in by the back door if Bombardier builds a 150-seater." Bombardier might well do so, he thinks: "There has always been a gulf from the regional jets into the single-aisle widebodies [such as the A320 and 737]. The CSeries might be a spanner between the two, if they were to stretch it."

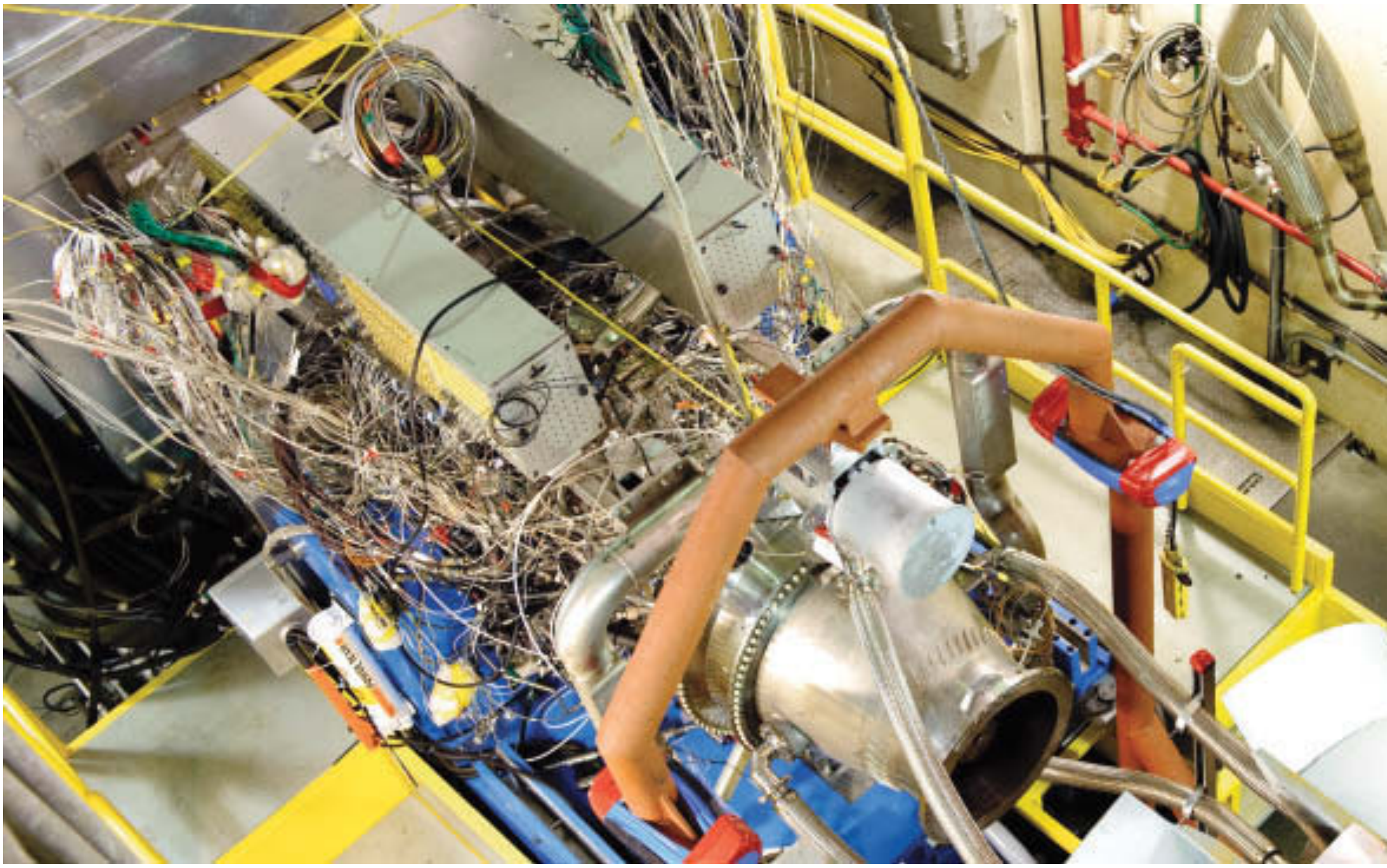
CFM International's new LEAP-X engine is P&W's most obvious medium-term competition. "LEAP-X has been by far the most vocal in there," says Adams. But he believes CFM is trading away some of the vaunted maintainability of its existing CFM56 engine family to meet customers' fuel-efficiency demands for a re-engined A320 or 737.

LEAP-X is "more like a widebody engine", claims Adams. "The interesting thing here is, in order to compete with the GTF product, the LEAP architecture has had to change significantly from the CFM56 architecture to a widebody architecture," optimised for fuel-efficiency and low-cycle operation rather than high cycles and durability. "We think the competition has had to compromise maintenance cost," he says.

Meanwhile, Adams thinks that the open rotor's noise, installation and blade-containment challenges, along with the need to provide a variable pitch mechanism for each of its two contra-rotating blade rows, will rule out an open-rotor design in the medium term. "Variable pitch is 10 times less reliable than a gearbox," he says. "And square that" for two rows of blades.

Phased improvements

Some have pointed to the apparent gap between the 12 per cent fuel-efficiency improvement P&W is promising from 2013 with the PW1000G and the 15-16 per cent benefit CFM says it can offer from 2016 — and the 30 per cent improvement Rolls-Royce is claiming



The full PW1000G core is tested.

from 2018-2020 with an open rotor. However, Adams says that, "apples to apples," all three engine manufacturers are essentially talking about the same levels of benefit being available at the same dates.

P&W's initial 12 per cent benefit with the PW1000G is only a starting point, he explains. In developing the new engine, P&W has adopted a programme to introduce "technological injection" packages at phased intervals to keep the programme "fresh", both for new-build engines and upgrades to in-service PW1000Gs: "We think we get to the same number at the same point in time" as the other manufacturers.

Generally, "turbomachinery [efficiency] improves at 0.75-1 per cent a year" through manufacturers' continuing research, says Adams. "The reason we stepped to the geared turbofan was that we saw we were actually getting nearer to the limit ... with traditional concepts. We had to work harder and harder to get the improvements. The GTF-style architecture allows us to continue that rate" more easily. "In 10 years the geared turbofan can be 7.5-10 per cent better than it is now. We think that for at least the next 15 years we can continue to run that out at the historic trend or better."

Will the 737 or the A320 use the PW1000G?

If a re-engined A320 or 737 appears, it will be important to P&W to be on it, Storey believes. P&W was the sole provider for the first generation of 737s with the JT8D, but subsequently "Pratt & Whitney played themselves out the game and they're keen to get back in, in a big way, and to be at least one of the engines on the Airbus or Boeing plane. It would mean a lot for [P&W's] bottom line."

The PW1000G's large fan size - the diameter of the CSeries fan is 73in, compared with the CFM56-7B's 61in, the IAE V.2500A5's 63.5in and the CFM56-5B's 68.3in — will create challenges if it is chosen to re-engine the 737. "It certainly fits pretty easily with the A320, even now," says Storey. "At the time the A320 was designed [Airbus] probably anticipated larger and larger engines" being used. But the same isn't true for the 737, whose design started life some 20 years earlier.

However, Storey says senior P&W executives have assured him the PW1000G could fit

> *In 10 years the geared turbofan can be 7.5-10 per cent better than it is now. We think that for at least the next 15 years we can continue to run that out at the historic trend or better.*
> **—Paul Adams, senior vice president of engineering, Pratt & Whitney**

In developing the new engine, Pratt & Whitney has adopted a programme to introduce "technological injection" packages at phased intervals to keep the programme "fresh", both for new-build engines and upgrades to in-service PW1000Gs.

under a 737 wing. "I think the possible road to that is a somewhat lengthened nose gear," says Storey. "It's probably not feasible to lengthen the main gear on the 737 — you might as well redesign the plane." He declines comment on how much longer the 737's nose gear would need to be. But reports suggest that, assuming the nacelle design was flattened like that of the CFM56-7B, a four-inch nose gear extension would produce about a two-inch clearance for a PW1000G.

IAE and the PW1000G

A320 re-engining presents a different problem: P&W is, along with Rolls-Royce, one of the two largest partners in IAE, which has won more than a 50 per cent market share on the A320 family with the V2500. Airbus has stressed it wants any P&W path to market on a re-engined A320 to be through IAE.

Asked for comment, IAE responds: "We intend to offer an engine solution that meets our customer's needs and we're in ongoing discussions with Airbus and our shareholders to determine the right approach to meet those needs. We are considering all available technology options and will offer the best solution once Airbus has clearly defined the aircraft's requirements."

Presenting P&W's view, Adams says: "We both clearly state we like IAE and it's a good channel to market, and we continue to work with Rolls-Royce to see if there's a resolution to the problem. There are some philosophical differences and we're not sure where it will come out." He confirms "we have done studies with both airframers" and notes "a 737 approach wouldn't necessarily have to be through IAE".

What this means, says Storey, is that "Rolls-Royce obviously hasn't jumped on the bandwagon. It's always been a triple-spool proponent and possibly also of an open rotor. I can't see Rolls-Royce coming out [for an A320/737 re-engining] with its own 25,000-30,000lb engine ... so I would think [Rolls-Royce's presence] would be either through IAE or nothing. That would lead me to believe Pratt & Whitney thinks it is bringing the most to the table and would want a bigger share" of a new GTF-based IAE engine for the A320 than the 32.5 per cent it now has on the V2500.

Ultimately, says Storey: "I think both Boeing and Airbus are going to prefer two engine options, and if they're not both open rotors, I think they will be the LEAP-X and P&W. It seems Rolls-Royce is the one not in lockstep." While Boeing might not be actively favouring two engine options, "if the LEAP-X doesn't deliver as advertised and Airbus has options with both the LEAP-X and the geared turbofan, Boeing would be at a disadvantage. My assumption now is that both manufacturers will offer two engines, and they'll be the same two engines".

The GTF as a widebody engine

Adams confirms Embraer is also considering the PW1000G in its "studies of what its next product would be like". But even more interesting is Adams confirmation that "the overall concept of the geared turbofan is scalable up to pretty much any size", including a potential 100,000lb-thrust engine for a 777-300ER replacement — or perhaps for the A350XWB-1000.

"We would architect a widebody product differently to the narrowbody product," says Adams. "For long missions, we would make some design trades that advantaged fuel burn versus high-cycle maintainability, consistent with low-cycle operations. The disk design would trade weight for cycle life. We would run the engine hotter, with higher operating ratios. The cooling technology would be different: the design margin in the turbine disks, how much cooling air, what kind of cooling."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The Trent 500 — designed for the ultra long-haul

***Maurick Groeneveld,* director of aircraft management at *Doric Asset Finance,* takes a look at smallest member of the Rolls-Royce Trent family.**

In June 1997, Rolls-Royce was selected by Airbus to satisfy its requirements for a higher thrust engine to power the stretched versions of the A340. The Trent 500 was developed by Rolls-Royce to be the exclusive powerplant for the A340-500 and the slightly longer A340-600. It combines elements from both the Trent 700 and the Trent 800. The fan diameter of the Trent 500 is the same as the Trent 700, whereas a reduced version of the Trent 800 core has been selected as core for the Trent 500. All the compressor and turbine airfoils in the Trent 500 use advanced 3D aerodynamics for improved efficiency. Like other RB211 and Trent engines, the Trent 500 also features a three-spool design. The first run of the Trent 500 was in May 1999 and certification was awarded in December 2000. The first flight of the Trent 500-powered A340-600 was in April 2001 and the first A340-600 was delivered to Virgin Atlantic Airways in July 2002. Although the Trent 500 is certified for 60,000lb thrust, the two thrust versions are the 53,000lb variant for the A340-500 and the 56,000 lb variant for the A340-600.

Fleet

With a fleet of about 125 Trent-powered A340s in existence, the number of installed Trent 500s is about 500 and it can be estimated that the total number of Trent 500 engines (covering both installed and spare engines) is about 600. The major Trent 500 operators are Lufthansa, Virgin Atlantic Airways, Iberia, Etihad Airways, Emirates Airline and Thai Airways. Etihad Airways and Thai Airways are the only operators which have both versions of the Trent 500 in their fleet. The entire fleet of Trent 500 engines has accumulated just over 10 million engine flight hours and about 1.2 million engine flight cycles. The lead engines of the Trent 500 have over 30,000 engine flight hours and 4,000 engine flight cycles. The aggregate number of engine flight hours of the global fleet of Trent 500 engines presently increases by two million engine flight hours per annum. The average flight duration for the Trent 500 engines is about 8.7 flight hours and most operators use their Trent 500 engines for flights of between eight and 10 flight hours. Singapore Airlines leads in using its Trent 500 engines on the longest sectors: the average flight duration is regularly close to 17 flight hours per flight!

Versions

As mentioned above, there are two thrust versions for the Trent-powered A340s that are in service. The 53,000lb rated Trent 500 (for the A340-500) is identified as Trent 553-61 or Trent 553A2-61. The 56,000lb rated Trent 500 (for the A340-600) is identified as Trent 556-61 or Trent 556A2-61.

According to Doric's understanding, the difference between the "A2" and the "non-A2" designation is linked with the embodiment of a package of modifications that enhance the performance of the "A2" engines. The Trent 553 and Trent 556 basically differ in thrust level. Both versions have the same turbine gas temperature (TGT) red line limit of 900 ˚C, which obviously implies that the Trent 500 rated at 53,000lb has a higher TGT margin than the 56,000lb rated one. About 25 per cent of the Trent 500 engines in service are rated at 53,000lb, whereas 75 per cent of the Trent 500 engines in service are rated at 56,000lb. In terms of operational experience, the Trent 500's performance retention looks satisfactory and the TGT deterioration is presently not a primary contributor to engine removals.

Technical issues

In managing Trent 500 engines, Doric has come across the following more significant issues:

- Cabin odour (oil smell): for some years now, Trent 500 engines have been generating cabin odour events. This has caused a number of engine removals. The intensity and frequency of this phenomenon varies and Rolls-Royce has been working on it with different concepts. In the mean time, the engine manufacturer has been able to find a solution for the majority of the cabin odour events. This is achieved by revised intermediate pressure compressor stage 8 (IP8) air tube assemblies with an increased tube size external diameter and complementary changes (SB RB211-72-G120), which addresses the primary source of the oil smell. The modification can be incorporated on-wing as well as in the shop. The majority of the engines are now modified and the modification looks successful. A secondary source of the oil smell is the intermediate gear box (IGB), which can leak across the hydraulic seal housing joint and the IGB/intercase joint, and Rolls-Royce is developing a solution to address this as well.
- High pressure turbine nozzle guide vane (HPT NGV) convex airfoil cracking: during regular inspections, cracking on the convex surface of the airfoil has been reported. This is caused by higher than predicted temperatures following local thinning of the airfoil thermal barrier coating in this area. Initially, extended limits have been provided by Rolls-Royce in combination with comprehensive borescope instructions (NMSB RB211-72-G240). In the mean time, Rolls-Royce has also developed a revised HPT NGV with improved leading edge convex surface cooling, which should address the cracking issue. The revised HPT NGVs are installed during shop visits and hospital visits (SB RB211-72-G232).
- Intermediate pressure turbine nozzle guide vane (IPT NGV) thermal distress: due to potential fuel spray nozzle blocking during operation, there is a chance that — when significant fuel spray nozzle blocking occurs — this may result in asymmetric thermal distress of turbine hardware. Accordingly, Rolls-Royce introduced in-shop manifold cleaning and flow check fuel of spray nozzles during each shop visit (Alert SB RB211-73-AG327). In the mean time, Rolls-Royce strongly recommends replacing (on-wing) the right hand fuel manifold (Alert SB RB211-73AG422) and an EASA AD is likely to be associated therewith. A modification to the design of the right hand fuel manifold assembly has reportedly been launched and could ultimately alleviate the requirement for that alert SB (and related EASA AD).
- Fuel pump bearing wear: wear is experienced on the faces of the bearing in the fuel pump (Mk3 version), which is leading to thermal distress and release of material into the hydro mechanical unit (HMU). This can ultimately lead to fuel pump and HMU removals. It is recommended that a revised fuel pump (Mk4 version) be incorporated during engine shop visits and — as a complementary modification — an upgraded Mk4 HMU also be incorporated (replacing the MK3 HMU) at the same moment.
- Spinner and spinner fairing polyurethane (PU) delamination: a new nose cone assembly and nose cone fairing assembly is now available (SB RB211-72-G102).
- Fuel Oil Heat Exchanger (FOHE): due to the

Trent 500 Characteristics

LPC	1 fan stage
IPC	8 stages
HPC	6 stages
Combustor	annular combustor chamber
HPT	1 stage
IPT	1 stage
LPT	5 stages
Fan Diameter (inches)	97.4
Length (inches)	155
Dry weight (lb)	10,660

Like the RB211, the Trent 500 features a three-spool design.

"

It can be estimated that the Trent 500 engines would be able to remain on-wing for around 3,000 engine cycles (for first-run engines) and for around 2,500 engine cycles (for second and subsequent run engines). In reality, however, particularly for the first run engines, the above on-wing periods are not being achieved.

The Trent 500 received its certification in December 2000.

possibility of fuel restriction at the FOHE cooler matrix (like what occurred with the similar design Trent 800 FOHE), a revised FOHE needs to be installed (Alert SB RB211-79-AG346). This Alert SB must be accomplished on all Trent 500 engines within 6,000 engine flight hours after 10 July 2009 (EASA)/03 May 2010 (FAA) or by 01 January 2011, whichever is the sooner. This Alert SB is covered by EASA AD 2009-0257 and FAA AD 2010-07-01.

Shop visits

It can be estimated that the Trent 500 engines would be able to remain on-wing for around 3,000 engine cycles (for first run engines) and for around 2,500 engine cycles (for second and subsequent run engines). In reality, however, particularly for the first run engines, the above on-wing periods are not being achieved as the Trent 500 engines require a replacement of the HPT disk, which presently has a certified life of 2,600 engines (see below). Shop visit cost of Trent 500 engines should not be underestimated as — according to Doric — the price of a refurbishment shop visit is very expensive compared with engines of a similar thrust level. Fortunately, the long average flight duration of the Trent 500 is able to somewhat lower the high shop visit cost impact when expressed in an hourly rate. This also makes the cost per event somewhat less visible, particularly since many Trent 500 engines are covered by flight-hour agreements.

Life limited parts management

As with other Rolls-Royce engines, Rolls-Royce is splitting the life limited parts into Group A and Group B parts. The Group A parts cover the typical life limited parts in an engine (disks, shafts etc.), whereas the Group B parts cover the fan blades and the annulus fillers (note that the annulus fillers presently have no life limit). Although most of life limited parts in the Trent 500 engines have a certified life of 10,000 flight cycles, there are some Group A parts which presently have a significantly shorter certified life. These Group A parts are the HPC stage 1-4 drum (with 5,000 cycles), the HPT front cover plate (with 4,000 cycles), the IPT disk (with 5,000 cycles), the LPT disk stage 3 (with 7,990 cycles) and the HPT disk (with 2,600 cycles). The HPT disk's certified life is causing the engine to go into the shop significantly before it would have, had this HPT disk's certified life been higher (see above). Rolls Royce is working on extending the certified life of the HPT disk (from 2,600 cycles to 3,000 cycles) and it is likely that during the second half of 2010 Rolls-Royce will make more details about this life extension available.

Support

There are three engine shops, which are certified for Trent 500 maintenance and repair. These shops are Hong Kong Aero Engine Services Limited (HAESL) in Hong Kong (HAESL is a joint venture between Hong Kong Aircraft Engineering Company Limited (HAECO), SIA Engineering Company (SIAEC) and Rolls Royce), Singapore Aero Engine Services Private Limited (SAESL) in Singapore (SAESL is a joint venture between SIAEC, HAESL and Rolls Royce) and N3 Engine Overhaul Services GmbH & Co. KG (N3 EOS) in Arnstadt (Germany). N3 EOS is a joint venture between Lufthansa Technik and Rolls-Royce. With Rolls-Royce having a stake in each of the engine shops, it effectively controls the maintenance market of the Trent 500. Based on today's fleet size of Trent 500 engines and the lack of any new orders for Trent 500 powered A340s, it can be expected that the number of Trent 500 engine shops will not increase. According to Doric's assessment, most of the Trent 500 engines are under long term dollar per flight hour maintenance support agreements ("Total Care Agreements") with Rolls-Royce, which is using its network of engine shops to do the maintenance and repair of the engines.

Conclusion

The Trent 500 is a modern and reliable engine. Like any other engine, it does have some issues, but Rolls-Royce either has a solution in place or is working on it. For example, for the cabin odour issue Rolls-Royce has a solution in place and the majority of the engines have been modified. The short life of some of the life limited parts, particularly the HPT disk, has caused a somewhat shorter time on-wing than would have been possible based on the Trent 500's performance. Through its network of engine shops, Rolls-Royce has been able to control the maintenance market for the Trent 500 and unsurprisingly many Trent 500s are under long-term maintenance support agreements. ■

Doric Asset Finance, with offices in Frankurt, London and New York, provides proactive, hands-on asset management and remarketing services to owners, investors, financiers and operators of aircraft and engines. Aircraft and engines under long term asset management include aircraft the Airbus A320-family, the A330/A340 family, the A380 and the 777, and CFM56-5, the Trent 500, the GE90-115 and the GP7200 engines. The company also performs asset management activities via project assignments with a more limited scope, such as aircraft inspections and technical records audits.

whose technical skills complement one another are really in the best position to succeed," she added. "GE and Pratt & Whitney have very strong jet engine technologies that have come together beautifully to create a high-performing engine."

The GP7200 literally combines the best engine technologies of both companies. Its core is a derivative of the GE90 hot section, and its fan module and low-pressure sections incorporate technologies from P&W's PW4000 engines (see sketch A).

In addition to teaming with each other, GE brought in Snecma and MTU as partners on the GP7000 high- pressure compressor and turbine, respectively, and P&W contracted with MTU and Techspace Aero on the fan module and low-pressure turbine section, respectively (see sketch B).

The GP7200 core is manufactured at GE's Durham, North Carolina facility. That and other engine modules are shipped to P&W's engine centre in Middletown, Connecticut for final assembly and transport to Airbus headquarters in Toulouse, France.

EA personnel, who are seconded from the two member companies, are located at P&W in East Hartford, Connecticut (EA East), and at GE in Cincinnati, Ohio (EA West). Although member company campuses are used, the EA offices are located apart from the rest of P&W and GE. Team members are entirely EA-focused and constantly conscious of firewalls that allow only appropriate sharing of information. Mandatory refresher training helps ensure everyone remembers the non-disclosure terms of the EA agreement.

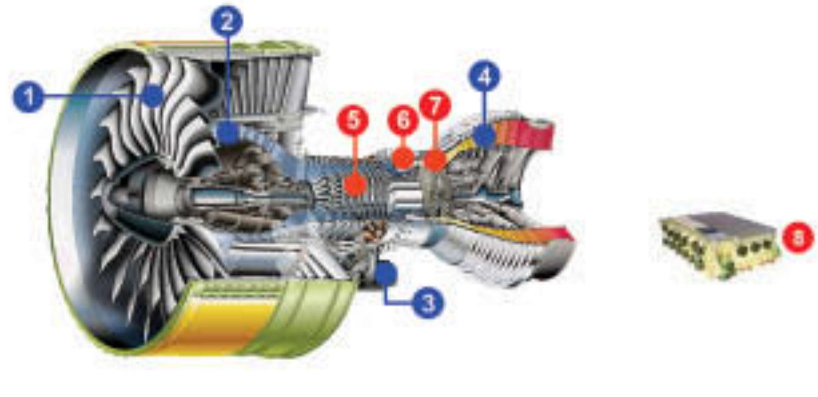
As with other JVs, the EA strives to maintain an equitable balance of representation from the member companies. The offices of the president and CFO are rotated equally between members of GE and P&W on a three-year plan. At the end of Jones' term, the role of president will be assumed by a GE executive. At that time, the CFO's position will be assumed by a P&W associate. The key functions of engineering, customer support, industrial management, quality, and sales and marketing are equally staffed at EA East and EA West.

GP7200 customers

The Engine Alliance won its first A380 engine order from Air France in 2001. Since then, Air France has increased its original order from 10 aircraft to 12 and EA has garnered orders for an additional 84 aircraft. The JV is now contracted to power 52 per cent of the186 firm A380s (with engine selections) on order.

By the end of 2010, EA expects to have 19 GP7200-powered A380s in service: Four with Air France and 15 with Emirates. Doric Asset

GE & Pratt & Whitney technologies in the GP7200 Turbofan



Pratt & Whitney	GE
1 - Swept hollow titanium fan	5 - 9-Stage HP Compressor
2 - 5-Stage LP compressor	6 - Low Emission Single Annular Combustor
3 - Accessory Gearbox	7 - 2-Stage HP Turbine
4 - 6-Stage LP Turbine	8 - FADEC III

Finance (Doric) became the first lessor with GP7200-powered A380s in its portfolio when it purchased two of the Emirates A380s in a sale-leaseback agreement. Korean Air is scheduled to receive its first A380 in 2011.

In-service performance

The media is quick to criticise when the A380 experiences any technical issues, but the aircraft's reliability during its first 12 months in service was actually better than that of today's most-utilised widebody aircraft. The A380's dispatch reliability rate exceeded 98 per cent during its first year of service. Compared to the first year dispatch reliability ratings for the 747-400 (91 per cent) and the 777 (97 per cent), the A380's reliability has been remarkable.

The GP7200's performance is equally impressive. Since entering service with Emirates in 2008, the GP7200-powered A380 fleet has not experienced a single in-flight shutdown or aborted takeoff. The 12-month rolling average dispatch reliability rating for the EA-powered fleet typically exceeds 99.9 per cent.

These are numbers, Jones said, that are consistent with a mature engine. "It's the result of continuously testing these engines under extreme conditions to expose potential issues and resolve them before they can become problems for our customers," she noted. "It's also a tremendous tribute to the teamwork inherent in this GE-Pratt & Whitney partnership."

The specific fuel consumption (SFC) of the engine in service is one of its best features. Prior to service entry, the engine demonstrated it would perform better than its specification required. But analysis of the GP7200-powered A380s in service show that the engines are performing better still. Airbus notified EA in March, 2010 that it plans to revise the next GP7200 performance document to reflect a 0.5 per cent SFC improvement.

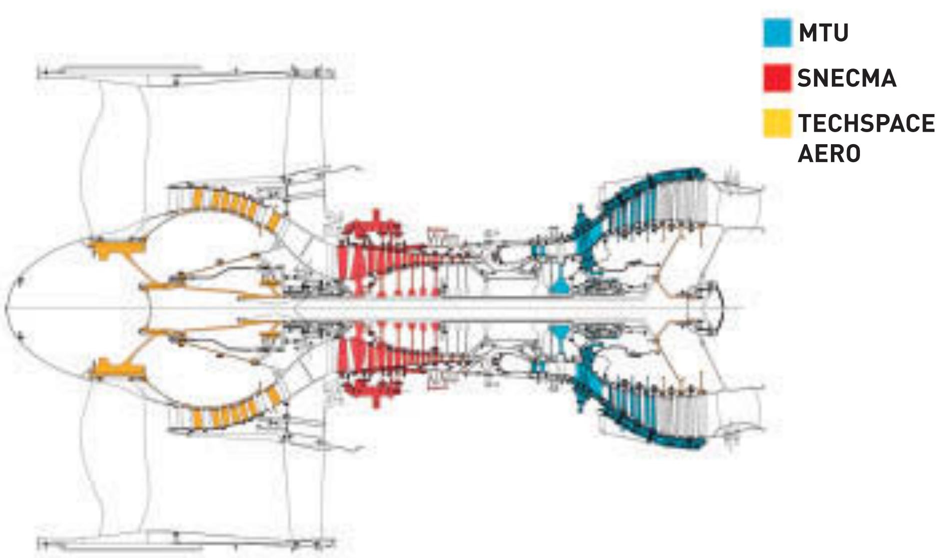
"We're very pleased with the engine's performance in service," Jones said, "but more importantly, our customers are."

"We're delighted to be one of the main GP7200 operators," Adel Al Redha, Emirates EVP engineering and operations, said. "The in-service experience of the engine has proven to be meeting the performance and reliability expectations set by the manufacturers." Doric

Engine Alliance customers include:

Airline firm orders:

Air France	12
Emirates	58
ILFC	4
Korean Air	10
Etihad	10
Air Austral	2



GP7200 Revenue share participants

GP7200 Engine Specifications

Takeoff Thrust	70,000 lbs./311 kN
Flat Rate Temperature	86°F / 30°C
Bypass Ratio (Takeoff)	8.8
Overall Pressure Ratio (Takeoff)	36.1
Engine Length	187.1 in. / 4.75 m
Maximum Diameter	124.0 in. / 3.15 m
Fan Blade Tip Diameter	116.7 in. / 2.96 m
Noise Margin to Stage 3	27.6 EPNLdB

Single Fan, 24 Swept Wide Chord Hollow Titanium Blades, and Single Annular Low Emissions Combustor.

is also pleased with the engines. "What we have seen up to now with the GP7200 points to a very promising time on-wing, even in a demanding operating environment," Maurick Groeneveld, Doric Aircraft management director, commented.

Worldwide customer support

Emirates, Air France and Korean Air, all customers with engines in service or preparing for service entry, are active participants in the EA's airline working group (AWG), a team comprised of EA engineering and customer support leaders which meets periodically to review the engine's performance and develop improvements. These and other EA customers have full access to the GE and P&W member companies' worldwide customer support networks, for comprehensive coverage around the clock. "When customers choose the GP7200 they have the option of selecting either member company as their single point of contact for aftermarket support," notes Mike Hoffmeister, EA customer service director. "This is just one additional way our JV is an advantage for them."

The EA team sought input from its customers very early in the programme, with particular attention paid to maintainability and logistics. For example, the vast majority of GP7200 line replaceable units (LRUs) are readily accessible and designed to be replaced within four hours.

Borrowing a best practice from the GE90, the GP7200's fan and propulsor were designed to be separated for shipping to enable the large engine to fit into a variety of aircraft. "We've modularised the engine so you can take it apart with minimal tooling," John Romprey, EA quality manager, said. By design, any given GP7200 propulsor will assemble with any GP7200 fan. "This also allows for shipment of just a propulsor for off-station engine changes," Romprey explained. "The customer doesn't always need or want a full spare engine, so this approach helps them to manage their inventory costs and also provides great transportation flexibility."

Technical issues

All jet engines experience at least a few technical issues upon entry into service and the GP7200 is no exception. All issues are addressed with a rigorous root cause analysis and corrective action plan, which is then reviewed with customers, to ensure they are resolved. For example:

- Three months after entry into service an engine experienced an oil hiding event. The oil pressure reading briefly dropped and returned to normal, indicating that oil was temporarily hiding somewhere in the engine. The root cause was attributed to a low baffle clearance in the oil tank. Existing oil tanks were inspected for sufficient clearance and the assembly procedure was modified to ensure adequate baffle clearance on future builds.

- In 2009, an engine experienced rapid oil loss that was caused by a fracture in a scavenge tube fitting. The fracture was caused by high cycle fatigue in the fitting. A bracket was added to the system to reposition the scavenge tube, effectively reducing the dynamic response.

- After a year in service, several piston rings were found loose or missing during a routine engine inspection. These piston rings form a floating seal between the turbine centre frame (TCF) casing and the oil service lines that penetrate the TCF outer shell. The piston ring's loose fit was attributed to premature wearing of the case cover plate and an excessive lead in the chamfer at the assembly interface. The assembly interface was redesigned to eliminate the lead in the chamfer and the TCF cover plate material was changed from Titanium to Inconel to improve the wear characteristics of the joint.

Emissions and noise

At development, the GP7200 was required to comply with CAEP4 emissions requirements and London Heathrow QC4 noise standards. The engine's emissions are well below CAEP4 allowable levels and also meet the more stringent CAEP6 limits with margin.

In order to meet the stated QC4 noise requirements, the GP7200 was configured with a 2.8m (110 in.) diameter fan that produced a bypass ratio of 8:1. This would have easily allowed the engine to meet QC4, but customers demanded that the A380 meet the more stringent QC2 noise requirements. Subsequently, the fan diameter was expanded to 2.96m (116.7 in.) effectively increasing the bypass ratio from 8:1 to 8:8. As a result, the GP7200 meets QC2 departure noise limits and QC0.5 limits on arrival. European Aviation Safety Agency (EASA) certification test data confirmed the GP7200 is the quietest engine on the A380.

The GP7200-powered A380 may even be too quiet. Four months after Emirates received its first aircraft, It was reported that the Emirates crew was finding it difficult to sleep on the A380 due to the lack of engine noise, which they typically rely on to drown out passenger cabin sounds.

A look ahead

The Engine Alliance enjoys a fuel burn advantage today, but realises it must continually explore ways to increase fuel efficiency to maintain its competitive advantage tomorrow. Since entering service, the GP7200 has lost 150lb of weight and EA engineers are working to trim it even more.

The EA also continues to run fleet leader engines in the factory to identify potential issues and improvements. Additionally, as each EA customer prepares to enter service the AWG will grow, increasing the influx of ideas for enhancements.

"We want to ensure the GP7200 remains competitive for its current use on the A380 and for any potential aircraft derivatives as well," Jones said, "EA East and West are completely aligned when it comes to maintaining the GP7200's advantage".

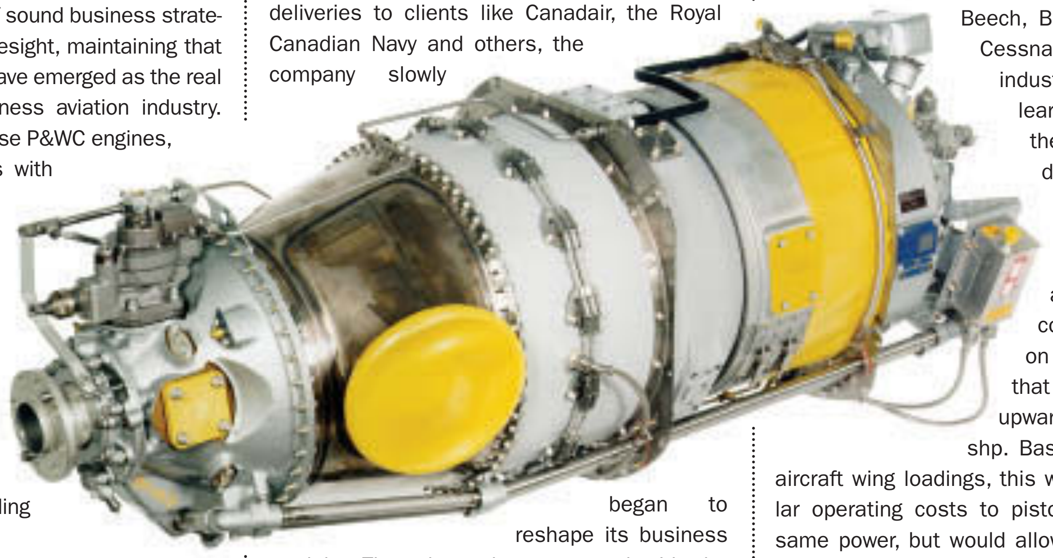
"Completely aligned" is a notable achievement for two companies who weren't supposed to get along.

Pratt & Whitney Canada provides a new chapter in PT6 engine development

After several years of tough economic challenges, the aviation industry is in the early stages of a period of renewal and prospective growth. February, traditionally the weakest month for passenger air travel, showed a strong uptick in 2010, with passenger demand 9.5 per cent higher than the previous year. As *Anna Maria di Giorgio* of *Pratt & Whitney Canada* (P&WC) writes, engine manufacturers aim to lead and innovate as we enter a new era of renewal and growth.

Positive signs for commercial air travel bode well for business aviation as well. A recent New York Times article, titled Daring to Think Private Jet Again, noted that business aircraft flights in January, monitored by the aviation research firm Argus, rose 5.3 per cent over the same month in 2009.

Pratt & Whitney Canada (P&WC) believes it has prevailed because of sound business strategies and true market foresight, maintaining that the company's engines have emerged as the real workhorses of the business aviation industry. More than 700 airlines use P&WC engines, and the company works with more than 35 original equipment manufacturers (OEMs). With over 46,000 engines in service, operating in more than 198 countries, it's safe to say that just about every second a P&WC-powered aircraft is taking off or landing somewhere in the world.



The PT6 engine, used by 10,000 global operators, is one example of the company's continued reinvention and responsiveness to emerging customer needs. During periods of dynamic transformation, like those we currently face, industry leaders take what history has taught us and use that knowledge to drive further innovation.

Powering flight for 50 years

Pratt & Whitney Canada began in 1928 with the assembly, overhaul and service for engines. It was not until 1941 with the launch of Canadian Propellers that the company was officially marked a manufacturer. This government-financed venture provided an opportunity for the company to construct a new, distinct manufacturing plant.

After World War II, P&WC expanded its vision and began to offer service to both Canadian and US military. With successful deliveries to clients like Canadair, the Royal Canadian Navy and others, the company slowly began to reshape its business model. Throughout the years and with the expansion of customer markets, it kept its focus on being a trusted source of flight power.

Customer expansion brought dramatic increases in both its workforce and profits. Responding to rapid business growth, Pratt & Whitney Canada matured from a small company with 230 workers to a market leader with 2,000 employees and saw earnings leap to $29m by 1956.

The late 1950s marked the informal development period for the PT6 engine. Market studies in 1958 validated a new industry need for turboprop 250-500 shaft horse power (shp) engines. Following its proven success in manufacturing military aviation products, Pratt & Whitney Canada had the foresight to identify a new and potentially large growth opportunity to innovate in an uncharted field. The company conducted informal consultations with potential customers such as Piper, Beech, Bell Helicopter and Cessna, verifying the industry's needs and learning more about the infrastructure of different customers.

Initially, after much speculation and research, the company decided on a 450 shp engine that could be scaled upwards to provide 500 shp. Based on the current aircraft wing loadings, this would provide similar operating costs to piston engines of the same power, but would allow aircraft to travel 50 miles per hour faster. This new, cutting-edge concept was named the DS-10.

Working to incorporate a free turbine design, the DS-10 allowed for a no-clutch configuration, simpler fuel controls and use of 'off the shelf' propellers rather than costly, custom-made prop blades. The PT6's free turbine system incorporated a reverse-flow combustion path and used two counter-rotating turbines — one driving the compressor and the other driving the propeller through a reduction gearbox. The latter turbine is free of the compressor turbine, an innovation that has allowed the PT6 engine to cover a diverse range of applications across all aircraft markets. The engine's diameter remains constant although it is scalable from the original 500 to 2,000 shp. More recently, higher-powered models incorporate a two-stage power turbine.

The new design resulted in a much quieter engine. The engine's mechanical configuration, with an opposing shaft design instead of concentric shafts, also made the unit much easier to maintain. The combination of the opposing shaft and the free turbine served as the initial architecture of the PT6 engine.

As PT6 turboprop development continued, the engine evolved into three different families that range in size — small, medium and large — all offering unique, scalable power levels. Regardless of engine size, they share the same, basic game-changing architecture. The small PT6A family has three stages of axial compression and one centrifugal stage, driven by a one-stage axial compressor turbine, and a single, independent power turbine. With the medium PT6A, the company added a second power turbine to extract more power. The large PT6A added a fourth axial compression stage to increase the overall pressure ratio.

PT6A: An evolution in advanced technology

A complete PT6A with a propeller was first tested on February 22, 1960, just 14 months from full design launch. This marked the beginning of an 8,000-hour pre-production testing programme and by June 1961, the PT6A had made its first flight on a Beech 18 mounted in the nose for flight-testing and demonstration.

Many other experiments followed on various installations, but the real breakthrough occurred with Beech aircraft, when the PT6A was selected to power the Beech Model 65 Queen Air, originally produced with 340 horsepower Lycoming engines. In May 1963, the newly designated NU-8F transport and training aircraft took to the skies for the first time with PT6A-6 engines for testing. And on December 22, 1963, the first production PT6A engine, S/N 20001, was delivered to Beech Aircraft. Engine production began in 1963, and by 1964 the PT6 engine entered into service.

P&WC says that since the engine's commencement, the PT6 has become the penultimate turboprop engine, powering commuter, corporate and utility aircraft, aerobatic trainers, agricultural aircraft, short takeoff and landing (STOL) aircraft and water bombers. It adds that 'unmatched versatility', dependability and performance have made the PT6A the most thoroughly proven and popular turboprop engine family in the 500- to 1,700-shp class.

Turboprops remain a workhorse of business aviation.

Understanding what has worked in the past, evaluating the technologies that have served as stepping stones throughout the decades, and then making improvements, will help carry the industry and interested stakeholders into the next era of business aviation. Pratt & Whitney Canada maintains that its innovative concepts, like the PT6 engine, have provided the platforms from which the industry has literally taken flight and will continue to do so in this new, exciting era.

The PT6: a legendary engine

Pratt & Whitney Canada recently celebrated the 50th anniversary of its landmark PT6A turboprop engine's initial test run. At the 10th annual European Business Aviation Convention and Exhibition (EBACE) in Geneva, Switzerland, the company marked five decades of innovation and flight while recognising what the future still holds for the engine. Its core technology has been developed and reshaped over the years, redefining the possibilities and enabling a single engine technology, which has helped propel the industry forward. During this time, Pratt & Whitney Canada has become a valued supplier, trusted partner and thought leader in business aviation. The company's near-constant development and enhancement of the PT6A engine has made it one of the most sought-after, proven sources of power for turboprop aircraft.

"Since its first test run, the PT6 has continued to evolve with customer needs and through the application of innovative technology," states Maria Della Posta, SVP sales and marketing. "The PT6 is a scalable technology that can be redeveloped and redesigned based on

Beech Aircraft took delivery of the first PT6A engine in 1963.

the specifications of the customer or need."

She adds: "Pratt & Whitney Canada has delivered more than 46,000 PT6 engines using more than 89 engine models. And today, more than 26,000 PT6 engines are flying: this is a testament to the technology improvements, customer focus and reliability of the product."

Keeping a watchful eye on the environment has been a hallmark of the engine's development, even at its inception. The company has continually invested in the technology to make all its engine families the most sustainable in their class. This has offered immense value in the form of higher performance and digital engine control and has generated a loyal customer following.

P&WC maintains that the PT6 engine is unmatched in the marketplace and that although others have made efforts to launch similar products, none has matched its versatility, durability and reliability. The engine manufacturer has consistently introduced newer versions of the engine, leading to more than 130 applications for business, commuter, utility and trainer aircraft and helicopters. The engine has logged more than 350 million hours of flight. P&WC has certified seven new PT6 engine models in the last five years alone. These new models build upon the engine's already legendary reputation for reliability and durability.

Pratt & Whitney Canada is now writing a new chapter in PT6 development. The core architecture is being supplemented with technological advances and scaled to meet the challenges of today's business aviation industry. "Successful innovation requires equal measures of inspiration and discipline, as well as a healthy and systematic process for bringing new ideas to the marketplace," remarks Della Posta.

Inventing the future: next generation turboprop

During EBACE 2010, Pratt & Whitney Canada announced the creation of a new multi-disciplinary team to focus on the next generation of turboprops. The team's mandate is to create an even more impressive PT6 engine offering and ensuring rapid entry into the marketplace.

"Our ultimate objective is to bring incremental value to customers while maintaining our leadership position in the turboprop world," says Della Posta. "The technology we develop may also be applied to existing PT6 engine models, and it will allow us to continue the tradition of adding value through technology evolution and innovation."

The engine manufacturer has created the industry standard with the PT6 engine. It has been one of the few names in the market sector that has not only kept pace with the changing trends of the business aviation industry, but also created the trend 50 years ago. The PT6 has pushed the edge of what is possible and continues to expand the boundaries of performance. "We believe it offers boundless promise for decades to come," concludes Della Posta. ■

Disruptive technology that made good sense

The design team selected the opposed shaft layout to:

- Avoid the complexity of concentric shafts and the attendant bearing and turbine disc design problems.
- Allow the packaging of the accessories box at one end, and the output gearbox at the other for safety and easy access.
- Maintain duct and exhaust losses to compare favourably with a conventional through-flow layout.
- Use a double scroll exhaust design to handle the power turbine exit swirl (found to be not needed).
- Use a screen protected compressor inlet plenum to eliminate FOD.
- Allow a split between the power and gas generator sections for ease of maintenance.
- Allow use of a simple low frontal area two-stage epicyclical output gearbox, for fixed wing or helicopter installations.
- Reduce inlet noise level.

Headquartered in Longueuil, Quebec, Pratt & Whitney Canada is a world leader in the design, manufacture and service of aircraft engines powering business, general aviation and regional aircraft and helicopters. The company also manufactures auxiliary power units and industrial gas turbines.


TOUGH TIMES, TIGHT BUDGETS
REAL SOLUTIONS
In an economy where every penny counts, operators are looking for ways to minimize maintenance costs. Pratt & Whitney Canada's Component Repair Business took up the challenge and developed improved repair processes to salvage key engine components that would otherwise be scrapped, enabling even more cost-effective solutions. Thinking outside the box. It's what managing through tough times is all about. And it's what you can depend on from P&WC.
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Engine maintenance from an OEM perspective

When it comes to maintenance, engine OEMs are frequently seen as being victims of their own success. Today's high-by-pass ratio turbofans are so reliable that engines are frequently several years old — and with tens of thousands of hours on-wing — before they need a shop visit. As *Geoff Thomas* of *CFM International* writes, many CFM56-5B and -7B engines are still operational with around 30,000-hours on-wing which equates to an operating cost of around $100 per hour if the upcoming shop visit costs between $2m and $3m, excluding life limited parts (LLP).

From an individual airline's perspective this is good news — although the realisation that an engine needs to have considerable amounts of cash spent on it while it's being overhauled can come as a shock to the financial system if it hasn't been adequately budgeted for. And even if the on-going costs have been fully taken into consideration, airlines are always looking to reduce their expenditure on maintenance — so long as passenger safety and airline reliability aren't compromised.

At the outset it's important to state that CFM, unlike some other major international engine suppliers, neither has its own maintenance operations nor does it offer any form of 'lease' deal on its engines. All brand new CFM engines are bought outright on new airframes from either Boeing or Airbus.

However, the company does make an effort to offer operators customised service solutions that enhance the overall value of the CFM56 product line. These offerings include everything from line maintenance support, to repairs, to inventory support and other customised material solutions, through to complete engine workscoping.

CFM — a 50/50 joint venture between GE Aviation of the USA and France's Snecma — believes that its on-going success with power-

We love our engines, that's why we look after them for life.
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Introducing our new, comprehensive customer care service.
We love the engines we make and we're very passionate about being given the opportunity to maintain them for you. No other supplier knows our engines as well as we do. Our services are competitively priced and you can be sure of quick turnaround, 24/7 support and reduced cost of ownership over the life of your engines. Contact your local Snecma representative today for further details. Snecma. The Enginologists™

The CFM56-7.

ing today's single-aisle airliners is due to many reasons. Not least of these is its claim to enjoy a lower overall cost of ownership (including maintenance) than its direct competitors.

But don't just take CFM's word for it. Speaking in 2009 at the launch of the airline's all-business class service between London's City and New York's JFK airports, British Airways' CEO Willie Walsh said: "The CFM56-5B-powered A318s will bring great operating economics to this route. The Tech Insertion package brings a wealth of benefits including lower fuel burn, lower emissions and lower maintenance costs, all coupled with the outstanding reliability of the CFM56 product line." British Airways is a long-time CFM customer and currently operates a fleet of more than 80 CFM56 engines (including spares), powering its 737 Classic and A320 families of aircraft.

CFM believes that maintenance costs are a key 'value element' in determining whether an airline buying new or second-hand aircraft from the A320-family of single-aisle airliners chooses its engines, or those of its competitor International Aero Engines (IAE) which makes and sells the V2500 powerplant. In the case of the 737NG family, CFM is the sole supplier.

"The lowest cost shop visit is the one you don't have."

It has often been said that the only real low-cost shop visit is the one you don't have. But airlines are getting smarter and smarter at stretching time on-wing by investing in a variety of techniques and activities to enhance engine life. These include regular engine washes to ensure that the working parts inside the engine are as clean and contamination-free as possible, as well as asking pilots not to use full throttle unless strictly necessary due to load, airfield altitude or atmospheric conditions. According to CFM's Cincinnati-based Tom Henning, director, product marketing, all these techniques can increase time on-wing by as much as 10 to 20 per cent. Henning also explains that CFM is continuously enhancing the engine data and analysis capability of its remote monitoring/diagnostics to further improve time on-wing and departure reliability.

Both of CFM's parent companies provide some level of remote diagnostics now and about 13,000 CFM56 engines are covered by the programme. Going forward, CFM plans to expand the functionality of the service.

CFM is also conscious of considerable regional variations in the amount of wear and tear experienced by airlines in different parts of the world. Henning says that much of the variation is 'route specific' and he explains that CFM is working with airlines throughout the world to identify geographic regions with adverse runway and atmospheric conditions such as sand, grit and FOD (foreign object damage) that can cause challenging situations.

Over 25 per cent of CFM56 fleet granted TRUEngine status

CFM International's TRUEngine programme, launched in mid-2008, has been well received by customers worldwide. CFM launched the programme to help the industry more accurately appraise used CFM56 engines and to enhance the resale value of these assets — yet another 'key value element' in the decision-making process when engine choice is on the agenda.

To date, more than 5,000 CFM56 engines in service with more than 40 operators around the globe have been granted TRUEngine status.

"The industry asked CFM for better ways to determine the value of engines as they are redistributed in aircraft fleets," says Eric Bachelet, president and CEO of CFM International. "The TRUEngine programme allows you to more easily evaluate used CFM56 engines by serial number, based on data currently not widely accessible."

The TRUEngine designation is available to all CFM56 engines meeting the criteria and several fleets of engines are currently being evaluated.

To qualify for TRUEngine status, the engine configuration, engine overhaul practices, spare parts and repairs used to service the engine must be consistent with CFM requirements for that engine model. In addition, all maintenance must comply with CFM-issued engine manuals and other maintenance recommendations. The qualification data is obtained through a combination of fleet operational and maintenance records.

Commercial jet engines typically are in service for more than 25 years and change ownership at least once in their operational life. The engine's configuration, material content, maintenance history, and supportability impact overall value as it changes ownership.

The TRUEngine designation also facilitates CFM's ability to provide technical support. Jet engines contain multiple, complex systems whose interactions must be carefully controlled. CFM's engine support is built upon technical expertise for genuine CFM56 parts and configurations, as well as data gained from the vast operational history of the global CFM56 engine population.

A modern high-by-pass ratio turbofan engine is an extremely complex and sophisticated piece of equipment that is designed by each manufacturer to function effectively, efficiently and economically (and in an environmentally-friendly manner) with all its thousands of parts operating within pre-determined parameters and with each individual part mutually dependent upon every other component.

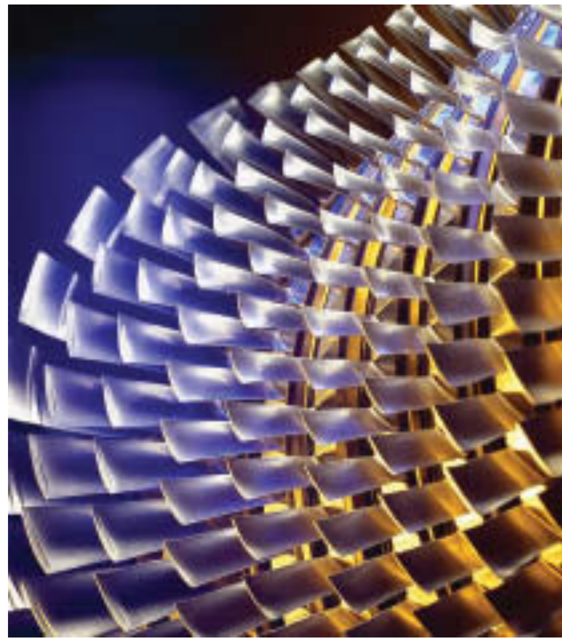
The original manufacturers argue that by changing one or more parts in the engine for ones that may be cheaper — parts manufacturer approval (PMA) parts — at least when initially purchased, may result in reliability issues, not to mention the possibility that the asset may realise considerably less financial return when it is eventually sold.

They are also concerned that the modification of engines they design and build, beyond the type-certified configuration, reduces their ability to provide technical support. These concerns resulted in the FAA's Aircraft Certification Service issuing a 'special airworthiness information bulletin' (SAIB) in August 2008 alerting owners, operators and certificated repair and maintenance providers of the 'responsibilities of type and production certificate (TC/PC) holders, supplemental type certificate (STC) holders and the PMA holders to support the continued operational safety (COS) of their product or part design.

Advanced design tools help keep CFM56 engines on-wing longer

When CFM was designing the -7B engine, now used exclusively on 737NGs , future maintenance was one of the major contributing factors considered by the engineers.

Use of the latest digital product definition tools at all stages of the engine's design helped to reduce definition cycle time and the first -7B engines came to production faster than had ever been done in the industry before. With full implementation of the advanced CATIA numerical sys-



The CFM56-7 rotor.

The CFM56 Tech Insertion on its test flight.

tem for design, the engine was the first powerplant to be developed using a full digital mock-up at all engine and installation levels.

All this high-tech computer-aided design resulted in far improved accessibility as well as removal and installation envelopes that have been optimised — with remarkable results. The replacement times for line replaceable units (LRUs) have been reduced by up to 80 per cent (compared with the CFM56-3 engine) while an entire engine replacement can now be achieved within four hours - an industry record.

A philosophy of continuous investment

CFM56 Tech Insertion, which is the production configuration for CFM56-7B and CFM56-5B engines, had a highly successful entry into service in 2007 on both the 737NG and A320 families.

Over the engine's life cycle, CFM56 Tech Insertion could provide operators up to one per cent better specific fuel consumption, which translates to better fuel burn and with longer time on-wing through an equivalent 15 - 20° C additional exhaust gas temperature (EGT) margin; and between five and 15 per cent lower maintenance costs (depending on the thrust rating) through enhanced durability.

The engine also meets the new International Civil Aviation Organisation (ICAO) Committee of Aviation Environmental Protection standards (CAEP /6) that took effect in early 2008. These benefits are achieved through improvements to the high-pressure compressor, the combustor, and the high- and low-pressure turbines.

In addition to the compressor kit, CFM also offers a full Tech Insertion core upgrade, as well as high- and low-pressure turbine hardware, for the more than 7,250 CFM56-5B and CFM56-7B engines that were delivered prior to the production shift in 2007.

Up to May 2010, more than 3,740 engines had been delivered to 196 unique operators. This fleet has logged more than 15.3 million flight hours and 8.6 flight cycles without a single engine-caused field issue.

In April 2009, Boeing and CFM together launched the new CFM56-7BE engine enhancement programme that coincides with 737NG airframe improvements.

The CFM56-7BE-powered 737NG enhanced aircraft/engine combination will provide a two per cent improvement in fuel consumption, which, in turn, equates to a two per cent reduction in carbon emissions. Additionally, the enhanced -7B will provide up to four per cent lower maintenance costs, depending on the thrust rating. This lower cost is achieved through a combination of longer time on-wing, improved durability, and lower overall parts count in the high- and low-pressure turbines.

CFM used advanced computer codes and three-dimensional design techniques to improve airfoils in the high- and low-pressure turbines to improve engine performance. In addition, it is improving engine cooling techniques and reducing parts count to achieve lower maintenance costs.

In 2010, the engine completed an extensive ground test programme, which included a grueling 150-hour block test and a nearly 60-hour flight test programme on GE Aviation's modified flying testbed. The engine is on track for FAA certification in the third quarter of this year and begins flight testing on the 737 in early 2011. The new aircraft/engine combination is scheduled to enter service in mid-2011.

The spare CFM56 engine you need, when you need it

When an airline needs a replacement engine fast — either because of maintenance requirements or — rarely — a failure that results in an aircraft unable to fly on revenue-earning routes, CFM-subsidiary SES comes to the rescue. Originally formed in 1988 and based at Ireland's Shannon Airport, SES is the world's largest CFM56 engine lessor. With a portfolio of more than 250 CFM56 engines - and with offices and pool locations located in 13 different countries worldwide - SES is positioned to deliver the most reliable, flexible and cost effective CFM56 spare engine solutions to CFM56 operators around the globe.

As the CFM56 in-service fleet continues to grow, SES continues to adapt the size and mix of its engine pool to ensure that its customers have access to a comprehensive range of CFM56 spare engine solutions. It currently offers a number of CFM56 engine lease options including:

Short-term lease

SES offers its customers a genuine short-term lease product whereby no minimum lease term applies. Customers pay for the number of days they need and redeliver when finished, with no hidden costs or extras built in.

Operating lease

This is a more widely available product generally running over a longer term of three+ years. There is an agreed delivery and redelivery condition and the lease term is fixed. The airline pays for the engine regardless of whether it is installed and typically takes maintenance responsibility during the lease term. Operating leases are an effective solution

The CFM56-5B.

where expected utilisation is high over a given period and where an airline is not in a position to buy its own spares.

Engine sales & exchange

SES can offer its customers a wide range of CFM56 assets for sale at any given time. In addition SES offers an engine exchange programme whereby an asset owner/operator may elect to swap out its unserviceable or older generation CFM56 engines with similar asset types that have greater on-wing life remaining. With a large portfolio of CFM56 engines to select from, SES can tailor a number of sale and exchange packages to suit specific customer requirements.

Guaranteed availability

This service is unique to SES and more commonly known as 'GAF'. It is an insurance-type product devised to protect airlines against the risk of an AOG (aircraft on ground). Engines are made available for lease within 24 hours of request.

Whatever the CFM56 spare engine requirement, with access to more than 250 CFM56 engines and expertise across a broad range of spare engine solutions, SES is well-positioned to support its growing base of CFM56 operators around the globe.

Today's powerplants stay on-wing so long that it's easy to forget that the time will come when there will be a $2 or $3m bill for maintenance — albeit a shop visit that will return an engine 'almost like new' according to CFM. If an airline also invests in replacement of all LLPs then the engine will be fit for a further 20,000/30,000 hours on-wing — figures unimaginable only a decade or so ago. ■

> ***"It has often been said that the only real low-cost shop visit is the one you don't have. But airlines are getting smarter and smarter at stretching time on-wing by investing in a variety of techniques and activities to enhance engine life. These include regular engine washes to ensure that the working parts inside the engine are as clean and contamination-free as possible, as well as asking pilots not to use full throttle unless strictly necessary due to load, airfield altitude or atmospheric conditions … all these techniques can increase time on-wing by as much as 10 to 20 per cent.***

Today more than 40 per cent of the installed V2500 fleet is backed by an IAE Aftermarket Services agreement, and over 80 percent of future deliveries.

standardising elements of the delivery to ensure we can maintain the promised levels of support for all our customers."

Affordable aftermarket support

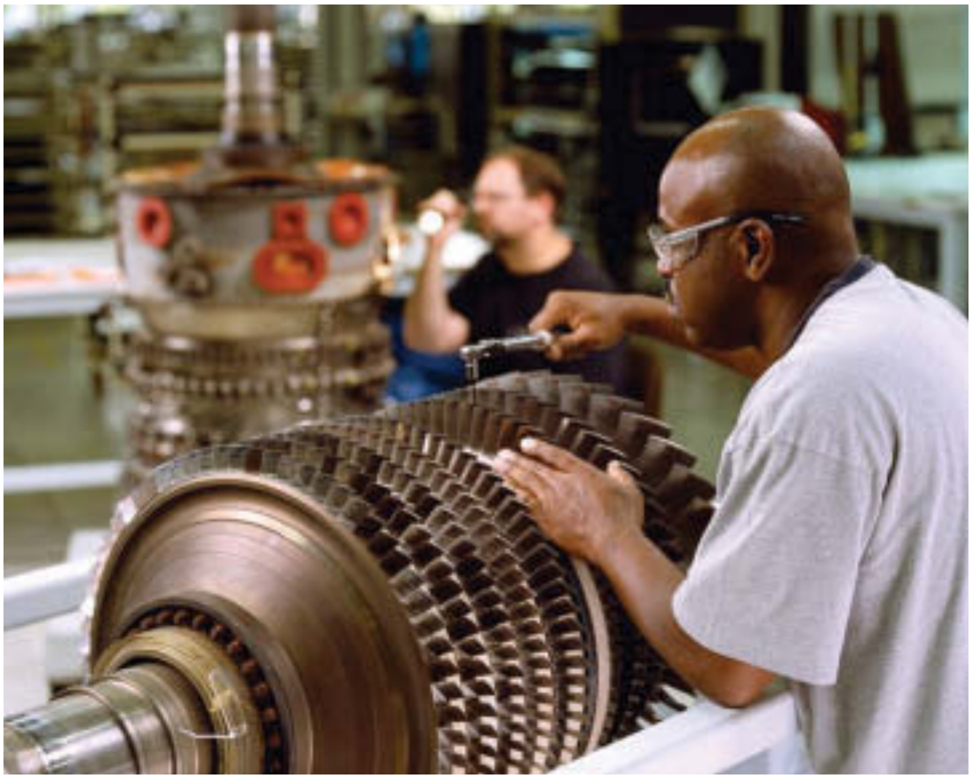
IAE has always been sensitive to its customer's needs and this is increasingly important in the tough economic environment. In 2005, IAE introduced its latest IAE aftermarket services programme, aimed at reducing customer costs. In the four years since its launch, 85 per cent of customers completing new engine business with IAE utilised the OEM-backed aftermarket service agreement. And on the product side, V2500 SelectOne entered service in 2008, delivering up to one per cent greater fuel burn benefit and 20 per cent longer time on-wing.

IAE aftermarket services agreements can also include upgrading existing V2500-A5 engines in service to the V2500 SelectOne standard, providing much of the performance benefits from the new engine design to existing engine assets. The incentive of a fleet hour agreement creates a relationship in which the customer pays a fixed monthly cost without any surprises while IAE is fully responsible for both planned and unplanned engine maintenance. The result is the complete transfer of risk, budget visibility for the customer and the spreading of maintenance support costs, rather than forcing repair bills at the time of a shop visit.

In addition, IAE helps customers to proactively manage their V2500 fleet with resources dedicated to understanding their operations, and arranging maintenance as required, when it best fits with the airline's schedule or aircraft maintenance plans. Working together with customers' engineering departments, IAE's fleet managers ensure a seamless flow of information in both directions to try and ensure there are no surprises when it comes to engine services.

"Our aftermarket programme is incredibly strong. It's a great way for us to offer our customers the chance to have complete visibility of the exact costs associated with their engine fleet. We help our operators to manage their engine fleet more efficiently, which means we can accurately forecast maintenance requirements and our own scheduling of spare parts. There are no hidden costs, there are no surprises. Our operational business models are

Customers like US Airways and Etihad have signed up for an IAE Aftermarket Services agreement to generate additional cost benefits across the engine lifecycle.



V2500 overhaul is completed by network of maintenance centers that leverages the capabilities of the company's four shareholders.

aligned and the relationship is beneficial to both parties," comments Davie.

> ***By talking to our customers and developing the service framework around their requirements, we've adopted a customisable approach that tailors a services programme around their needs, whilst standardising elements of the delivery to ensure we can maintain the promised levels of support for all our customers.***
> **—Chris Davie, SVP, IAE**

Bringing the best-of-the-best together

Throughout its existence, IAE has been a demonstration of taking the best-of-the-best and creating a solution that is greater than the sum of its parts. Back in 1983, the V2500 was created using this approach, taking the best technologies from the four shareholder companies (Pratt & Whitney, Rolls-Royce, MTU and JAEC) to produce an engine that has become the workhouse of nearly 200 airline fleets around the world.

When it came to designing the IAE aftermarket offering, the company adopted a similar approach. While aftermarket services agreements are centrally managed and run by IAE, giving the customer one point of contact, a world-class service is delivered through partnering with market-leading service providers to deliver the key components of its engine management solution.

Engine overhauls are completed by the IAE network of maintenance centers which leverage the capabilities of the company's four shareholders, and ensure worldwide overhaul capability. So regardless of location, IAE's customers will have a world-class maintenance facility within easy reach.

Real-time engine health monitoring is a standard service included in IAE aftermarket services and is administered through the class-leading OSyS (Rolls-Royce) and ADEM (Pratt & Whitney) systems. Access to current engine health and performance enables IAE to proactively troubleshoot and offer maintenance recommendations for engines in service while minimising operational impact.

On-wing maintenance is delivered through the Pratt & Whitney line maintenance services and, in addition, IAE has partnered with Hamilton Sundstrand to provide comprehensive accessories coverage through the company's comprehensive accessory repair and exchange (CARE) programme.

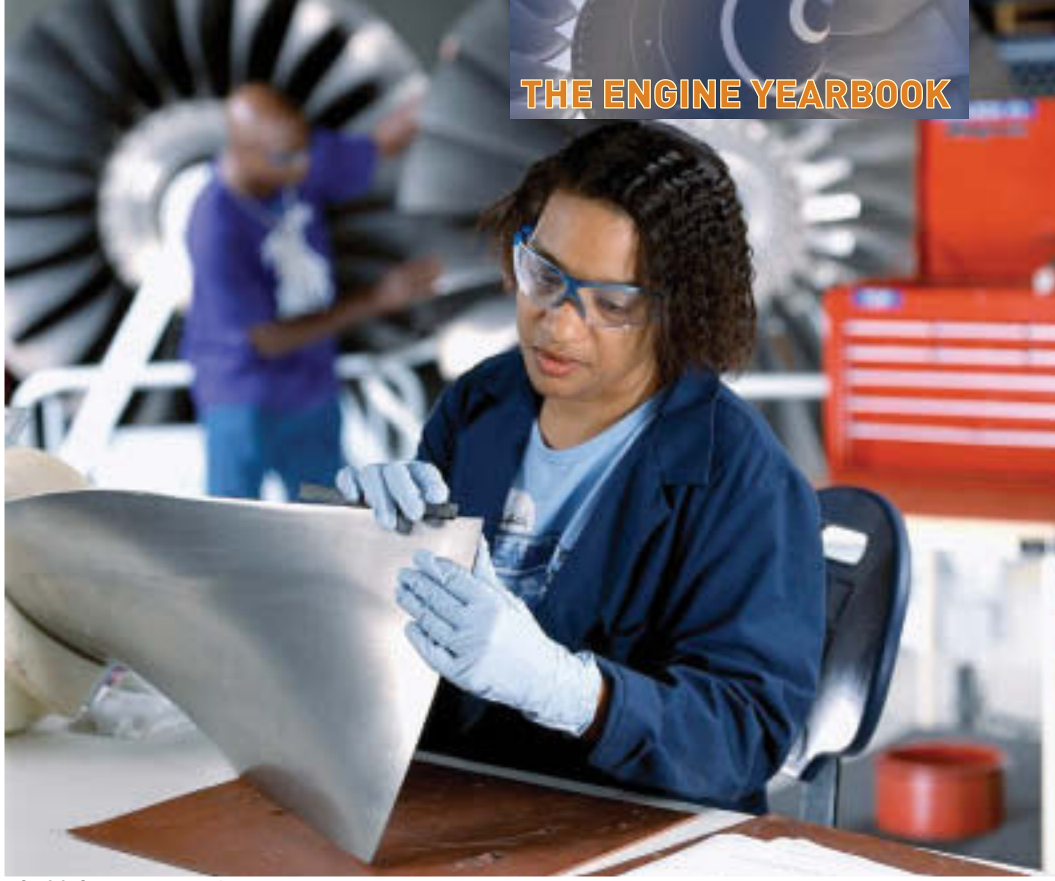
Market success

This approach has proved successful in the marketplace. Today more than 40 per cent of the installed V2500 fleet is backed by an IAE aftermarket services agreement, and over 80 per cent of future deliveries are now accompanied by a fleet hour contract — a figure which is set to rise as the backlog is delivered and services agreements become almost the default option. This is a measure of the programme's success when it's considered that the organisation's focus on providing comprehensive and managed aftermarket services is a relatively recent development.

"The services offerings and the network we've put in place have become a massive part of our growth," says Davie. "We have been delivering over 300 V2500s a year for the last five to seven years and more than 1,800 V2500 engines in service today have yet to see their first shop visit. These are now starting to hit the overhaul shops and there are a lot more out there still to come in for their first shop visit. It's a pretty exciting future being in IAE with that level of growth coming forward."

These support arrangements even contribute to the selection of the V2500 in engine sales campaigns. But it is not just new engine deals that have contributed to the growth of IAE aftermarket services as many customers sign up to new contracts part way through the engine's life. Similarly, several operators have added coverage to an existing fleet after taking a services agreement with a new engine order.

For example, at the Paris Air Show in 2009, Etihad placed a repeat order for the V2500 SelectOne variant covered by an IAE aftermarket services agreement. It followed this announcement six months later at the Dubai Air Show with a retrospective services package for 30 installed and spare engines powering its existing, in-service fleet of 14 A320-family aircraft. In Singapore in 2010, Middle East Airlines confirmed a similar agreement for six firm and three option A320s, citing the ability to better retain performance levels as a key driver in its decision.



V2500 fan blade repair.

As Davie explained: "Once we agreed an FHA to accompany the engine order for their 20 new aircraft, it became clear that a similar services package for the V2500s already in-service was the way to go. Because their original A320s came from various directions at different times — some new aircraft, some leased, and some from other operators — we'd simply not got round to discussing an OEM services contract. Now we'll see real benefits through a consistent arrangement across the Etihad fleet."

"In the last five years we have grown our aftermarket delivery function to cope with the rapid growth we've experienced and to ensure we can deliver service levels that our customers expect," says Davie. "Because of this growth we've had to focus on our tools and processes to streamline work practices and develop the organisational structure to fully support our customers."

Continuous improvement

IAE has always maintained a philosophy of continuous improvement and this has translated into the aftermarket. Performance and reliability are the two major drivers of product upgrades, but with V2500 SelectOne, IAE designed for maintenance as well. With the introduction of this new build standard, time-on-wing will increase by 20 per cent, meaning even more benefits for IAE customers.

"Again, it comes down to listening to what our customers are asking for and delivering to meet those needs," says Davie. "More importantly, we have made some of those benefits available to existing customers by enabling some of the V2500 SelectOne upgrades available through retrofit at a scheduled shop visit, maintaining the continuous improvement cycle."

On February 12, 2009, the first V2500 SelectOne retrofit was completed by the Pratt & Whitney Columbus Engine Center overhaul facility in Columbus, Georgia. The V2500-A5 engine, registration V10301, which is operated by US Airways, has been in service since February 16, 1998, successfully completed all tests and was returned to the customer on schedule. It has over 38,000 hours on-wing with nearly 15,000 cycles.

"Updating existing assets adds great value for our customers. Without having to buy a new fleet of engines, we provide them with the option to take the V2500 engines they already own and upgrade them to the new build standard. They receive the majority of the benefits they would from purchasing an engine that rolls directly off the shop floor, allowing for further reduced costs," Davie adds. "The ability to upgrade existing equipment to the latest standards is yet another mechanism IAE uses to keep its customers satisfied and continuously up-to-date with technology." ■

MTU Aero Engines:
developing expertise in engine manufacturing

***MTU Aero Engines* has been providing propulsion systems to power aircraft for decades. Germany's leading engine manufacturer designs, develops, manufactures, markets and supports commercial and military aircraft propulsion systems and aero-derivative industrial gas turbines. MTU has made a name for itself around the globe with its compressors, turbines and manufacturing techniques which are one of the company's domains of expertise.**

The engine company pursues its manufacturing activities at two locations — high-tech components for commercial and military engines are manufactured at corporate headquarters in Munich, while in Poland predominantly low-pressure turbine parts are produced. The company has a highly advanced machine park. "What's important, in addition to having in-depth know-how of the individual manufacturing processes, is the capability to optimally combine them into complex process chains," explains Richard Maier, SVP production development and support at MTU Aero Engines in Munich. Comprehensive simulations, too, play an increasingly important role. Engines are made up of a variety of materials with very different properties; whereas the testing of actual components takes a lot of effort and money, computer simulations are less expensive and time- consuming, notes Maier.

Aircraft propulsion systems are a special kind of high-tech product - their manufacture calls for innovative technologies and processes. Use is made of conventional methods of machining, such as turning, milling, drilling, grinding, and broaching. The materials involved, for example nickel-base alloys, are difficult to machine. They have a high strength and a high temperature resistance — material properties that are essential to the proper

Repair beats replacement!
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Awarded "Best Engine MRO" at UBM Aviation's Aircraft Technology Maintenance & Engineering Awards 2010
The MTU Maintenance group is renowned for excellent-value engine maintenance. For a quarter of a century, the company has been a reliable partner of many airlines, offering a compelling choice of customized service packages.
We aim to repair rather than replace, using the very latest inspection, maintenance and repair technologies. Forget about expensive replacement parts and keep costs down. Expect us to provide outstanding repairs and short off-wing times – worldwide and at affordable prices.
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MTU
Maintenance

In six minutes the laser drill shoots as many as 180 cooling air holes into a component.

operation of engines. MTU has many years of experience in the field and is developing innovative methods and improving existing ones. "Our technological capabilities are top-notch," says Maier, claiming that in some technology areas, MTU is the undisputed number one in the world.

Lasercaving

Among the turbine and compressor specialist's most important high-tech processes are lasercaving, a technique used to produce contoured cooling air holes in high-pressure turbine blades and vanes, as well as adaptive milling, precise electro-chemical machining (PECM) and friction welding for blisks production.

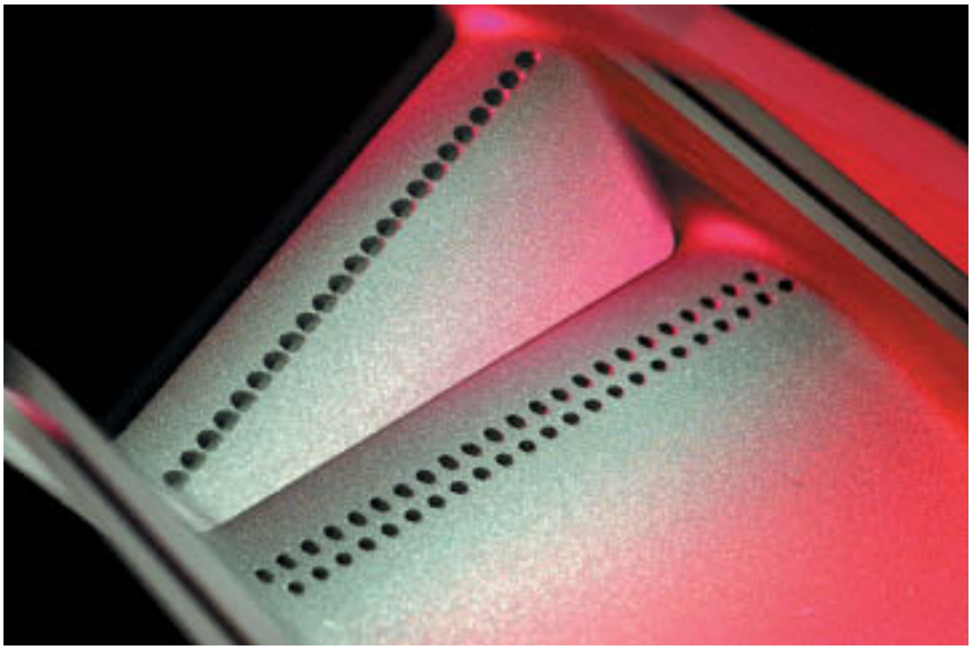
MTU's engine specialists have developed the lasercaving technique and hold a global patent on this method of manufacturing, which combines two separate processes - laser drilling and laser ablation - and is a key technology when it comes to boosting turbine efficiency further. It uses a laser to generate flared cooling air holes in high-pressure turbine blades and vanes. Through such holes, the outflowing air spreads more advantageously over the component surface. As a result, less cooling air is required and efficiency is improved. On the GP7000, which powers the A380 mega-liner, high-pressure turbine efficiency is increased by fully one percent, with a resulting reduction in fuel burn in the same order of magnitude of one percent.

Blisk manufacture

Blisks (blade integrated disks) are high-tech components manufactured in one piece that eliminate the need to fix separately manufactured blades to the disk. This increases strength and reduces weight. Blisks are used in low-pressure and high-pressure compressors for military and commercial applications. Maier says: "We're currently also looking into options to use blisks in turbines."

Larger blisk airfoils are fitted to the disk one by one by linear friction welding and then finish-machined by adaptive milling. Medium-sized airfoils are milled from the solid, whereas small airfoils can alternatively be produced by PECM, the latter technique obviating the need for surface finishing, an operation otherwise routinely required after electro-chemical material removal.

Tandem blisks and compressor spools — several successive compressor stages arranged in line — are produced by rotary friction welding. MTU says its shop in Munich boasts the world's largest and most precise



Above - left: ***At the Munich MTU facility, high-speed milling is used to produce blisks for the EJ200 high-pressure compressor.***
Above: ***Blisk production of an EJ200 low-pressure compressor at MTU Aero Engines in Munich.***
Left: ***Laser-drilled shaped cooling holes in a high-pressure turbine vane.***

rotary friction welding machine. The equipment, which is about 20 meters in length, is a double-spindle configuration that permits a wide range of components to be welded with an ultra-high degree of accuracy. When friction welding compressor spools, a pressure of 1,000 metric tons is applied.

For MTU, friction welding is a key technology needed for the production of rotors for next-generation engines that are made from higher-strength materials and are markedly larger in size than conventional components. The technique lends itself to the manufacture of more compact, highly integrated compressor rotors made from titanium and nickel-base materials whose reduced weight helps cut down on fuel consumption.

The reduction of fuel consumption will be a key success criterion for next-generation aero engines. Engines will have to use less fuel, be cleaner and quieter. MTU is pressing ahead with the development of the technologies needed. Jointly with its partners — the world's biggest players in the engine industry — the company is pursuing innovative engine concepts. The German engine manufacturer is convinced that the geared turbofan, which it is developing and building in partnership with Pratt & Whitney, will be the propulsion system of the future. An expert in high-tech manufacturing processes, MTU contributes a key component to the geared turbofan: the high-speed low-pressure turbine. MTU is the only manufacturer in the world to build this high-speed component. ■

MTU Aero Engines is a long-established player in the engine community. The company operates affiliates around the globe and has a total workforce of about 7,600 employees. In fiscal 2009, MTU posted consolidated sales of approximately €2.6bn. The engine specialist excels in low-pressure turbines and high-pressure compressors, as well as manufacturing and repair techniques. In the military arena, MTU is Germany's industrial lead company for practically all engines flown by the country's armed forces; in the commercial area, MTU Maintenance is the world's largest independent provider of engine maintenance services.

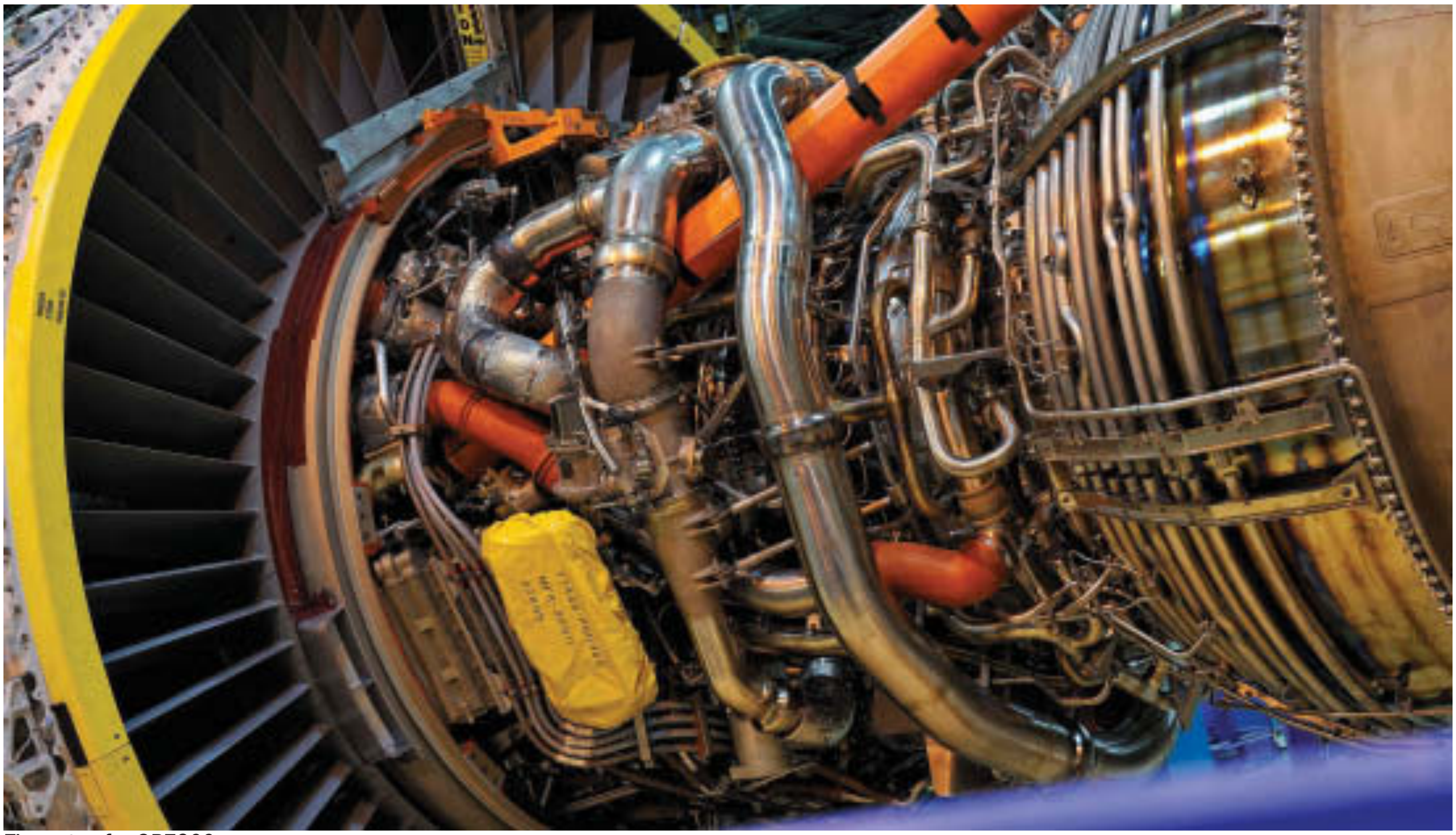
Paris — future global capital for very big engine overhauls

The Paris engine repair facilities overhaul (PERFO) project was launched in 2007 to provide *Air France Industries KLM Engineering & Maintenance* (AFI KLM E&M) with a comprehensive MRO capability for the very big engines (VBE) powering the fleets of its parent airlines and third-party clients. The group promises that not only will it see MRO capacity virtually trebled, but it will also be able to offer the market's shortest turnaround time (TAT). The three-stage programme will equip AFI KLM E&M Paris facilities with new engineering resources, enabling it to keep pace with the increase in GE90 and GE115 heavy maintenance operations due to those engines' increasing maturity worldwide.

As the launch airline for the different types of GE90 engine brought to market, Air France has, over time, acquired one of the world's biggest fleet of VBEs, and currently operates 18 per cent of the global fleet. The size of its 777 fleet and the widespread adoption of this long-haul aircraft by other airlines, prompted AFI KLM E&M to develop MRO capabilities for this outsize engine very early on. "We positioned ourselves an alternative to the services provided by the manufacturer, General Electric (GE)," says Anne Brachet, SVP engine services. "About 10 airlines or lessors customers thus benefit from our expertise and experience. That's because we are the only operator able to integrate the unique requirements of airlines into our service offering."

New industrial resources to meet market demands

Despite the tough economic environment, AFI KLM E&M has committed to the long term by confirming its large-scale investment plans for its ongoing PERFO engineering programme. The MRO wants to increase its capacity for GE90-94, GE90-115 and GP7200 engines, in order to stay ahead of the curve with the looming increase in maintenance operations on these types. "The market shows that the ageing of the global GE90 fleet will in the next few



The guts of a GP7200.

years lead to a sharp increase in the number of shop visits," notes Brachet. "But our industrial programme is also designed to help us keep pace with the constant development of the GP7200 engine." As more and more A380s go into service, the number of these engines in circulation looks set to grow substantially on the world market. The PERFO programme will allow AFI KLM E&M to boost its GE90 overhaul capacity from 40 engines a year to 110, while maintaining its capacity to handle CFM56s in Paris at 180 engines a year. "It took us two years of research to develop the framework for the programme," explains Brachet. "Our clients have strong expectations when it comes to cutting engine downtime. AFI KLM E&M is accordingly implementing an efficient system whose foundations are rooted in optimised, new and sophisticated processes. What we are aiming for is even better control over TAT. And while the programme was originally designed to meet large-scale demand in the VBE sphere, we have nevertheless built in all the aspects relative to handling the CFM56 family. The innovations rolled out for VBEs will also benefit this engine type, which is still one of our flagship products. Our clients can also rest assured that we are deploying our new programme without any disruption to ongoing activities whatsoever. Our operational activities have been fully preserved throughout the duration of the construction work."

Constellation for star products

The new Constellation facility, located on the AFI KLM E&M maintenance base south of Paris, is central to the PERFO project. The 11,000m^2 building is exclusively dedicated to the disassembly and reassembly of the engines repaired in Paris: GE90 series, CFM56 family and in the near future, GP7200 engines. Inaugurated last summer, it was designed to meet high quality environmental (HQE) standards [the standard for 'green' building in France]. In addition to these environmental considerations, the aim is to provide a suitable, comfortable work environment for the mechanics. The ultra-modern facility also has many environmental and ergonomic qualities, including recovery of rainwater for re-use in all activities not connected with human consumption; a decrease in noise pollution; improved visual comfort; and increased insulation to avoid heat loss in winter and heat gain in summer. "With respect to engine overhauls," explains Brachet, "a new study of disassembly and reassembly sequences has led to the development of new processes. The Constellation building has two production lines- one for VBE and the other for CFM engines. For our engine disassembly operations, we have chosen a system of gantries and bridge cranes. This approach means we can optimise the time spent on each operation and improve working conditions for our mechanics." Thanks to the lifting systems, all parts of the engine are at human height and therefore more easily accessed.

"As the launch airline for the different types of GE90 engine brought to market, Air France has, over time, acquired one of the world's biggest fleet of very big engines, and currently operates 18 per cent of the global fleet.

The MRO has also paid special attention to engine reassembly processes. This sequence is broken down into several distinct stages during which the engine itself is now moved. At each stage the requisite parts and tooling for the job are deployed. Brachet maintains that this new approach to VBE reassembly is an AFI KLM E&M world exclusive. Last, but by no means least, the building is immediately adjacent to the core engine and low-pressure modules maintenance facilities. The improvements and innovations give AFI KLM E&M a threefold advantage, namely an increase in VBE handling capacity, the continued availability of CFM56 capacity, and a significant reduction in TAT.

Engine shop makeover

The second phase of the PERFO programme involves the renovation of the existing AFI KLM E&M engine shop at Orly, which will be dedicated to module repairs. This is designed to support the growth of VBE-related activities by increasing core engine handling capacity and developing new low-pressure turbine and compressor repair capability. “This new direction closely fits the maturity cycle of GE90 engines,” says Brachet. “During the first years of their life, VBEs don’t usually require any heavy maintenance on low-pressure modules. But the increased age of the worldwide GE90 engine fleet now makes this industrial development perfectly in line with the next needs of the market.”

The refurbished building will be ready in spring 2011 after 10 months’ work. Once again, AFI KLM E&M programmed the work to ensure that normal operations were not disrupted. Engine overhaul operations will be continue during the refurbishment. To achieve this, AFI KLM E&M used the findings of a series of studies which took place over a year. These suggested an original solution, which is a bit like a sliding-tile puzzle. “The delivery of the Constellation building last summer and the transfer to it of the related activities, freed up a considerable amount of space (about a third of the surface area) in the engine shop,” says Brachet. “This now-empty part of the building is thus currently being refurbished. Once that has been finished, it will house the low-pressure turbine and compressor production lines, thereby freeing up a new space, and so on.” The last tranche of work will be carried out in a succession of smaller moves. The refurbishment programme will allow the MRO to reorganise work areas, as it did for Constellation, so that it can optimise the mechanics’ different tasks. It will also deliver an improvement in the supply chain, notably through the creation of an air lock, the single point of entry and exit for parts. In addition to boosting handling capacity, this will also shorten TAT.

What does the future hold?

To meet future engine overhaul requirements, AFI KLM E&M is to go even further, as the final phase of the PERFO programme involves the creation of a new test bench for all VBEs, the latest generations of which are already being developed by the manufacturers. “This final phase,” declares Brachet,” which should reach completion in June 2012, will enable us to concentrate the entire GE90 overhaul chain around Paris… and shorten TAT even more.”

A technician gets to grips with a CFM56 engine.

The entire PERFO programme represents an investment of close to €80m. In this difficult period for the airline community, and despite a downbeat global economic climate, AFI KLM E&M is planning for the future needs of its customers and thus committing to supporting them. This extensive programme seeks to achieve a single objective, which is to continue satisfying them at all times. AFI KLM E&M believes it has what it takes to meet their current and future needs.

On-wing and on-site repairs — Lufthansa Technik's flying doctor service

Sometimes even small defects can cause large engine overhaul events, resulting in high costs and unscheduled downtimes. To avoid such high-cost events and the need for spare engines, *Lufthansa Technik* (LHT) pioneered the idea to provide certain repair and modification products on-site or even on-wing. From foreign object damage and premature wear of life-limited parts, to compliance with airworthiness directions of aviation authorities, the company's Airline Support Teams (AST) can resolve many problems directly at the customer's base. The teams can not only quickly repair an engine to airworthy status, but also extend an engine's on-wing time to reduce the cost per flight hour. The impact on an airline's operation is minor, since AST can resolve many issues without changing the affected engine.

"Since they mostly work at high speed directly in line with an airline's operation, the airline support teams often feel like they are playing in an imaginary sports stadium," says Dr. Horst Zoeller, director mainbase Frankfurt and AST engine services. "And whatever they do, nothing escapes the customers' eyes," adds Harry Haber, AST senior engineer. "But if they see their engine finally returning to service after only a few days, saving roughly $2m for an overhaul, the work of our AST leaves them with an impression that is absolutely priceless."

Saving engines from premature shop visits was not the only focus when Haber and his colleagues first started thinking about on-wing and on-site services as a reasonable complement to the overhaul shop portfolio in 1989. "Besides a reduction in operating costs we simply wanted to bring our technical expertise directly to the customer," he explains. Having fulfilled the plan with the introduction of the initial AST services portfolio in 1996, Haber sees no competition between the shop crews and the colleagues working in the field through AST services. "Both products have the same aim," he says, "maintaining and improving flight safety at competitive operational costs." Although flight safety is and will be the most important goal of LHT's AST, during nearly 15 years of on-wing and on-site services their capabilities have extended far beyond what technicians initially thought possible.

Four different service categories

"In general we are talking about four different categories of AST services", says Haber, "but we also see the boundaries between the respective fields often overlapping." The first category comprises mostly troubleshooting services. Collisions with foreign objects such as birds or small runway debris often ground aircraft due to damaged engine blades. The AST can quickly be at hand to carry out comprehensive borescopic inspections. Critical parts can hence be assessed and, in some cases, even repaired to a certain extent with special tools. Many inspections and repair services can be carried out overnight, enabling the aircraft to return to service the next day. If the borescopic inspection detects no detraction to the engine's safety and performance, the customer can quickly be assured that his asset is safe. If the inspection brings up a risk to the engine's airworthiness, Lufthansa Technik's experts can use their decade-long experience to advise the airline on what to do. "In 99 per cent of all AST troubleshooting services, a rectification can be provided in a way that saves the customer from a costly shop visit and the associated high costs and long downtimes," comments Haber.

The second group of Lufthansa Technik's AST services comprises a large variety of performance optimisations. "All newer generation engines have a built-in design life of around 40,000 flight hours," explains Haber. "But on its journey towards this mark there will always be parts that fail or deteriorate and hence reduce the engine's potential to reach its designed life. Our focus is on getting the engine as close to its design life as possible — to a point where it simply makes no sense to continue." Airline support teams can carry out numerous procedures to help an engine achieve this goal. Optimisations of an engine's life time often run in parallel with improving an engine's fuel consumption. In times where high fuel prices are combined with public pressure to reduce carbon dioxide emissions, LHT's AST

Lufthansa Technik's AeroTracer acts as an "artificial nose" that is capable of detecting and identifying different traces or pollutants in cabin air.

Cyclean engine wash reduces the inner friction of an engine — lowering fuel burn as well as carbon dioxide emissions.

offer several services to improve the airflow and the inner friction within an engine's duct leading to measurable reductions in fuel burn.

One product fulfilling this aim is the on-site replacement of worn high-pressure turbine blades. Being exposed to air contaminated with fine particles, these critical parts often show premature signs of erosion on their trailing edges or a blockage of cooling holes, both leading to sub-optimal airflow, overheating and hence a higher fuel burn. AST can replace a full set or single blades of the CFM56-5 or -7B engines on the customer's site. Due to the fact that no disassembly of the high-pressure turbine module is necessary, the entire procedure requires a turnaround time of only four days. It saves the customer an expensive and time-consuming shop visit. Furthermore the customer regains an engine operating with maximum efficiency.

Another way to improve an engine's performance is Cyclean engine wash, which is also offered world-wide through Lufthansa Technik. Operating with clean water and without chemicals, this high-pressure washing system is mounted to the fan spinner and removes any accumulations of dirt from an engine's duct. The friction reduction achieved hereby optimises the air flow and reduces fuel burn as well as carbon dioxide emissions. This kind of on-wing service has proven very successful with airlines operating in regions of the world where engines are permanently exposed to erosion caused by particles in the air. An engine regularly relieved from accumulations of these particles with Cyclean can be saved from a premature shop visit that is due when the EGT margin gets too low. A single engine wash can already improve an engine's EGT margin by up to 15 degrees Celsius (60 degrees Fahrenheit), with regular applications indicating even higher improvements. The main advantage of Cyclean is the ability to wash in normal short downtimes, thus making it easy to wash within optimal intervals without disturbing the operation.

Airworthiness directives, service bulletins and an artificial nose

The third group of AST tasks encompasses the implementation of numerous airworthiness directives and the service bulletins of aviation authorities as well as aircraft or engine manufacturers. During an engine's on-wing-time, numerous change requests can occur for a variety of reasons. In some cases, these directions have to be implemented within a very short time frame. If this is the case, aircraft operators are forced to act quickly, but retrofitting non-compliant engines in the shop is a time-consuming and expensive issue. LHT's AST can carry out a large number of demanded modifications at the customer's site or even while the engine is still mounted to the aircraft, thus ensuring that the customer is compliant with even the most recent regulations.

If the reason for an engine's malfunction is not yet known, the fourth group of AST services comes into play: diagnostics. Oil smell in the cabin, abnormal readings of engine parameters, vibrations and many other phenomena often leave aircraft operators with an unsure feeling and the fear of an in-flight shutdown of an engine. In these cases AST can quickly help to interpret early warnings and provide the customer with a comprehensive report on an engine's condition. For example, oil smells can quickly be tackled by LHT's AeroTracer services. In this case, specially trained AST mechanics examine the cabin air with a handheld detection device. This "artificial nose" is capable of detecting and identifying different traces or pollutants in cabin air. Focused on materials or oil types, this tool can trace residues in the cabin air back to specific oil types used in the engine thus identifying the region to search for faults.

A faulty seal is often responsible and replacing it normally requires a premature shop visit of the entire engine. As an alternative, AST can provide a replacement method for engines on-site. With the engine removed in advance, the teams carry out the seal replacement in only four days, leaving the customer with a safe engine and large cost-savings.

Expertise far beyond the engine itself

However, sometimes it is a long and winding road to achieve such customer satisfaction because assigning an AST in many cases requires much more than just comprehensive engine expertise. As Haber points out: "One of our most interesting AST services took place in southern America. An airline contacted us because they found production errors in the

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> **—Harry Haber, AST senior engineer**

Airline Support Teams can replace a full set or single blades of the CFM56-5 or -7B engines directly at the customer's site.

Oil smells can quickly be tackled by LHT's AeroTracer services. Specially trained mechanics examine the cabin air with a handheld detection device. This "artificial nose" is capable of detecting and identifying different traces or pollutants in cabin air, tracing residues in the cabin air back to specific oil types used in the engine, thus identifying the region to search for faults.

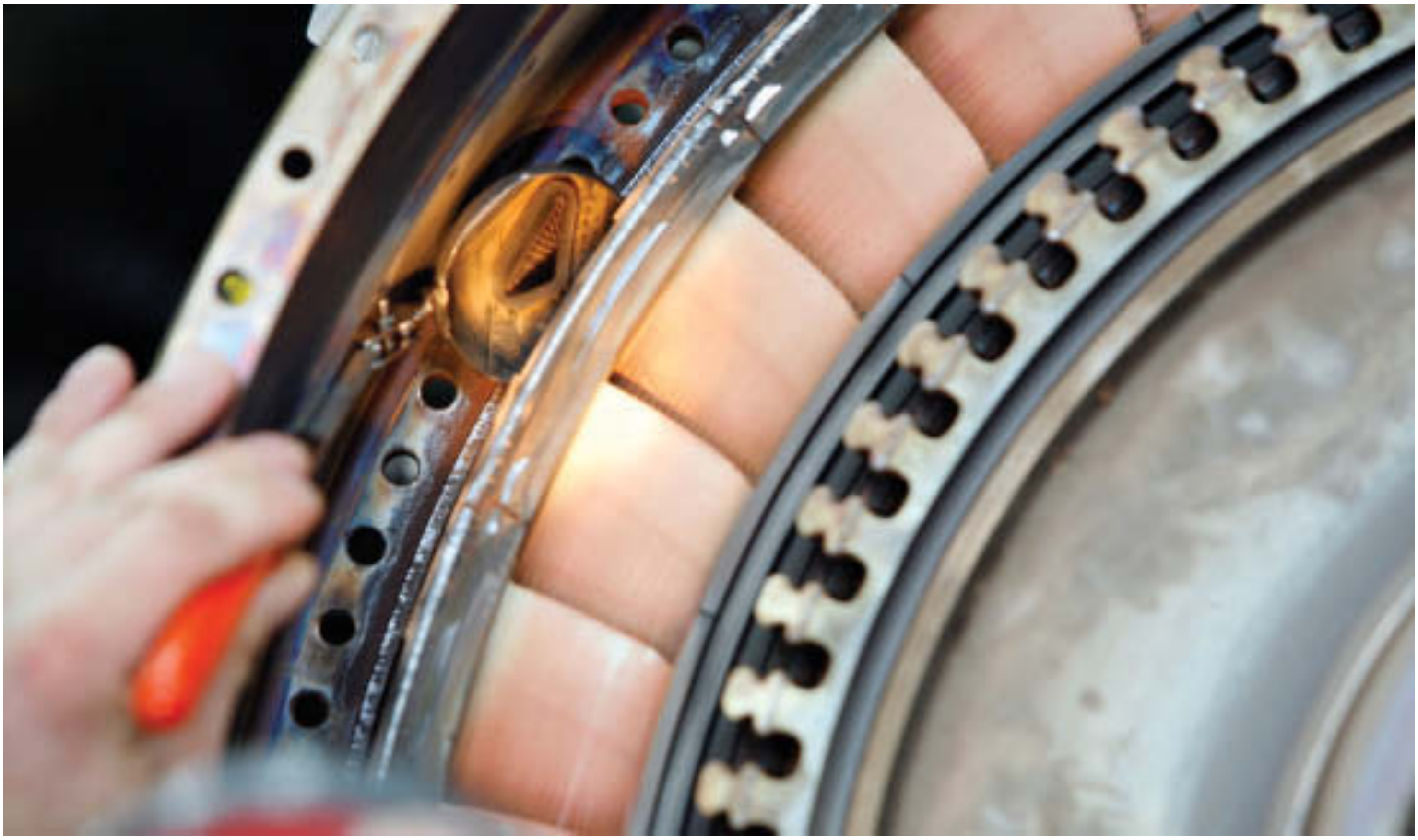
combustion chambers of no less than five engines." Under normal conditions, such findings would force all the engines to the overhaul shop immediately, leaving the airline exposed to long unscheduled downtimes alongside with high costs.

The airline support teams quickly worked out a solution to replace the faulty combustion chambers on the customer's premises and modified five engines in five weeks, saving the customer from an unscheduled withdrawal of several engines from service. "Spare combustion chambers can be easily procured and a team to carry out the services in southern America was quickly selected. But at that point the tricky part of AST services often begins, leaving us with a lot of questions ranging far beyond the engine expertise itself" says Haber. "Is all the necessary tooling available at the customer's site? Does the equipment brought in by the AST have an adequate power supply and the correct power plugs? Does the tooling work under the different environmental conditions? Do we work in conformity with regional airworthiness regulations and local employment laws? Do our employees need an extra passport or visa to enter the country, or even special vaccinations?" He adds that experience helped LHT to answer all these questions quickly so it could get teams to the customer as soon as possible. Sometimes team members do not know where they will spend their next night, or even on which continent, and so far LHT has covered all of them, excluding only Antarctica.

The exploration of different continents and cultures is not the only factor driving the high motivation to work in an airline support team. Most employees like to work in the small, flexible teams coping with the unexpected. "It's one team pulling together where one can rely on the expertise of each carefully selected member. And everyone is directly interacting with the customer," says Zoeller. "The technical expertise of our team members is further complemented by the fun and the experience of working with different cultures and people. Working in an AST really shapes the character."

Knowledge tailored to the specifics of the on-site business

The selection of the teams follows some basic principles in order to achieve the best qualifications. Thus, the AST are mixed for every new assignment, tailored to the specific tasks or products. Moreover, the quality mixture is not only emphasised in terms of age or experience, but if possible also in terms of nationality. Hence, technicians in AST are assigned from nearly all facilities throughout the worldwide engine services network of Lufthansa Technik. If an aircraft is grounded in Asia, for example, both colleagues from Frankfurt and



LHT`s Australian subsidiary LTQ Engineering are assigned to get it quickly back into the air. As Haber explains: "The mixture increases the understanding of other colleagues' solutions and helps all team members to learn from each other. Besides the collective feeling this is another factor that drives motivation of our AST members."

The exact number of employees performing AST services from the six locations Frankfurt, Tulsa, Buenos Aires, Hong Kong, Johannesburg and Melbourne is hard to tell because of the consequent selection according to qualifications and the hence regular fluctuations in the formation of the teams. "To this date, around 50 full time-equivalents of LHT's engine division are assigned to AST services, performing around 500 AST services per year," reports Zoeller. He claims the number has expanded in recent years and expects the number to grow in the future. "We still see a large potential," says Zoeller, "hence we are working to constantly expand the portfolio of AST services, tailored to the markets and customer demand." The product development carried out by special core competence teams in cooperation with the engineers hence focuses on new products as well as on the application of existing products on a steadily increasing number of engine types. "On average the developers come up with two new products every year," adds Haber.

The AeroTracer.

With the further expansion of its already large portfolio of on-site and on-wing services Zoeller sees LHT well on its way towards its initial goal of bringing comprehensive engine expertise directly to the customer. "Despite the incredibly high pressure, the close cooperation and contact between our enthusiastic teams and the customers during AST assignments in the end often leaves both parties with a lot of fantastic memories and a long-lasting relationship," says Zoeller. "But the most important thing is that the customer's aircraft can quickly take to the skies again." After four days of pulling together, the "imaginary stadium" at the customer's site, only winners leave the playing field.

Organisational changes are crucial to shorter TATs — but major challenges lie ahead

The financial crisis and subsequent industry downturn have dramatically increased the pressure on airlines to reduce operating costs. They are constantly looking for more flexibility and transparency, and demanding more innovative solutions from their MRO providers. In response, *SR Technics* has engaged in a major organisational restructuring that has significantly improved engine maintenance and parts repair turnaround times (TATs) to both contract and single-event customers. While excellent progress has been made, it is crucial to be aware of the MRO challenges that lie ahead.

Customer surveys have consistently confirmed the importance of reduced turnaround times (TATs) and lower costs. Having comprehensively restructured its operations, shop layout, and all related processes, SR Technics is now able to offer aircraft operators an industry-leading 45 calendar day (CD) TAT for engine maintenance, thereby improving engine availability and reducing engine lease periods and the number of spare engines required.

How was the new TAT achieved? The groundwork was laid by a major company restructuring that began in 2009, during which commercial, operational and engineering functions were centralised to realise improvements through synergies across all business units (aircraft, components and engines). Applying best practices in all business areas and downsizing management structures were responsible for considerably improved performance and decision-making speeds. Furthermore, focusing on core operational functions and optimising interfaces to the new supporting organisations resulted in output boosts in the maintenance shops. Additional factors that also helped improve overall performance include internal contracting, the elimination of non-value added work, together with setting new and ambitious targets.

Lean sigma — key to reorganisation

An essential factor in the restructuring was the introduction of a lean sigma programme, which quickly involved staff in workshops where they analysed and restructured their own working environments. Changes and solutions were then implemented promptly, with all financial improvements calculated and verified after implementation.

In the experience of SR Technics, to be successful lean sigma must include:

- Training of all employees.
- Expert availability for the chosen toolboxes (DMAIC, RCA root cause analysis, PARETO analysis, VSM value stream mapping, etc.).
- Full employee involvement and idea management tools.
- Company-wide standardised visualisation.
- Capital for investment (new machines and equipment, refurbishing and painting, etc.).
- Resources to adjust IT tools and data structures.

Coupled with the structured lean programme, communication with the workforce has been vital to providing a clear understanding of why changes are needed and why continuous improvement focused on customers is essential for success.

Achieving a 45 CD TAT for engine maintenance

In 2009, the engine maintenance group initiated a project with the target of defining and implementing processes and workflows to achieve a 45 CD TAT. Having started with a detailed analysis of the entire maintenance process, team members from all business areas met to develop and implement the action required. Communication through an intranet platform ensured that all employees were informed about the project goals and could track the progress of their individual tasks at all times. Within a two-week period, over 200 ideas had been suggested by employees on how to improve processes, reduce TAT, and save costs. The goal was to make improvements by reducing complexity in the workflow and eliminating non-value added work.

Work stages

The maintenance process starts with the contract, which defines the TAT (start and end), material exchange procedure (new or repaired material), workscope (performance restoration, repair, overhaul, ADs, SBs, DOA/DER usage, LLPs), pricing, on-wing time, EGT margin and warranty, etc. Reasons for excusable delays are defined as clearly as possible and minimised.

As soon as the documentation is finalised and the workscope defined, the shops start

Technicians perform a vane inspection.

work. The disassembly and assembly of the engine is driven by the TAKT parameter. Visualisation boards (waterfall charts) show the status of the engine and the tear down to modules, as well as the assembly. SR Technics now operates three engine lines: PW4000 (94" and 100"), CFM56-5B/7B and CFM56-5C. Staff cross-training provides maximum flexibility to cover variations in workload on the different engine lines.

Improvements deliver shorter TATs

Improvements were achieved in the kitting area by using standardised kitting carts that include material as well as consumables and expendables. Major changes were also made to the shop layout to minimise travel distances and avoid unnecessary movements, since optimising the transport system and delivery stations supports parts-tracking and TAT control. The existing interactions between routine (engine) and non-routine (part repair) work were also streamlined during process optimisation. Routine work is now limited to disassembly and assembly work. All parts which need repair are now assigned to internal or external rework within a very short time. Inspection for internal rework is now done in part repair as the first step in the repair cell. Wherever possible, a 'ship dirty' process is applied in order to avoid duplication of cleaning and inspection processes and to save TAT.

Part repairs with 21 CD TATs

The 45 CD TAT for engines has resulted in a 21 CD TAT requirement for in-house and external part repairs. SR Technics has strong in-house repair capabilities (82 to 89 per cent of all manual repairs) on all maintained engine types, and uses two main locations for engine part repair: Zurich and Cork.

SR Technics Airfoil Services Ltd (SRTAS) is the turbine engine hot section component repair company within the SR Technics Group. Acquired in May 2006, the company is based in Cork, Ireland, and has 25 years' experience of providing engine component repair solutions for airlines and engine shops. SRTAS' repair capabilities cover all CFM-56 variants, Pratt & Whitney and Rolls-Royce large commercial engines. Covering a host of OEM-approved repairs, the facility consistently produces higher than industry norm repair yields, which represents a significant benefit for SR Technics' worldwide customer base.

The remainder of SR Technics' in-house repair capabilities are centralised in Zurich. To achieve the targeted engine 45 CD TAT, any externally repaired parts must leave Zurich without delay. All LPT parts sent to the Cork facility are shipped dirty and go directly from disassembly to shipping. This alone has resulted in an average TAT improvement of two to four calendar days.

Lean in Zurich

In the past, SR Technics' part repair organisation used a 'home shop' structure. The setup has now been changed from a functional structure (milling/welding/plating area) to a part-oriented structure (blades and vanes, etc.). Parts responsibility was previously with the home shops, but parts were still travelling around the shop, which resulted in unnecessary handovers and travel distances. Although responsibility for costs and TAT was then given to home shops for their part group, it became clear that a non-optimised layout was preventing major improvements.

Centres of excellence

In response, a new centre of excellence (CoE) structure was introduced. The CoE holds full responsibility for repair costs, TAT, and the quality of the repaired products. Further improvements have been made by introducing dedicated shop layouts allowing a part to be processed within the cell as far as possible.

A CoE consists of several cells characterised by:

- U-shaped cell structure with counter-clockwise workflow and pull system.
- Maximum transparency across the whole repair process.
- Minimised floor space.
- Maximised in-cell production.
- Dedicated transport station.

An engineer inspects a fan module.

- Service level agreement with centralised service centres (cleaning, NDT, plating, water jet).
- Visual boards showing work in progress and performance indicators (TAT and OTD [on time delivery]).

The evaluation and optimisation of the entire maintenance process resulted in numerous changes. Major improvements were made in terms of process responsibility, organisational (affiliation) assignment, workflow and resource utilisation. With the new setup fully aligned with the new process requirements, no compromises were made to fit previous organisational structures.

The human factor in the changes cannot be overestimated. According to Roberto Furlan, VP part repair, "transparency in the shop and performance visualisation is the key to world-class performance. People like to take responsibility and they want to see their performance. Non-performance is a stimulus to identifying the root cause and to improving. Data integrity and traceability are essential to success."

Visual control of process flows

In part repair, the new cell layout allows visual control of process flows. Bottlenecks become visible very fast and can be fixed easily. Not all processes can be handled within the cell, however, and some must take place in service centres. Typical processes in centralised service centres are cleaning/NDT (FPI [fluorescent penetrant inspection] and x-ray), plating and thermal coating (plasma/HVOF). Single machines with high capital costs like water jet strippers, laser/EB welders, vacuum furnaces and horizontal lathes serve many different cells. Local cleaning and FPI, as well as dedicated plasma equipment and vacuum furnaces, are installed wherever possible.

SR Technics has taken the opportunity to analyse the flow of products in the new setup. As an example, it took just three weeks to reduce the TAT of an LPT case repair from over 59 CD to 35 CD. About 40 per cent of the working steps were saved by optimising the shop router, thus reducing the number of handovers by 59 per cent. Travel distance was reduced by another 73 per cent. Further capital investment into the LPT case cell will lead to the required TAT of 21 CD in the near future.

Airfoil excellence: lean in Cork

Over the past three years, SR Technics has also used a comprehensive lean programme to improve performance at its Cork plant. Employees equipped with the standard lean methodology have successfully tackled issues that affect plant performance across all functions. As a result, Cork is now the SNECMA CoE for the repair of CFM LPT blades, a significant recognition of performance by a leading OEM.

As well as achieving internally focused improvements, the company is continually working to develop relationships with its customers through new repair developments: OEM, DER and DOA, and participating in international projects on new repair processes through the Marie Curie EU programme. Added to these activities, improved operational logistics such as the ship dirty programme and rotable material support programmes give customers a comprehensive airfoil repair service that meets, and often exceeds, their operational requirements.

Major changes ahead for the MRO business

As the industry changes in response to the economic environment, airlines are increasingly focusing on their core business: operating aircraft. Although most major airlines still have their own technical divisions for aircraft, component and engine maintenance, a major change has taken place with the conversion of airline technical support shops to competitive service providers. SR Technics was a pioneer in this process in 1997, when the technical division of Swissair was established as a separate subsidiary within the SAirGroup.

To keep costs under control, airlines require competitive market prices and TATs from their own maintenance shops. As a result, they have started to compete with OEMs, and have developed repairs where no OEM repairs are available. This has led to the situation today where there is strong competition between OEM-

owned, airline-owned and independent MRO shops.

Third-party repair business — a challenge to get right

Many airline MRO shops are now forced to accept third-party repair business in order to cover cyclical shop loads and fixed costs. Higher utilisation of resources and innovative parts repair development can make an important contribution to profitability. However, such shops are often poorly prepared to take third-party repairs, leading to difficulties in handling parts and unsatisfied customers. The critical issues are:

- Goods receiving: this needs careful management.
- Inspection: individual customer requirements instead of routine workscoping.
- TAT tracking: particularly important for parts for the engine build-up plan.
- "No exchange": parts are made serviceable or scrapped.
- Customer communication: this is very different for third-party business.
- Packing and shipping: a highly time-critical aspect.
- Invoicing: the process may be totally different from an engine invoicing process.
- Pricing: it is an advantage to have fixed prices.

To successfully drive third-party business, shop layout is critical. If the repair shop is not constantly performing in all areas, the biggest challenge is to get priority for third-party parts. Third-party business also requires a different setup in commercial organisations compared to those in the engine part repair business. Quick responses on RFQs (requests for quotations), intensive communication with the external customer, and flexibility in fulfilling customer requirements are mandatory.

Competition is strong in third-party business as customers can select between many different providers. Independent repair specialists have the advantage of being fully focused on third-party business requirements. On the other hand, they lack system know-how (parts interaction) and performance feedback on the repaired parts. It takes close collaboration between the repair shop, engine engineering and operator, as well as with the OEM, to guarantee the best solutions for the customer.

Flight hour agreements benefit OEMs

Looking into the future, the next engine generation looks likely to be more closely linked with the OEM than in the past. Airlines are increasingly seeking flight-hour agreements on their leased engines, but to maintain the value of their assets, leasing companies often forbid the use of non-OEM solutions (PMA material and DOA/DER repairs). By offering flight-hour agreements, OEMs are thus trying to keep the maintenance business in their own shops, and offering operators predictable operating costs.

New technologies in next generation engines will impact repairs

Major technical changes to engine design and manufacturing are being driven by ever more demanding requirements to lower emissions, fuel consumption and noise levels. To achieve these goals, OEMs are following a variety of approaches. One OEM, for example, is focusing on a new geared turbofan concept, whereas other OEMs are optimising their current two- or three-shaft turbofan engines. In all cases, new materials and designs will help achieve the targets. Customers will appreciate the cost savings, but should be concerned about life cycle costs.

The on-wing time delivered by modern engines has been increasing over the past decades, and first engine removal can be driven by LLP exchange requirements. Ideally the new materials and technologies should result in reduced maintenance costs. However, due to the increasing number of proprietary and protected technologies, the market is becoming controlled by fewer providers. It is understandable that development costs need to be covered by aftermarket business, but this should be within reason. For independent maintenance shops, access to these new technologies will become crucial to survival.

A check on a core module.

> *Due to the increasing number of proprietary and protected technologies, the market is becoming controlled by fewer providers. It is understandable that development costs need to be covered by aftermarket business, but this should be within reason. For independent maintenance shops, access to these new technologies will become crucial to survival.*

Repair concepts will change in line with the new materials and technologies introduced in the next generation of engines. CFRP (carbon fibre reinforced plastics) or composite material usage will be extended in the low-pressure compressor section. Composite material will be used to manufacture fan blades, vanes and fan cases. Introducing blisks (blade integrated disks) in the LPC and HPC sections will enable weight and thus fuel savings. Ceramic matrix composites and titanium aluminides will better support the high temperatures in the turbine section. Complex 3D airfoil geometries, shaped laser drilled cooling holes, and next-generation thermal barrier coatings are also being introduced.

Although new designs and materials claim to be more damage tolerant against FOD or DOD, repairs will still be required. The testing and validation of new repairs has always been a cost driver in the past. Repairs will become even more expensive in future due to increasing large-scale integration. OEMs are marketing the reduced number of parts in an engine as a benefit. This may be correct in terms of the required logistical effort, but on the other hand, repairs on highly integrated parts will become much more complex and expensive.

What about (DOA/DER) repairs?

In the past, the growth of DOA/DER repairs and PMA usage was eagerly followed by non-OEMs in the industry. Discussions on the quality of DOA/DER repaired parts versus OEM repaired parts remain ongoing, and there are still countries where operators and local authorities are unfamiliar with or do not accept the legality and processes of DOA/DER repairs. However, since an engine OEM started to develop PMA parts for a competitor's engine, the discussions have shifted from a legal to a more technical level.

A great deal of know-how has been built up by non-OEM maintenance companies on existing engines, and has been used to approve minor repairs. Customers accepting DOA/DER repairs have benefited from these extended repair capabilities, which have prevented the exchange of material. However, the more complex the repair, the higher the validation and approval costs.

Ready for change

The MRO business faces major changes over the next decade. Financial pressures will further increase the need for cost savings by airlines, and MRO providers will be called on to help airlines reduce their operating costs and respond more flexibly to their needs. The next generation of engines will be linked more closely with OEMs since flight hour agreements and increasing numbers of leased engines, coupled with the refusal of engine lessors to accept DOA/DER or PMA solutions, will favour OEM business. The introduction of new technologies by OEMs will also provide challenges for MROs.

SR Technics is preparing for these challenges today. Strengthened by its membership of the Mubadala MRO network and using lean sigma processes, SR Technics will continue to offer innovative and cost-effective solutions. TAT times of 45 CD on CFM engines, and new sale and leaseback arrangements with our partner company Sanad Aero Solutions will help customers save money, while new technologies developed with OEMs will guarantee that SR Technics customers continue to receive outstanding service in future. ■

SR Technics is well-known in the industry for its high quality standards based on over 40 years of experience in engine MRO. With its extensive engineering expertise, SR Technics has developed solutions that can substantially enhance engine performance and thereby deliver longer time on-wing. A significant number of in-house repairs on high-cost engine parts have been developed over the years, several of which have been approved by OEMs and found their way into the corresponding engine manuals. SR Technics will continue to cooperate closely with OEMs, but will also use its DOA organisation to develop new repairs.

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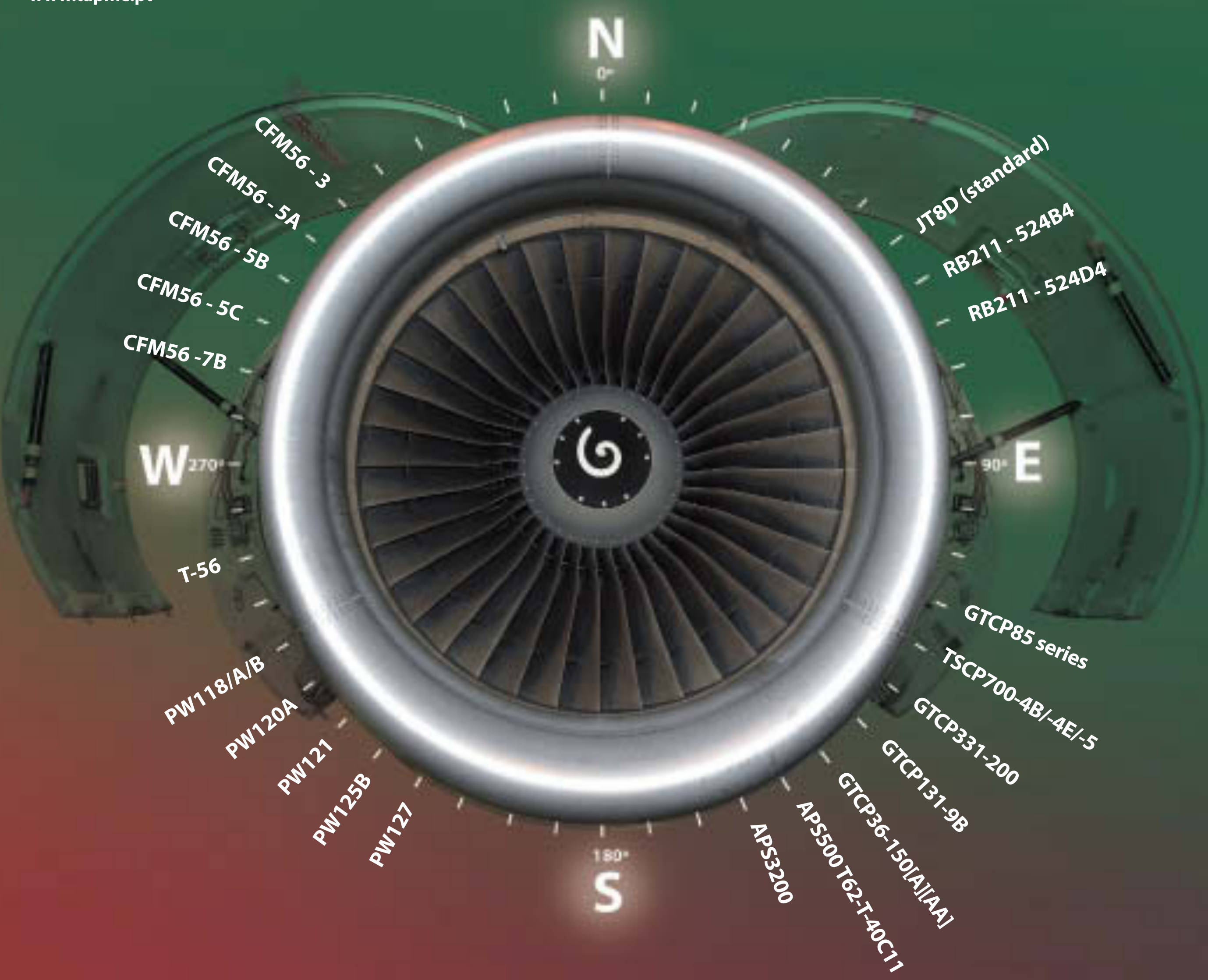


When the world aerospace community thinks of engine nacelles and thrust reversers, one name usually comes to mind — Goodrich Aerostructures. Formerly known as Rohr Aircraft Corporation, its main products are nacelles and mounting pylons for both commercial and military aircraft. *Kenneth Karl,* lead: integrated nacelle services, *Goodrich Aerostructures,* details the history of nacelle integration at the company.

Nacelle integration

A bit of history: Fred Rohr, who designed and developed the fuel tanks for Charles Lindbergh's Spirit of St. Louis, founded Rohr Aircraft Corporation on August 6, 1940. In the 1960s and '70s, Rohr Industries made a foray into mass transit equipment manufacturing. The company manufactured railcars for the Bay Area Rapid Transit (BART) in the San Francisco Bay area, and the first 300 subway cars for the Metro in Washington, D.C., among others. In 1970, it produced an experimental aérotrain design. Rohr divested itself of or discontinued these programmes by the late 1970s to focus on aerospace. Rohr Industries became Rohr, Inc. in 1992.

BFGoodrich was founded in the late 1800s and over its 140-year history was best known for its line of tyres. The company diversified, entering the aerospace business in the 1940s. In 1988, it sold its tyre brand to Michelin in order to focus on aerospace products. Rohr was acquired by the BFGoodrich company in 1997. In 2001, Goodrich divested its specialty chemicals business to focus even further on the aerospace industry. To signify the completion of its transformation into a defined aerospace supplier, BF Goodrich dropped the "BF" and became the Goodrich Corporation. Today, the company has 11 major business units, spanning aerospace capabilities such as landing gear, wheels and brakes, surveillance systems, lighting, interiors and evacuation systems, actuation systems, flight control systems and nacelles. Goodrich technology is onboard more than 90 per cent of the world's commercial aircraft and aims to continually build on that.

Since 1956, Goodrich has provided nacelle systems and products on over 50 commercial aircraft; 50 nacelles in 50 years. It has produced for Lockheed, Convair, McDonnell Douglas, Boeing, Airbus, and Embraer; and the product portfolio continues to expand. The company has a strong product presence on the 787 Dreamliner and A350XWB, along with its newest contract award — the Pratt & Whitney PW1000G geared turbofan (GTF), which will power regional jets built by Mitsubishi and Bombardier. Goodrich is also positioned to participate in the development and delivery of the nacelle system for the next-generation single-aisle aircraft.

Today, its main focus is integration; integrating its technology into the physical product, integrating overall design to deliver the needed platform airframe and engine performance, integrating systems to optimise the core aircraft systems, and focused support integration with direct airline customers.

Integration; development and design

Today, Goodrich's technology, research and design are focused on specific platform needs for the future. Technologically advanced materials, manufacturing processes, and composite systems are used and overall designs are focused on operating efficiency and performance of the engine and airframe. At a very high flight level, nacelles and thrust reversers serve two purposes: the first is directional control of the airflow into and out of the engine, and the second is acoustic attenuation of engine noise. These designs concentrate on drag reduction, machine efficiency, weight optimisation, and maximising acoustic performance. The structural and systems composition is then honed to deliver the performance needs, while balancing the drive for cost reduction and maintainability. The company maintains its major input into the design process is the element of

"lessons learned". It believes its wide product breadth and history have allowed it to amass a significant database of in-service product issues and opportunities.

The development process begins many years before aircraft programme launch. An example is Goodrich's involvement with Boeing on advanced acoustic design programmes such as the Quiet Technology Demonstrator 2 (QTD2). This programme began in 2005 as a joint effort with Boeing and its QTD2 partners—General Electric Aircraft Engines, Goodrich Corporation, NASA, and All Nippon Airways. The goals were simple: firstly to reduce interior cabin noise to enhance passenger comfort, and secondly to reduce external community noise to allow an aircraft to fly earlier in the morning and later at night. This programme resulted in technology embedded on the 787 and available for other future designs. Enhanced engine exhaust mixing, a single piece inlet cowl acoustic inner barrel, and heavy use of acoustic composites developed and used in this testing are all core features. Add to these technologies a laminar flow inlet design and optimised reverser actuation system, and the nacelle for the 787 is the most advanced ever designed and built by Goodrich.

Another example has been the company's efforts on the Pratt & Whitney GTF. Development work on this nacelle system and integration also began in 2005. The unique characteristics of this new engine technology required specific nacelle performance to complete the propulsion package. In one application, the nacelle will provide an advanced system to optimise engine performance during different ranges of the flight envelope. This engine and Goodrich's complementary nacelle will deliver performance currently not realised on a commercial regional aircraft, such as revolutionary improvements in fuel efficiency, exhaust emissions, and noise.

Integration, OE customer:

The production and physical delivery of these technologically advanced nacelles is another form of integration with the engine and airframe customer. For many years, Goodrich has embraced and engaged lean (a Toyota production system) throughout all areas of the business. The focus is to eliminate waste, resulting in efficiency in design, manufacturing, and parts and services delivery to the end user. During the development phase, the Goodrich lean product development system (GLPDS) is employed and includes the use of several lean techniques. Innovative technologies demand a thorough look at risks and the development of qualified counter-measures. Every aspect of the programme is rationalised to eliminate waste and deliver repetitive quality in the most efficient system possible.

One important element of this programme involves a process known as voice of the customer (VOC). Through a series of collaborative efforts, Goodrich strives to thoroughly understand each specific customer need, without assumption. Understanding product needs, optimising delivery to just-in-time and co-location are all significant elements of VOC, which is also a key component of GLPDS activity. For airline customer services, the company is one of the few suppliers in the industry to measure itself against actual customer delivery expectations (see below).

Integration, production:

Another example of integration is in production, where Goodrich has moved to customised systems delivery. For the 787, through many lean events, it was determined that the final integration of the nacelle system should be co-located with final assembly of the aircraft. Goodrich will do final integration of its nacelle at a specific facility dedicated to this activity near the Boeing final assembly plant location in Everett, Washington. Another example is with Airbus, where Goodrich has maintained manufacturing capability specific to the Airbus fleet in its Toulouse plant for over 30 years. To further optimise delivery, production processes have changed to that of a moving assembly line as a best fit to the aircraft production scheduling and pace. The A350XWB will benefit from these and other continuing improvements.

Integration, customer support:

On most of its programmes, the company is committed to providing a full suite of aftermarket services for nearly the entire lifetime of the flying fleet. Goodrich maintains that its culture

is driven by a theme of customer intimacy, whether it is delivery of technical support, spare parts or MRO services. All aspects of the aftermarket are focused around this theme, using the foundational concept of speed and ease. One specific example is spare parts delivery, where the company measures itself against customer request date. Every aspect of the supply chain is driven to this measure, including inventory management, external suppliers and production value streams.

Goodrich maintains the largest nacelle repair capability in the world and has an extensive global presence. In addition to the main facilities in Singapore; Foley, Ala. in the US; and Prestwick, Scotland, Goodrich has MRO capabilities in several other locations. Its Dubai campus in the United Arab Emirates, Toulouse, France MRO facility; Istanbul, Turkey facility (in-work), and newest location in São Carlos, Brazil were established specifically to support regional customer activity. MRO services are further facilitated through an array of rotable assets which can support both unscheduled demand and planned repair and overhaul on a global basis.

Design evolution

The original commercial aircraft nacelles were typically built of sheet metal; basically an aerodynamic fairing. Their relatively simple construction was mostly impervious to environmental damage and if damaged, easy to repair. There was not much consideration or planning involved with maintenance. As designs have improved and matured, the nacelle has transformed into a highly complex and integrated system, serving a much more critical role in acoustics, fuel burn, landing efficiency, aircraft safety, and even delivering structural strength to assist with engine weight reduction.

Over the years, airlines have typically found themselves striving to keep up with technology. Some have built vast infrastructures to support maintenance and overhaul, outsourced repairs, spare parts, troubleshooting and line maintenance. These support systems have and will continue to be challenged by the general growth in complexity and size of the nacelle, examples being the 777, 787, and A350XWB. Transportability and logistics issues involved with nacelle damage mitigation have been crucial elements of design and support services planning. Inlet design had to incorporate technology for transport packaging to fit into cargo aircraft and to accommodate many global over-the-road transport limitations. Robotic installation of fasteners is used in the 787 nacelle system to maintain ultra-tight tolerances, a crucial technology which allows the laminar flow inlet. Reparability needs to be addressed as traditional methods will not serve. Composite system repair involves the use of an autoclave of sufficient size to accommodate these products. Single-piece 360° acoustic inner barrels are designed to deliver the maximum acoustic area available in nacelle design, yet these technologies push the need for such autoclaves and complex support/bond tooling. Today's nacelle is not a simple sheet metal fairing.

Maintenance planning for cost control is important, for example, consider the thrust reverser. The industry drive in its design has been toward weight reduction, acoustics, and reverse thrust efficiency. From a systems point of view, all modern reversers are designed with redundant systems for operation, attachment mounting and latching. As such, Goodrich designs are reliable and extremely safe, which minimises their attention during maintenance planning development (MSG III and typical); they are all typically identified as "on-condition."

All reversers will require overhaul; the challenge is balance and optimised time-between-overhaul, continued on-wing reliability, and maintenance cost relative to the overhaul event. Time on-wing is a function of several variables, including thrust rating, reverser operational procedure, relative operating environment, thermal cycling (stage length), rigging, preventative maintenance levels, etc. Understanding the impact of these variables is challenging due to complexity. As an original equipment manufacturer, Goodrich has clearly found that reversers of a like configuration will behave and mature differently across the fleet.

Yet, maintenance (overhaul) cost escalates exponentially with time on-wing. If an operator does not take a proactive approach to reverser maintenance, an "on-condition" removal will lead to a considerable overhaul event at between six and 10 years, depending on variables. There needs to be balance in life cycle management.

Integration, life cycle management:

This has been a focus of Goodrich for the past 10 years. While it has instilled lean principles into business and aftermarket services, these services typically perform in a reactive nature, triggered by customer request. The challenge has been to push engagement to the next level, a level where the company can work proactively with airline customers.

Goodrich's concept of aftermarket integration comes in the form of its Prime Solutions products. It has developed proactive systems and methodologies of support to deliver uninterrupted service. Spare parts inventories can

be pre-positioned and maintained to tailored safety stock levels at multiple store locations. Spare major unit assets can be pre-positioned on a global basis to support incidental demand from damage; no longer will aircraft sit on the ground for days waiting for a replacement inlet cowl due to bird strike. Inherent in these products is a Goodrich-developed nacelle maintenance and overhaul programme that offers structure, repeatability, and cost efficiency to long-term customers.

Prime Solutions hinges on Goodrich embedding its intellectual property knowledge, involving detailed shop sampling to determine wear patterns and developing optimised on-wing maintenance and shop removal schedules. A key component is its assumption of the airline infrastructure to manage the nacelle using dedicated systems and on-site product managers to coordinate all activity. The net result can be a complete transfer of operational and cost risk from the airline to Goodrich; a virtual life of platform warranty. The customer base, including airlines such as British Airways and Airtran, says Prime Solutions provides considerable product reliability and maintenance cost reduction over traditional reactive maintenance approaches.

Goodrich Aerostructures has been a proud industry supplier and integrator of nacelle components and systems since the rise of global commercial aerospace. It is excited about the pending delivery of its latest systems and ready to support these new platforms for their lifetime. Tomorrow will bring the next-generation single-aisle aircraft and another wave of nacelle technological improvements. With each generation, the company pledges to continually hone its products and services in order to remain at the forefront of nacelle integration.

Keep them flying – the secrets of a successful MRO shop

The past 10 years have been extremely challenging for the aviation industry, and airline profitability has been closely tied to economic growth and trade, especially in today's emerging economies. As *Jim Harkenrider* of *Triumph Air Repair* (TAR) writes, how the commercial aviation industry arrived at its current state can be attributed to many factors, which go back much further than just the past decade.

During the early 1990s, the airline industry suffered from worldwide economic recession, concerns with the Gulf War, and the backlash of airlines over-ordering aircraft in the late 1980s, causing an excess of overhead costs to many carriers who struggled to stay solvent in the leaner years which were to follow. It was during these lean years that airlines started recognising the need for major changes in their operations to ensure their survival and profitability. Many made aggressive cost cuts to reduce capacity and increase their load factors. These actions helped start to return the industry as a whole to prosperity, but many airlines remain under-profitable compared to the success they once enjoyed in the 1980s.

Today, a number of factors remain which require airlines to become even more efficient in their operations. The European Union (EU) has ruled that governments in Europe should not be allowed to subsidise their unprofitable airlines. Elsewhere around the world, where some governments run the major airlines operating in their countries, those governments are becoming more and more concerned with their own finances, and some have begun to recognise the benefits of airline privatisation. This has led to a gradual transfer of ownership of airlines from the state to the private sector.In order to appeal to prospective shareholders, these airlines have had to streamline their operations and become more competitive.

Airlines today are offering conveniences such as ticketless travel, bar coded boarding passes, touch screen entertainment systems and more comfortable seating to attract new customers and retain their existing customer base. Many airlines have entered into alliances, offering customers extended benefits for using their services. On the other hand, to increase cost savings, it is becoming more common for airlines to charge customers for items such as carry-on baggage, drinks and meals.

In 2010, airline markets in general started recovering, with growth concentrated in Asia, Latin America and the Middle East. In Europe and North America the growth has been slower, putting even more pressure on those airlines to

TAR works with customers to determine what parts are negatively impacting reliability of the APU and affecting operating costs.

find ways to keep costs down. Fuel prices have remained the wildcard as far as planning for future costs. As airline demand, capacity and load factors have risen steadily, so have fuel prices. Airlines have responded to this challenge by operating more fuel-efficient aircraft when possible, and by reducing non-fuel related costs wherever they can.

Provide exceptional value

As airlines have been weighing their options and developing various strategies for increased profitability, some have found that partnering with a maintenance, repair and overhaul (MRO) shop for the repair and upkeep of specific product lines can provide exceptional value. An MRO may have specific experience and capabilities that fill a gap in an airline customer's own capabilities. Additionally, because of work-in-process volumes and specific technical expertise, an MRO may be able to perform certain functions more efficiently and economically than the airline customer. If the MRO has more repair experience with a certain component, it may be able to provide a more reliable product, thereby reducing disruptions in their customer's operations and the associated costs, ultimately resulting in reduced cost per aircraft hour. As every airline operator knows, an aircraft can only be profitable when you are able keep it flying.

In order to be an effective partner, an MRO needs to be sensitive to the customer's operational needs, as well as having the know-how and desire to provide innovative solutions to a customer's problems (a.k.a. 'opportunities'.) Solving some of a customer's maintenance problems can allow the operator to focus more on other areas of their business as needed. An MRO partner providing an airline with efficient solutions makes for more cost-effective operations overall. That's the pay-off to the airline customer. What's in it for the MRO organisation is a steady stream of challenging work, which not only keeps a shop busy and profitable, but also keeps a shop nimble enough to come up with new and better solutions for the customer. The MRO must also become a true partner with their customer, to have their finger on the pulse of the customer's specific operational needs.

One such MRO, Triumph Air Repair (TAR), an FAA-approved repair station specialising in repair and overhaul of APUs and related accessories, has taken up the challenge of becoming a real partner with the airline customers it services.

As a senior APU R&O engineer, Rob Summey joined the Triumph Air Repair team in 2009. Summey has this to say about deciding to end a long career working for an OEM and start afresh with this Phoenix, Arizona-based MRO facility:

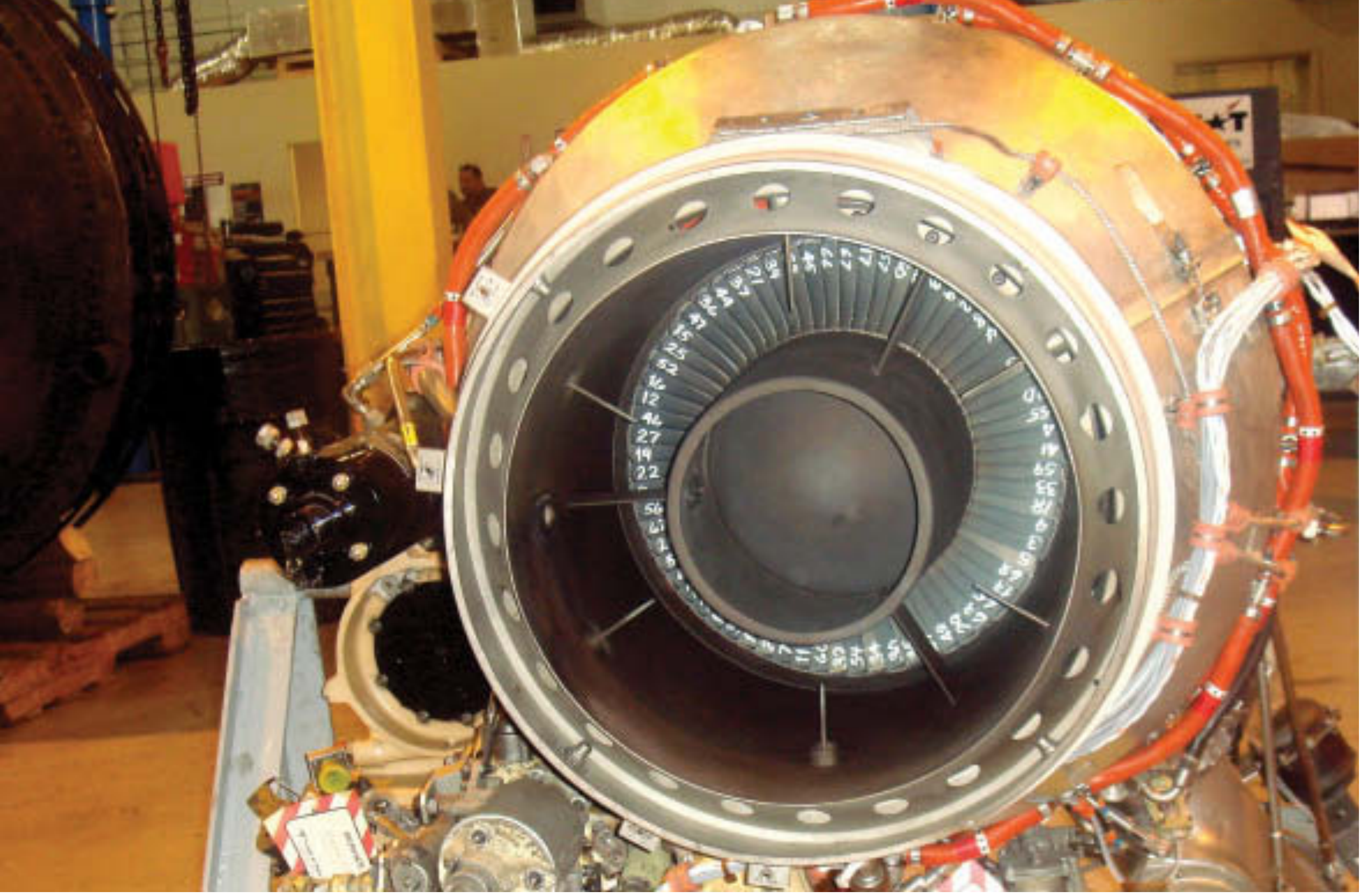
"I had worked for an OEM for over 29 years, and as I came toward early retirement age I started thinking about a move away from that big corporation feeling... Where it seemed to me there was little room for individual creative fulfillment. At the same time, I was having doubts about giving up big corporation security and benefits. While at the OEM, I had supported TAR for many years, as one of our OEM-authorised service centers. In dealing with TAR I got the feeling those folks felt like they were making an individual contribution, and I found the innovation and flexibility they portrayed invigorating. Now that I'm onboard, I experience that feeling myself on a daily basis."

He says Triumph Air Repair is a business unit small enough to adapt quickly to customer needs, but large enough to keep most of the work inhouse and under their control. The backing of the larger Triumph Group of companies means the resources and security of a larger corporation are still there.

Elizabeth Rakestraw, TAR president further explains: "Triumph Group's operating philosophy, respecting the autonomy of the individual operating units, allows us the agility of an entrepreneurial company, with the strength of a larger organisation. We take pride in the strength of our engineering capability and the ability to provide our customers with a wider range of options for the repair and overhaul requirements."

The Triumph Group companies began as part of the former Alco Standard Corporation, a conglomerate of companies in a variety of industries. Alco called itself a 'corporate part-

"I had worked for an OEM for over 29 years, and as I came toward early retirement age I started thinking about a move away from that big corporation feeling.
—Rob Summey, APU engineer, Triumph"



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Because of work-in-process volumes and specific technical expertise, an MRO may be able to perform certain functions more efficiently and economically than the airline customer. If the MRO has more repair experience with a certain component, it may be able to provide a more reliable product, thereby reducing disruptions in their customer's operations and associated costs, ultimately resulting in reduced cost per aircraft hour.

nership," which provided the advantages of a large corporation, while its individual companies remained entrepreneurial and responsive to the needs of their local markets.

A group of Alco Standard's management in league with key outside investors bought out a select 13 of these individual companies, and Triumph Group became an independent company. To achieve greater strategic focus, Triumph Group began to acquire additional aerospace companies, and divested its non-aviation companies, all the while maintaining the original philosophy of the corporate partnership. As an integral part of this larger group, TAR continues that tradition.

Close relationship with customers

Triumph Air Repair's management team keeps in mind that as many companies grow in the industry, they sometimes tend to insulate themselves from their customers through layers of management, procedures, cost cutting, and outsourcing. TAR strives to stay away from that way of doing business, and instead desires to maintain a more intimate working relationship with individual customers, and demonstrates to the customer that they care about their needs, no matter how big or small.

This internal communication is essential in creating an MRO that can adapt and can effectively provide the customer with the personal attention they deserve. Kevin Rhodey, TAR's director of operations has a favorite saying: "I have three words for you: communicate, communicate, communicate."

Whenever there is a breakdown in communication, Rhodey is not afraid to slow down for a second and pull the teams together to ensure that everyone is onboard and on track, with the needs of each job fully understood by each member of the larger team. Triumph Air Repair operates on the knowledge that good communication is easier with a flatter structure and that layers of management tend to inhibit that flow.

Sports legend Vince Lombardi once said:

"Individual commitment to a group effort — that is what makes a team work, a company work, a society work, a civilization work."

This individual commitment to the group goal is another facet to the philosophy of corporate partnership, and is a big part of the reason why TAR is still going strong in times of uncertain market conditions, maintaining their status as one of the world's top APU MROs.

This philosophy sounds good, but at some point you've got back it up with actions which demonstrate success. You've got to put your money where your mouth is,, go beyond words and sentiments and produce the desires result. The end product must speak for itself. A successful MRO organisation must have the talent, know-how, equipment, and facilities to go the distance. So, besides having a forward thinking philosophy how has TAR equipped themselves to become a successful MRO business?

Experience is invaluable and with more than 32 years in the aviation MRO business, TAR has repaired over 8,000 APUs and 200,000 accessories. As an authorised Honeywell service center, it became the exclusive factory service centre for the GTCP 660 and TSCP700 product lines. Through the expertise and dedication of the company's workforce, the MRO offers a flexible range of services in support of a large range of APU models. It not only has experience supporting airlines, but also shares its knowledge in support of OEM operations, whether by providing reliability information of OEM parts, assisting in sourcing hard to find materials and parts, or assisting the OEM with overflow from their shops.

Equipment is a key factor. In any successful business you have got to have the right tools for the job. TAR has three cross-functional, OEM-correlated, APU test cells to support the GTCP85, GTCP131, GTCP331, GTCP660, TSCP700 and PW901 series of products, and the organisation is continually evaluating the opportunities to add more APU models to their capabilities.

Let's get technical

In a competitive industry, an MRO will not last long unless they possess an intimate technical knowledge of the products they support. TAR utilises its knowledge not only to perform manual repairs, but to develop and perform advanced technology repairs, as an important contribution to reducing the operating costs of their customers. These alternate repairs target components that have high replacement rates and high failure rates. The ability to rebuild components to reduce the failure rate ultimately improves the on-wing performance and reliability of the APU. With an in-house engineering department, TAR works with customers to determine what parts are negatively impacting reliability of the APU and affecting operating costs. Once the specific components are highlighted, the experienced engineering team pursues repairs and establishes processes that reduce operating costs while maintaining the reliability of the part. In many cases, the applied repairs improve the durability of components. To bring these alternate repairs to life TAR has its own in-house DER, who is certified to create and document non-manual alternate repairs to parts which might otherwise be scrapped if either no manual repair exists, or if the manual repair is limited or simply not robust enough to serve the need. All of this is done in close collaboration with the operator, to save cost to the customer and increase profitability.

TAR has repaired more than 8,000 APUs and 200,000 accessories.

The customer-focused team at Triumph Air Repair adapts their services to meet many varied customer requirements. Support includes 24-hour AOG support, troubleshooting, customer-training programnes, and APU health trend monitoring. A programme manager is assigned as the single point of contact for each customer. If a customer has an 'expedite' request or trouble-shooting requirement, the dedicated programme manager provides the customer with immediate options to meet the need. In less urgent situations, this same customer care team takes time to customise maintenance programmes and proposals to meet each customer's special needs. The maintenance programmes can be tailored to address a customer's operational, regulatory and/or cash flow requirements.

As a FAA-approved repair station, Triumph Air Repair takes great care to maintain quality assurance (QA). Their QA group is dedicated to strict adherence to FAA and EASA requirements and believes that quality cannot be an afterthought at the end of a job. The QA process of any job performed begins before the customer's unit arrives for repair. The QA group works closely with the customer's quality programme to assure compliance with the governing agencies as well as the customer's unique quality requirements which may go beyond FAA or EASA requirements. Triumph Air Repair is on the audit schedule of major airline and cargo carriers and is CASE-registered and audited on a bi-annual basis.

It would be impossible in the context of this article to present every possible aspect of an MRO. A successful MRO is in tune with the customers they service, so it could be said that the advantages of partnering with an MRO are myriad as the variety of aviation customers that exist in the world— each customer being unique with different needs. This article seeks to give some insight into the many reasons an airline might seek to partner with an MRO for their repair and overhaul needs. There are many choices available, which in a healthy market helps keep pricing competitive. In any business action, the advantages must be weighed, and whether an airline chooses an OEM or an MRO, the important thing to remember is that there is a choice. The best advice for an airline considering an MRO would be to make contact, and find out what that MRO has to offer. Check out as many shops as needed until an MRO is found that is a good fit your unique operational needs. Keep them flying!

Small businesses challenge today's aerospace market

Making it in today's aerospace market can be tough. Even tougher if you are a small business. Small fish in a big pond face many challenges and stiff competition from the major players as everyone battles for a bigger piece of an ever-shrinking pie. *Sam Symonds,* president and CEO of *Co-Operative Industries,* discusses his views on the subject and explains his company's approach.

Co-Operative Industries Aerospace and Defense has supported the aerospace industry for over 63 years with the design and manufacture of electrical wiring harnesses. The company is a small, privately-held business that built a reputation as an organisation that could turn a 'design parameter' specification into a cost-effective, repeatable and efficiently manufactured electrical wiring harness. The company has also achieved certification as a repair station for the FAA, EASA and CAAC on electrical wiring harnesses for aircraft engines. This puts it in that unique category of being both an original equipment manufacturer (OEM) as well as a part 145 repair station. Virtually all the harnesses repaired in its repair station are manufactured by other OEMs, allowing it to keep the businesses (OEM vs repair) completely independent from one another.

Challenges facing today's small businesses

There are challenges as well as advantages to being a small OEM-type business in a dynamic industry such as aerospace. However, being a small business does not necessarily translate to small capabilities and service. Some of the challenges faced when competing with larger OEMs include:

- Less marketing muscle.
- Less investment capital available.
- Difficulty obtaining an invitation to participate in new projects.
- Fewer resources.

Most medium and large businesses in aerospace understand the value of marketing to targeted customers, regions or products. They also have the budgets available to take advantage of high-end media and broader circulations. The rule of thumb that two to five per cent of sales should be spent in marketing/advertising can represent a very significant differentiator when comparing a small business budget to a large one.

Additionally, the availability of investment capital for new product research and processes pales in comparison to that which is available to medium and large businesses. The downside here is that sometimes the ability to compete for projects, or getting into the competition, can be affected because a small business may need to wait until it has the funding to purchase necessary equipment or technology.

The industry continues to evolve in response to the requirements of the population as well as the environment. This evolution leads to new engines and aircraft. These in turn require upgraded accessories, which are then supplied by companies that specialise in the necessary components. Engine and aircraft manufacturers won't always search out all capable firms, as development time is short and it is easier — and more cost effective — to stay with suppliers they already know. For a small business, it is very difficult to get an invitation to participate in the quoting of these new programmes.

With limited resources at their disposal, the small business is forced to be selective about the projects it focuses on. Unfortunately, this can often stifle growth potential and compound the challenges.

However, it is not all doom and gloom. There are just as many benefits and advantages to being a smaller organisation, and thus opportunities to overcome the challenges of competing with the big firms. For many businesses it is how we manage these challenges and leverage our advantages that sets us apart and provides solutions that aid in our growth.

Outsourcing to small businesses that specialise in specific components and accessories allows major OEMs to focus on their core competencies.

Advantages of small businesses include:

- Agility in response.
- Usually 'no job is too small'.
- Teaming attitude.

There is a great deal of flexibility and agility in a small business' ability to respond to a challenge. There are fewer layers of bureaucracy and therefore decisions can be made quicker. If a project requires special tooling or other resources, we can move quickly if we deem it worthwhile to the success of a project. This added flexibility can be a huge advantage in certain circumstances. Should a special advertising opportunity arise with a narrow window, many large organisations may not be able to get the required approval within the allotted time. A small business could have a decision in a matter of minutes. In many cases this will offset the advantage of a much larger budget. We also tend to be more focused with our marketing budget — targeting resources to niche areas, thereby maximising marketing dollars.

Along the same lines, a small business will seldom turn down a new opportunity due to the project being too small. These opportunities are viewed as the beginnings of larger future business. Small business tends to believe

"Most of the engine and airframe OEMs realise there is a great deal of 'tribal knowledge' that has accumulated throughout the years and when they decide to outsource the product, the documentation will have holes in it. Some large companies may just build to the documentation "as-is" because they are too focused on other projects to do a thorough review.

A focus on good customer communications and the ability to offer alternative design solutions can improve throughput and reduce cost, resulting in win-win scenarios for everyone involved.

that every opportunity will spur growth. Additionally, there is the added incentive that this may be a 'niche' product on the cutting edge of an industrywide solution. This scenario offers another potential growth opportunity for the smaller enterprise.

Many small businesses approach customers with a 'teaming' type attitude. This approach can be very appealing to major OEMs that are seeking to utilise the supply base and reduce their vertical integration.

These programmes become a 'build-to-print' business as the OEM outsources existing programmes. A small business is willing to expend the resources to perform a complete programme review during the quote phase to ensure they will be capable of performing to the customer's requirements. At times, there are incongruities in the customer documentation. With a focused approach by an experienced design team, these can be identified prior to production.

Most of the engine and airframe OEMs realise there is a great deal of 'tribal knowledge' that has accumulated throughout the years and when they decide to outsource the product, the documentation will have holes in it. Some large companies may just build to the documentation "as-is" because they are too focused on other projects to do a thorough review. Often this results in a wiring harness that will not fit or function properly. This costs the customer time and money to establish what went wrong and then to correct it.

Offering alternate design solutions during the preliminary review and preventing a design/process flaw that may be difficult, if not impossible, to manufacture results in a win-win situation for all involved. This type of teamwork can lead to lower costs with faster throughput, and most importantly, results in a quality finished product. A company that is willing to accept this responsibility early on and identify where additional information is needed will be rewarded for that effort.

Challenges in the MRO market

Let's examine the challenges involved in MRO for a small repair station. Perception is a very real challenge for a small repair business. The prospective customers may be concerned that the volume of wiring harnesses they need repaired may be too much for a small business or that the turnaround time (TAT) may be too long. There may be a customer belief that the small business won't have the inventory to support their programmes and the customer will need to supply components or wait for supplier lead-time prior to their repair commencing.

Communication with existing and potential customers will generally dispel these concerns. As far as TAT, many large MROs that are also OEMs may try to run repairs concurrently with new production and therefore increase TAT. Co-operative Industries, for example, maintains a dedicated workforce for repairs and is not associated with new production. This greatly reduces TAT issues.

Companies with a dedicated workforce are able to ensure optimal turnaround times. There are some small businesses (such as ours) that have made it a major part of their business plan to perform repairs for the airframe and engine MROs. These large MROs have the benefit of reducing their cost by not having to support the component maintenance shops as part of their operation. This then allows these organisations to concentrate on their core competency, be it engine or airframes.

Additional savings are realised by outsourcing to an organisation with lower operational costs. Such an organisation also accepts the responsibilities of meeting the requirements of consistent product TAT.

Consistency and redundancy is an added benefit of dealing with a specialty company. A company that specialises in electrical wiring harness designs that range from the simplest construction to interconnects intended for extreme environments should give added confidence to the engine or airframe MRO that the repairs will be done correctly the first time.

One final benefit that small businesses bring to the industry is that they serve as a 'training ground' for many of the employees that large businesses will hire in the future. Conversely, when the large OEMs and MROs are downsizing, it is small business helps with employment. Generally speaking, an employee coming from a small business has a broader experience base than a contemporary with the same years from a large business. This broad experience is born out of necessity in a small business. By the same token, an employee leaving a large firm may relish the freedom to expand their capabilities from lack of restraints that may come with the more rigid work structure and boundaries of large companies.

The commercial and military aerospace market is a very large industry in terms of dollars, but it is very small in terms of human resources. Many of us that have been serving this sector for 25-plus years continually encounter many old friends and acquaintances, albeit at different companies than you may have remembered them.

As has been illustrated and discussed throughout this article, there are a multitude of challenges that face small business in the aerospace industry. But hopefully, it has also become evident that there are just as many if not more benefits, advantages and opportunities for the small business.

Flexibility in manufacturing processes can be key for small business survival.

If people have the ability to exercise their creative instincts, are hard-driving achievers, and like to take calculated risks, working in a small business is the place to be. Almost all challenges can be overcome with hard work, persistence and optimism. ■

Co-Operative Industries Aerospace & Defense

Co-Operative Industries is an AS9100 registered company based in Fort Worth, Texas. The company designs and manufactures electrical wiring harnesses, junction boxes, panel assemblies, ignition leads, and flexible conduits for airframe, engine, ground support equipment, and space applications. In addition to manufacturing capabilities, Co-Operative Industries also provides part 145 repair services such as check & test, overhaul and repair, and S/B incorporation for many of the aircraft wiring harnesses in service today.

"Generally speaking, an employee coming from a small business has a broader experience base than a contemporary with the same years from a large business. This broad experience is born out of necessity in a small business.

Cleaning turbine blades

Due to stringent safety requirements, consistency and repeatability is essential in both the manufacturing of new aircraft engines as well as the associated MRO operations, while at the same time increased cost pressures require a high degree of cost efficiency. Both requirements can only be fulfilled with innovative production and maintenance systems. Surface finishing specialist Rösler describes its surface preparation and finishing processes which help companies to achieve these objectives.

Weight reduction of key components which result in reduced fuel consumption and a reduction of noise emissions are the most significant areas of research and innovation in the aerospace industry. These goals are achieved by utilising new materials and applying new technologies which can improve the thermo-dynamic properties of aero engines. When it comes to safety, cost efficiency and eco-friendliness, blast stripping and blast cleaning processes play a key role in manufacturing as well as MRO. Rösler offers custom engineered shot blast systems — from relatively simple dry or wet blast cleaning systems to high-tech high-pressure water jet blasting and shot peening systems. These systems provide a high degree of automation, repeatable results due to constant monitoring and adjustment of all relevant blast parameters and high equipment quality. By taking advantage of innovative know-how, which the company has acquired during its takeover of Baiker and Vapor Blast, Rösler has become a technological leader in the field of aerospace surface finishing and surface preparation.

Dual cabin wet blast system for turbine blades

Aircraft engine components are exposed to extreme mechanical and thermal loads, which is why they are made from highly heat resistant steel and titanium or nickel-based alloys. Shot peening is used for newly manufactured turbine parts as well as for refurbishment of existing

Turbine blades undergo a shot peening process to induce a compressive residual stress in the upper surface layers of the parts. This applies to newly manufactured turbine blades as well as blades that need to be refurbished.

parts as it induces residual compressive stresses into the outer surface layers of the parts and, thus, increases their tensile and bending strength resulting in higher resistance to wear and fatigue corrosion.

Recently, Rösler delivered a custom-engineered wet blast peening system for turbine blade refurbishment to a leading aerospace company. The wet peening system is equipped with two highly wear resistant stainless steel cabins which ensures high parts throughput.

The peening system itself is designed for processing up to 14 different turbine blades, mainly fan blades, with a maximum length of 1,150mm. To start the programme the operator registers the blade to be peened with a barcode reader. Subsequently, the graphic display built into the control panel shows a picture of the turbine blade and the parts-specific work piece fixture. The fixture, which is completely masking/protecting the root of the turbine blade, is mounted onto a rotating satellite station. A computer numerical control (CNC) multi-axis gantry system working with a positional accuracy of 0.1mm controls the movement of the 12 blast guns. The combination of satellite rotation and blast gun movement ensures that the blast media, accelerated by compressed air and consisting of a mix of ceramic beads and water, always hits the parts surface of the curved turbine blades at an optimum angle.

A sophisticated rinse system reaching the complete interior of the cabin flushes the thrown blast media from the cabin and transfers it to the media cleaning and classification system. Broken-down media that is no longer usable is discharged with a hydro cyclone, and undersize media left in the water/slurry mix is carried out with a moving bed paper filter. The cleaned, re-usable media is transported back into the slurry tank with an auger. Water loss due to evaporation and carryout is made up with a special replenishment system. A specially-designed wear resistant pump pumps the mix of media and water to the blast guns from where it becomes accelerated with the introduction of compressed air. This process ensures that the ratio between water and media remains constant at the preset value.

The customer specifications called for an Almen value of 0.370 - 0.450mm on an "N" strip within a cycle time of 10 minutes, and 15 sequential Almen readings can only show a deviation of 0.02mm from the specified values. To maintain such tight tolerances all blast parameters concerning process stability and repeatability, such as media concentration in the slurry and air pressure, are constantly monitored and documented.

Highly flexible shot peening of turbine parts

Another leading manufacturer of aircraft turbines recently purchased a shot peening installation from Rösler for the peening of turbine components up to 1,200mm in width and 1,000mm in height. The blast system is equipped with two load stations which allow the shot peening of one part in the blast chamber, while the swing table is being loaded/unloaded with another part.

However, there are additional double features integrated into this system: It is equipped with two blast systems and two four-axis gantries that are mounted to the ceiling of the cabin and the rear wall. Each blast system is equipped with three guns. This arrangement allows the targeted blasting of different sections on the parts. Two double pressure vessels guarantee a consistent and continuous shot peening process. This dual concept allows simultaneous blasting of the outer and inner parts surfaces with different blast intensities, and it also allows the use of two different sizes of media, which can be

The work piece fixtures holding the turbine blades are placed on rotating satellite stations. The 12 blast guns are moved by a multi-axis CNC gantry system with an accuracy of 0.1 mm. The slurry consisting of media and water is accelerated in the blast gun by compressed air.

quickly exchanged. This flexibility guarantees a highly effective operation, even though the cycle times may last for several hours.

To ensure a high degree of process safety and repeatability, all process parameters such as media flow rate, pressure in the blast system and air volume are constantly monitored, adjusted and documented. The varying data tracking and adjustment systems are very precise so that the tolerance of the media flow rate is less than five per cent, and the pressure tolerance is not larger than 0.05 bar.

This particular peening installation is partially enclosed with a sound enclosing cabin so that the emitted noise level does not exceed 75 dB(N)

Stripping of thermal coatings with pure water

Refurbishment of aircraft turbines requires, among other operations, the removal of thermal coatings, such as very hard plasma coatings from various components. One of the largest maintenance and refurbishment organisations in the world is utilising a high pressure water jet system from Rösler for its stripping operations. The Rösler system is equipped with a stainless steel blast cabin and a turntable that can be moved in a linear direction which allows the treatment of turbine components with different widths and diameters.

The high performance plunger pump, with a 132 kW motor, generates a high pressure 4,000 bar water jet which is dispensed with a multi-rotational nozzle that is guided by a six-axis robot. For safety reasons all of the piping is specified for a pressure of 6,000 bar. The water delivery of 11.7 litres/minute combined with the nozzle rotation generates a “grinding” effect which causes a fast and precise, but, at the same time very gentle stripping of the coating without any deformation of the parts surface and without any residual surface contamination. Depending on the type and thickness of the coating, stripping speeds from four up to 75 mm-/sec are possible.

The high pressure water jet system is also equipped with a waste water treatment plant that allows the recycling of the process water for multiple uses. In a first step the process water contaminated with particles from the coating material is passed through a bag filter whose specifications depend on the type of coating material being stripped. There must be a bag filter for every type of coating in order to prevent a potential chemical reaction that could be caused by mixing the particles of different coating materials. The pre-cleaned process water then passes through a centrifugal filter with a centrifugal force of 2,010g that removes about 99 per cent of all solid fines from the water. Finally, in a downstream cartridge filter all fines with a particle size of less than or equal to 1.0µ are removed. Rösler’s unique water treatment process guarantees a long life of the high pressure pump. Any bacteria that might contaminate the process water are removed with a special ozone unit.

Shot peening and thermal coating removal processes are nothing new to the aerospace industry, however Rösler maintains that by combining experience and innovation it is possible to produce a range of state-of-the -art machines that ensure process repeatability and continuous monitoring of every variable.

This shot peening system with two load/unload stations is equipped with two independent blast systems and two four-axis gantries guiding the blast guns. This allows the simultaneous peening of the inside and outside surface of the parts.

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Translating in-service data from an aircraft or engine into information that enables rapid action sounds like a simple operation — collect the data on the aircraft, transmit to a location for analysis, and issue an alert if that analysis indicates impending or potential failure. In reality, the typical conditions in which airlines operate make the process of engine condition monitoring much more complex. *Optimized Systems and Solutions* (OSyS), a wholly-owned subsidiary of Rolls-Royce, discusses the intricacies of equipment health monitoring (EHM).

Unlocking the secrets of successful equipment health monitoring

Addressing complexities is the mission of the equipment health management (EHM) services provided by Optimized Systems and Solutions (OSyS). With more than a decade in the field, OSyS currently monitors more than 8,000 assets daily across multiple industries. OSyS' EHM process has the foundation of not only the lessons learned from experience, but also the industry trends in civil aviation during that time.

The focus of EHM remains the same — avoiding service disruption and reducing maintenance costs. However, in the last decade, the civil aviation industry has begun to move away from dedicated EHM teams within the airline to outsourced services delivered by the original equipment manufacturer (OEM) or specialist service providers. This change is partially driven by the industry trend toward transitioning to an engine leasing or 'power by the hour' aftermarket business model. With this model, the risk and costs associated with engine downtime and repair reside with the OEM, which provides the airlines with a more predictable cost model and allows them to concentrate on their core business. It also allows the OEMs to benefit from an engine's inherent reliability and their accumulated product knowledge.

With the OEM performing EHM, a fleet-wide view is achieved by establishing a single EHM database, a move that delivers a step change in EHM effectiveness. This enables first-of-type failures to be quickly investigated, diagnosis established, and the entire fleet examined, enabling proactive remedial action if any other engines are identified as exhibiting early signs of that failure.

Another industry change over the last 10 years has been the rise in effective utilisation of EHM data within the OEM. Rolls-Royce, for whom OSyS has provided extensive EHM services and helped develop long-term service agreement strategies, is a case in point. During

AIRCRAFT TECHNOLOGY
ENGINEERING & MAINTENANCE

THE MRO YEARBOOK 2012

Launched in 2007, The MRO Yearbook is an official annual publication of award-winning magazine, Aircraft Technology Engineering & Maintenance (ATE&M).

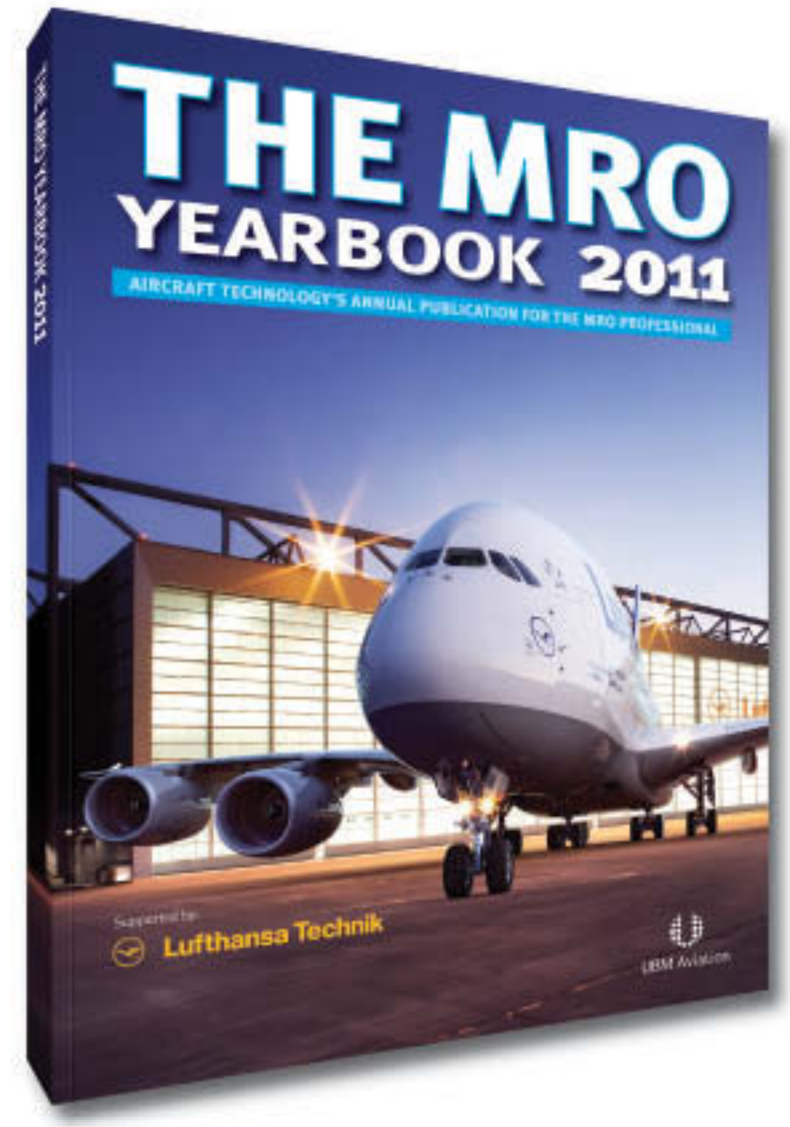
The MRO Yearbook is distributed in print to over 4,000 airline, OEM and MRO professionals worldwide. Readers include key decision-makers, working within airline engineering and maintenance departments; airframe; engine and component MROs; spare parts distributors; plus the OEMs. In addition, the online (e-book version) goes to over 20,000 aviation professionals worldwide.

The next MRO Yearbook (2012 edition) will be published in September 2011 and will also benefit from being at the MRO Europe Show 2011, plus at many UBM Aviation Conferences and Exhibitions throughout late-2011 and 2012.

CONTENTS:

- MRO Global Outlook
- Airframe Heavy Maintenance Directories – Worldwide
- MRO Focus – BRIC, USA – South East, Central & Eastern Europe, Middle East, Canada,
- Airbus A320 Maintenance and upgrades
- Airbus A380 Operations
- Airbus A330 & A340 Maintenance
- Boeing 777 Maintenance
- Boeing 737 Maintenance and upgrades
- Freighter Conversions
- Landing Gear MRO
- Spares Parts & Logistics Management
- Specialist Engine Repairs
- Safety Management Systems
- NDT Inspection
- Avionics Repairs
- PMA Parts

If your company has particular MRO capability you can take advantage of one of our special 'advertorial' and / or advertising opportunities opposite:



OPTION (A) Three pages of editorial on the MRO subject of your choice / or two page company profile with one full page ad at: £5,500 GBP / or €6,930 Euros / or $10,120 USD

OPTION (B) Two pages of editorial on the MRO subject of your choice / or one page company profile with one full page ad at: £3,850 GBP / or €4,851 Euros / or $7,084 USD

OPTION (C) Any regular size advertisement with *25% discount of the standard ATE&M 2011 rate card.

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Engine health alerts need to be accurate in order to avoid unnecessary flight delays.

this period, Rolls-Royce has invested significantly in their operations centre. Approximately 10 per cent of employees staffing the centre provide expert, real-time advice to customers 24 hours a day, 365 days a year.

In addition to this front-desk team, a larger back-office team works to achieve long-term goals such as: maintenance practice development, design validation for current and future engine programmes, logistic process development and commercial contract administration. This type of dedicated organisation is essential for extracting the maximum value from EHM data.

EHM process

Comprehensive EHM services such as these underpin an airline's financial, fleet and maintenance-capacity planning decisions. The end-to-end EHM process developed by OSyS addresses the difficulties of providing valued, reliable, actionable information to the customer. Some data challenges the customer may experience include:

- Frequently, the aircraft or engine data needed to diagnose problems is at a level of complexity from which only an expert would be able to distinguish abnormal behaviour from normal, often "noisy" data.
- Time is of the essence. Once an abnormal condition is detected, the correct diagnosis and recommended course of action need to be relayed to the OEM and the aircraft operator within minutes.
- The alerts generated need to be accurate in order to avoid unnecessary flight delays, cancelled flights, and operational disruption due to false alarms.
- As engine fleets age, new failure modes not seen before nor anticipated, materialise. This makes it particularly challenging for an EHM service provider to catch every disruptive event.

OSyS' EHM process follows a series of steps that begins with receiving information from aircraft sensors. Most modern engines are equipped with a range of transducers that enable a comprehensive analysis of engine performance. Only a handful, however, are dedicated to EHM purposes. Most are actively used in control or cockpit indication systems, monitoring such aspects as temperatures and pressures in the engine, shaft rotational speeds, vibration levels, etc. At this time, there is some reluctance to add additional sensors specific to EHM data acquisition, based on an historical mindset that they will add cost, weight and complexity. However, as the industry progresses and moves toward the aftermarket model, we may see more recognition that the benefits and savings to be realised in the total life costs of running the engine outweigh those concerns, enabling the use of EHM-specific sensors.

The next step is to acquire the data. The data acquisition systems, most often provided by the Aircraft Condition Monitoring System (ACMS), routinely deliver a handful of small 'snapshot' reports recorded at specific flight conditions such as takeoff, climb, cruise and engine shut-down. They can also deliver exceedence reports when certain pre-defined conditions, such as shaft overspeed, are breached.

Modern engines such as the Rolls-Royce Trent 900 on the A380 and the Rolls-Royce Trent 1000 on the 787 also have an engine-mounted monitoring unit (EMU). Essentially a mobile computing platform for running data acquisition, conditioning and analytical processes, EMUs are commonly configured to acquire detailed vibration spectral data or information on engine accessory behaviour. The big advantage of an EMU is that it is more easily updated to incorporate new algorithms than the ACMS. If a new type of fleet issue is detected, a new EHM algorithm can rapidly be developed and deployed throughout the fleet to help manage the emerging behaviour.

Once the data has been acquired, the next step is analysis. In most cases, that means transmitting the data from the aircraft to an on-ground location. Typically, the data OSyS analyses is transmitted off the aircraft in Aircraft Communications Addressing and Reporting System (ACARS) messages, small text packets of data transmitted by VHF radio link and routed to OSyS by a global network of ground stations. Using this method has proven highly successful during the course of OSyS' EHM services history.

In some instances, the choice has been made to do the analysis onboard in order to avoid the cost and potential delay that results from transmitting the data for offboard analysis. This onboard option can also allow a much more detailed analysis of the vibration and performance data as there is no loss in resolution through summarisation of the raw data. However, in using this method, it is often difficult to accurately predict exactly how algorithms will behave. This is particularly true when all the interactions with other engine and aircraft systems are taken into account and when maintenance activity is carried out on the equipment, all of which may upset the output of the onboard analytical processes.

OSyS' ground-based processing and analysis of the fleet data normally consists of the following steps:

1. The acquired data is compared to a high-fidelity model that represents what is expected based on the normal engine operation at the

particular operating conditions, such as altitude, airspeed, air temperature, etc.

2. Any differences between 'actual' and 'expected' engine performance are identified as anomalies that require further investigation.

3. All anomalies are correlated with other data to determine a diagnosis of the potential problem. This process could include using peer-to-peer comparisons with other engines, other performance data, the engine modification standard, or similar data.

Added value

Following the process generates a diagnosis that is based on the use of cutting-edge algorithms and delivered in near real-time. However, if that information is not acted upon in a timely manner, there is little value in having it. Therefore, the final step in the OSyS EHM process is to communicate the information to a defined set of people who can take the action necessary to mitigate the effects of a potential failure.

There are definite expectations concerning the EHM notifications delivered and the information they contain. The notifications must be:

- Delivered in time for mitigating action to be taken to prevent the incipient failure.
- Directed to the right people, those who are both empowered to act on the alerts and have knowledge of the defined processes to follow.
- Standardised in terms of the alerting terminology and message format to ensure that a consistent workflow is always followed.
- Complete with all the information necessary so the user has no gaps in the data.
- Correct, such as parameter values correctly reported and engine serial numbers and installation positions correctly identified.
- Auditable, which can be achieved by storing meta data about the EHM notification in order to monitor how well the EHM service is performing.
- Able to support investigation into its root cause, which OSyS typically accomplishes by providing detailed plots containing the history of the parameter trends with the significant trends highlighted.

There are also some less tangible expectations for the notifications that are more difficult to qualify. For example, the information in the notification must be trusted. The recipient must be confident that the notification has come from a reputable source and can be acted on without question. If an EHM system employs an impenetrable 'black box algorithm' at any point in the process, that lack of transparency results in less immediate trust in the information.

The focus of engine health monitoring remains the same — avoiding service disruption and reducing maintenance costs.

Independent of the need to trust the quality of the data, there is also a need for the information to be perceived as fit for the purpose. Notifications are valuable to customers only if they meet their operational requirements for information. If the information cannot meet this expectation, then meeting all the other criteria is immaterial.

OSyS and Rolls-Royce routinely gather information about the number of alerts and advisories that have been issued, the timeliness of the notifications and the root causes of the notifications. That information, together with frequent input from our customers, allows OSyS to continuously improve its EHM service and meet customer expectations.

Future of EHM

Looking to the future, it appears clear that the growth the EHM service operation has experienced during the past 10 years will continue. Indeed, past successes have placed greater expectations on the system, and customers are seeking processes to detect even more subtle failure modes with greater certainty in shorter timeframes.

As OSyS strives to meet the demands projected to result from this growth, we have identified particular areas of future system development, including the following:

- Continual development of advanced analytical capabilities, particularly around the more detailed dataset that is available from EMU-equipped engines.
- Fusion of such EHM data as performance, vibration, lifting, and oil debris in order to provide a richer information source for diagnosis and prognosis activities.
- Further integration of the airborne and ground-based elements of the end-to-end EHM system.
- Improved knowledge management systems, embedded within the EHM system, to support the continual improvement process.
- Greater integration of the EHM system with external enterprise systems such as logistical planning systems, maintenance databases, etc.
- Expansion of equipment monitored, based on the cost of failure of the equipment (e.g., landing gear, avionics).
- Integration with novel service offerings such as fuel management.
- Closer integration of EHM with associated services such as forecasting of required spares inventory and repair/overhaul shop loading.

The future may offer many new opportunities and hold many new challenges for airline operations. Employing a comprehensive EHM solution is an effective tool enabling airlines to face that future with value-added decisions concerning significant aspects of their equipment's operation.

Cold-section engine repairs

The components of the fan and compressor sections in aero engines are subject to wear and tear from a range of different causes. This article addresses some of these issues and looks at current developments in the industry.

Erosion, component fretting, and friction, as well as foreign object damage (FOD) are the main sources for aero engine fan blade damage. The first three of these usually cause consistent, gradual deterioration over a given period of flight hours/cycles, which can be planned for and rectified during scheduled maintenance intervals. By contrast, FOD (such as a bird strike) can happen at any time during operation and may require immediate repair. Deformations such as nicks and dents in the fan blade's leading edge are typical consequences of FOD. Provided it is not too extensive, this may even be repaired on-wing. For example, blending a chipped leading edge would mainly be done to secure the weakened area in the highly stressed part and prevent the damage from becoming larger over time. However, depending on the foreign object's size and mass as well as the aircraft's airspeed and engine power setting, FOD can be more severe and extend further across and/or into the aerofoil's body, potentially causing an unscheduled shop visit.

The ingestion of particulate matter such as sand, dust, salt or ice is the main cause of erosion of aerofoils in the fan as well as compressor modules; the cold-section of a gas turbine aero engine. Fan blades typically suffer from leading edge erosion and worn chords, which translate into a loss of aerodynamic shape and reduced efficiency. As a consequence, flight crew might select higher thrust settings, which may further accelerate the engine's deterioration. Also midspan shrouds ('clappers') on older-type engines with narrow-chord fan blades suffer wear and tear through erosion. However, it is not just airborne debris that can damage an engine's aerofoils: MD-80s, for example, are notorious for fan blade leading edge erosion as a result of water cavitation taking place during takeoff and landing due to the position of the landing gear and wing relative to the engine.

Fan blade repair

Worn fan blade roots, midspan shrouds and blade tips are typical example of fretting and friction-related wear and tear in the engine's front section. Root fretting is caused by the different loads and movements that fan blades are subjected to. Plasma sprayed coatings, usually copper nickel or copper nickel indium, are used as lubricating, sacrificial protection layers to provide wear and impact resistance; as a sacrificial coating they need to be periodically re-applied. Midspan shrouds are subject to constant impact and friction and can be restored by tungsten inert gas (TIG) welding, subsequent machining and the application of high-velocity oxygen fuel (HVOF) tungsten carbide coating. At the top end of the fan blade, tip length and shape may be lost as a result of friction against abradable coatings in the fan casing. The original dimensions can be restored by welding a strip of titanium along the tip, followed by reworking to obtain the correct profile.

In principle, the same process is employed to return eroded leading edges to their original shape and measurements. If the damage on the aerofoil section of a titanium fan blade extends further along the chord width or the blade material has become too thin in places, the relevant section may be cut out and a replacement patch inserted through an electron-beam (EB) welding process. The weld would then also be machined back to seamlessly blend in with the original blade material.

GKN Aerospace Chem-tronics in San Diego, California, specialises in the repair of fan blades and has approvals from all major engine OEMs. The company uses a range of processes such as hot reforming, TIG and EB welding, automated optical aerofoil inspection systems, computer numeric controlled (CNC) precision machining as well as manual blending. Protective coatings can be applied via plasma or HVOF spray processes. "The main challenges with the fan blade is to ensure the repaired item has maintained its dimensional conformity and structural integrity following the repair process," says Steve Pearl, VP and GM. "Each item must also complete rigorous non-destructive testing (NDT) to ensure the repair has left no defects that could cause the part to fail."

Given the high prices for new fan blades, it is not surprising that repairs offer substantial expenditure savings. The cost for a repair rarely exceeds 10 per cent of the cost of a replacement part, according to Pearl. This is even more the case with the newer wide-chord fan blades (no matter whether they are solid or hollow) despite the fact that they are less suitable for conventional welding than solid, shrouded fan blades. The reason is that the prices for these new fan blades have outpaced the increase in repair cost. The repair process for the wide chord fan blades is actually simpler. However, the NDT requirements have become more intense.

The increasing use of carbon fibre reinforced plastic (CFRP) is arguably the most significant development in the fan section at the moment. While the GE90 has long been the single large commercial aero engine with composite fan blades, after it was introduced in 1995, the similarly equipped GEnx-family of engines will enter service on the 787 and 747-8 in due course. Furthermore, GE and SNECMA are planning to install composite fan blades in the CFM LEAP-X engine, provided the consortium pursues the new engine generation in a turbofan rather than open rotor configuration. If this is the case, the CFM56 successor is planned to enter service in 2016. "The change to composite blades will have a pronounced effect on repairs," states Phil Grainger, senior technical director and chief technologist at GKN Aerospace. "For the run of the mill damage created to [titanium] leading edges from FOD common to short range applications, the procedures for blending and polishing will be very similar. Where more severe impacts from small birds or other FOD occur, a more complex erosion shield removal and laser repair of the sacrificial carbon layers can take place. Another common area of slight damage is the abradable tip, which can be undertaken at first line maintenance using standard adhesive repair techniques. There are some special erosion protection materials on the blade which can tolerate quite high degrees of damage without anything more than a paint touch-up. Beyond that, it is a factory replacement."

Midspan shrouds are prone to wear and tear, and periodically require material building and machining.

Compressor repairs

Further downstream from the fan, erosion is also the major source of aerofoil damage in the compressor section. An extreme example of this kind of deterioration is the deployment of military helicopters to desert areas with sand particles of over 200µm (0.2mm) in size, where the aerofoils in the compressor have been

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reduced to paper thin sheets after just a few hundred flying hours. While most commercial operators will not have to worry about these kinds of conditions, it should be noted that sand can form part of the atmosphere up to 10,000ft above the Gobi desert. Volcanic ash can rise to even greater altitudes.

In the initial stages of the low-pressure compressor, where the air stream is still relatively slow, erosion is most significant towards the blade tip at the leading edge; the loss of material therefore results in a reduction of the aerofoil's chord width. Further downstream, however, with increasing air velocity and changing direction, the blade erodes more laterally towards the trailing edge, resulting in a reduction of the aerofoil's thickness. The loss of chord width and blade geometry, as well as generally roughened surfaces in the gas path, reduce the engine's efficiency and hence are directly linked to specific fuel consumption (SFC).

PAS Technologies' aerospace division in Kansas City, Missouri, has traditionally offered cold-section part repair services and is now expanding into providing comprehensive material management programmes across a wider area of the engine, increasingly including the hot section. Typical examples of the company's services are: dimensional restoration of fan and compressor blades and subsequent coating with varying overlays against erosion and corrosion; weld-repairs of the variable inlet guide vanes (VIGV); renewal of abradable coatings and liners in the shrouds on the inside of the compressor cases and adjacent to stator vanes; and restoration of carbon seals, seal seats and housings in the bearings compartment. One of the latest innovations is a seal surface restoration for the inside diameters of booster stage vane rings of the low-pressure compressor, which is based on low temperature curing of grades of room temperature vulcanised rubber (RTV) that are reinforced with hollow glass spheres.

Aside from material and technological advances, one of the main areas of development since 2006 has been to improve process efficiency through lean and six sigma initiatives. Making the company more competitive through shorter turnaround times (TAT), higher productivity and consequently greater yields has certainly been the main objective. However, it has become equally important to make material savings in the face of ever increasing material prices. "One of our larger material costs is powder applied in our coating technology," reports Robert Weiner, CEO. "Using six sigma, we were able to refine the coating processes and work the output closer toward the lower specification limit in coating thickness. Using kaizen events on coating families of parts, for example, we were also able to adjust spray patterns and nest parts within previously wasted space to make better use of our powder. The result was a 25 per cent improvement in powder savings."

Repair versus replacement

For Tony Matacia, GM of General Electric's (GE) repair technology centre of excellence headquartered in Cincinnati, Ohio, one of the main areas of development at the moment is blisk (bladed disk) repairs. While the new component generation offers significant weight savings and aerodynamic efficiency/performance gains, it will also shift the 'repair versus replacement' debate firmly towards the 'repair' side. There will be no argument to replace a blisk if, for example, one or two blades have suffered FOD or erosion damage and need to be replaced. GE has been working on EB welding processes to cater for such a scenario but, as Matacia explains, welding metal with conventional methods, including EB welding, tends to go with a varying degree of material property degradation at the joint between the individual metal pieces. There may be certain repairs where the conventional welding methods will not provide sufficient strength to sustain the stresses in a blisk. "A normal welding process is a fusion process, where the material actually melts. [In this area] one gets cast material properties. So the material properties are generally not as good as a forged material." As a solution the company's research and development team is looking at at a number of unique solid state welding processes. "With solid state welding, such as translational friction welding, you obtain improved material properties compared to conventional fusion welding," says Matacia.

Making sure that a repair process will not lead to any material deficiencies in the respective part, to ensure the safe operation and continued performance of the engine, is the overall objective in the development of repairs. High-cycle material fatigue is thus one of the main challenges that engineers need to address. As the compressor blades rotate in-between the stationary vanes inside the engine, they are susceptible to excitations which will cause them to vibrate. If, for example, the compressor has 50 vanes at the respective stage, every blade receives 50 pulses per revolution. The resulting vibrations will not only vary according to different power settings and changes in the atmospheric conditions, they may also induce other, secondary vibrations within the blades. To make the matter even more complex, the blades might receive further impulses through contact between the tip and the shroud, turbulences or foreign objects, which could induce further, secondary vibrations and associated stresses.

It is this kind of intimate knowledge about the design and manufacturing of parts and components which gives the OEM a natural advantage over independent companies when it comes to the development of DER/DOA repairs as well as PMA parts. As the technology is becoming more advanced, the challenge to develop alternative repairs and materials that are as reliable as the OEM's offerings might become too large to overcome, as Matacia suggests: "We [GE] have all the design engineers, materials engineers, and manufacturing engineers. We have the capability to engine-test our parts and component-test our parts. As these parts [compressor blades] go from simple two-dimensional shapes to very complex three-dimensional shapes, you need that kind of engineering expertise in order to develop a successful repair. If you don't have that, there is some risk that you may miss. That may have worked 20 years ago, [but] may not work now."

For Tom van der Linden, VP sales of Chromalloy, the main challenge for the future does not lie in mastering the technology, materials or complexity of parts for new engine generations, but in the availability of the engineering data that is necessary to develop alternative repairs and spare part material. The Orangeburg, New York-based company has been a specialist for cold and hot section repair processes for decades, encompassing casing repairs, section restorations for blades and vanes, flange replacements for different parts, and various coating applications, including abradable coatings. The company is also aggressively expanding its development and production of PMA parts.

High-velocity oxygen fuel (HVOF) spray can lead to better coatings compared to standard thermal spray in atmospheric conditions.

van der Linden maintains that the OEMs are trying to protect the aftermarket for their parts by restricting engineering data and instructions in the engine maintenance manuals (that was previously available and is necessary for the safe maintenance and operation of the engine), and requiring aircraft operators to use only the OEM or their approved licensees for engine maintenance. "The OEMs are protecting their data and engines in such a way that is very difficult to be able to fairly compete in the aftermarket for certain engines. What we see is that the OEMs try very hard to prevent their customers from having an alternative source."

The situation is particularly dramatic for aircraft such as the 737, 777-200LR/300ER series and the two A340 generations, where airlines do not have a choice between engine models. While all OEMs have delivered in providing highly modern and efficient engine technology despite this market of relatively limited choice — compared to other industries — have customers also had a chance to arrange the most cost-effective maintenance? No doubt, the debate goes into another round while the technology continues to advance. ■

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The change to composite blades will have a pronounced effect on repairs. For the run-of-the-mill damage created to [titanium] leading edges from FOD common to short-range applications, the procedures for blending and polishing will be very similar. Where more severe impacts from small birds or other FOD occur, a more complex erosion shield removal and laser repair of the sacrificial carbon layers can take place.
—Phil Grainger, senior technical director and chief technologist at GKN Aerospace.

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Fulfilling The Promise Of Open-Rotor Technology

Increasing fuel costs coupled with anticipated international fuel emission (CO2) regulations have prompted renewed interest in open-rotor technology. In addition, the United Nations' Committee on Aviation Environmental Protection (CAEP) is considering noise regulations stricter than current Chapter 4 standards.

Above: Following UDF tests on a 727, GE mounted the engine on an MD-80 and flew it to and from the 1988 Farnborough Air Show.

Below: Flight-testing of the UDF engine on a 727-100 aircraft was successfully completed in 1986.

Consisting of two rows of counter-rotating blades outside the core engine, open-rotor propulsion systems have higher levels of propulsive efficiency due to their very large bypass ratios when compared with modern ducted turbofans. However, without an inlet duct, they tend to be noisier because it is not possible to design the fan for first blade passing frequency cutoff, or to suppress noise using acoustic treatment.

GE is in a unique position to advance open-rotor technology as it pioneered the concept. In 1973, the Organization of Petroleum Exporting Countries (OPEC) declared an oil embargo that resulted in an eight-fold increase in fuel prices. This prompted a shared-cost initiative between GE and the US National Aeronautics and Space Administration (NASA) that culminated in the counter-rotating unducted fan (UDF) flight demonstrator in the 1980s.

Snecma of France, a 50/50 partner with GE since the early 1970s in the CFM engine programme, assumed a 35 per cent share in the design, development, and fabrication of the UDF engine.

The 1980s UDF technology programme focused primarily on the propulsor. It included two unducted, counter-rotating stages of synchronised, variable-pitch blades. A unique characteristic of the blades at that time was their fabrication from lightweight advanced composite material that was corrosion-proof and highly resistant to impact damage. Moreover, the strength-to-weight ratio of the blades was measurably superior to that of titanium blades.

A gas generator drove a counter-rotating turbine that was directly linked to each of the propulsor stages. The simplicity of direct-drive, rather than a geared-drive arrangement, was a defining feature of the UDF engine.

A GE F404 turbofan engine, without tailpipe and exhaust components, served as the gas generator during engine testing, demonstrating the premise that other "off-the-shelf" engines could be adapted for other open rotor applications. The F404 engine normally powers the F-18 Hornet and the F-117A Nighthawk military aircraft.

Proof-of-concept testing began in 1984, and full-scale engine testing began in August 1985. The UDF engine produced 25,000 pounds (111 kN) of static takeoff thrust and demonstrated 20 per cent lower specific fuel consumption (SFC) than any turbofan engine in the same thrust class at that time. The fan bypass ratio of 35:1 figured significantly in the attainment of the unprecedented SFC.

Flight-testing of the UDF engine, installed as one of the engines on a 727-100 twinjet aircraft, was successfully completed in 1986, followed by a similar flight test the next year on an MD-80 twinjet. The MD-80 flew to and from the 1988 Farnborough Air Show, and was demonstrated during the show.

Following the demonstrator programme, a significant amount of engineering design work and component testing continued in support of the GE36 product design. A new core engine was tested in mid-1989 for approximately 50 hours, and design engineering of a full gas generator and a product propulsor were well along when the program was terminated.

Open-rotor development, stimulated by rapidly rising fuel prices in the 1970s, succumbed to an equally rapid decline in fuel prices that curtailed the interest of potential customers in the continued development of the UDF engine.

However, the UDF demonstrator had validated the open rotor design concept.

Today, GE believes that the open-rotor concept holds significant promise as the propulsion system for the next generation of single-aisle, narrowbody aircraft. Therefore, GE has launched a comprehensive open-rotor technology development programme to demonstrate fuel burn advantages while minimising noise levels to meet more stringent future noise regulations.

Based on its long-term potential, GE's open-rotor programme has been awarded funding by the U. Federal Aviation Administration (FAA), under provisions of the Continuous Lower Energy, Emissions, and Noise (CLEEN) programme, specifically to support critical technologies such as blade aero-acoustic design and pitch-change mechanism. The CLEEN programme represents a joint FAA/GE effort in the development and maturation of key engine technologies that reduce fuel burn, noise and emissions for future aviation products.

GE is leveraging its highly successful UDF programme and the subsequent GE36 open-rotor product design experience to develop a modern open-rotor propulsion system. It is advancing its open-rotor experience with modern design technology and resources to integrate advances in engine technology that have matured during the 25 years that have elapsed since the UDF programme.

CMM (Coordinates Measuring Machine) inspection of an open rotor reduced-scale blade.

Snecma is a partner in this effort.

Under the modern open-rotor engine programme, a model-scale test demonstration and development programme was launched in close cooperation with NASA.

Current state-of-the-art modelling and simulation tools facilitate analytic evaluation of engine components and systems. For example, compu-

tational aero-acoustics codes enable design optimisation for aircraft engine noise. The reduction of noise, which continues to be a significant challenge for open-rotor propulsion, requires the use of physics-based advanced design tools and diagnostics to develop innovative blade designs that do not sacrifice aerodynamic performance and, hence, fuel burn reduction. One change from the 1980s design was the incorporation of larger-diameter, lower-speed blades.

During 2009-10, GE and NASA jointly conducted tests in the Low Speed Wind Tunnel at NASA's Glenn Research Center in Cleveland, Ohio. To facilitate testing of the modern open-rotor model-scale blade designs, NASA restored the original UDF test rig. The extensive rig refurbishment included several newly designed and built sub-systems. Each blade-set of the counter-rotating rig is independently controlled via a nested shaft design. Separate digital telemetry units for each shaft transmit data through a base unit to the facility performance data measurement system.

Acoustic technology development testing of the modern so-called generation-one model-scale blade designs has yielded results that, when projected to full-scale conditions, demonstrate significant progress relative to 1980s' test data. The full-scale projections indicate that an aircraft powered by such open-rotor propulsion would easily meet current CAEP Chapter 4 standards.

The generation-one designs tested in the recent acoustic campaign included five sets of forward and aft blades. Each set is distinctly different and was designed using three-dimensional aero-acoustic design tools to optimise acoustics and aerodynamic performance. GE designed three of the modern blade sets tested, and Snecma designed two.

Testing in the High Speed Wind Tunnel at the Glenn Research Center is planned to evaluate aerodynamic performance and acoustics at high-altitude cruise conditions.

In addition to the generation-one blades, generation-two blades are being designed for testing in 2011. The cumulative results of all of the testing, targeted for completion in 2012, will provide current state-of-the art acoustic and aerodynamic performance for modern open-rotor concepts over the full spectrum of engine operation, from takeoff to cruise.

Fuel savings are the essential benefit to be offered by an open-rotor engine. To that end, GE is maturing the critical technologies related to large-diameter, variable-speed and variable-pitch rotor blades that will enable double-digit reductions in fuel consumption compared with the most advanced turbofan engines. These include a reliable blade pitch-change system that will control the blade angle throughout the full range of engine operation, including reverse thrust, plus drive mechanisms for the large-diameter, lower-speed rotors.

Preparation for water-jet machining of an open rotor reduced-scale blade.

Open-rotor rig tests have confirmed that the technology development is on track to deliver dramatic fuel burn reduction and impressive acoustics. The tests have also substantiated the use of advanced aero-acoustic computational tools to guide future open-rotor designs.

Engine overhaul directory — worldwide

Company	Address	Contact details	Types (commercial)	Checks	Test cells
THE AMERICAS - OEMS					
GE Aviation, Services	GE Aviation, Services - Strother 4th and A Streets - Strother Field Arkansas City Kansas 67005 USA	John Macaulay GM T (1) 620 442 3600 F (1) 620 442 9003 E-mail: john.macaulay@ge.com www.geaviation.com	CFM56-2, -3, -5, -7 CF34-All CT7-All	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Five test cells
GE Aviation, Services	GE Aviation, Services - Celma Rua Alice Herve 356 Petropolis, Rio de Janeiro Brazil 25669-900	Marcelo Soares GM T (55) 24 2233 4401 F (55) 24 2233 4263 E-mail: marcelo.soares@ge.com www.geaviation.com	CFM56-3, -5, -7 CF6-80C2, -50	HSI, MC, MO, OH HSI, MC, MO, OH	Two test cells
GE Aviation, Services	On-Wing Support Cincinnati 3000 Earhart Ct. Ste 100, MD W21 Hebron Kentucky 41048 USA	Robert Soehner Business leader T (1) 859 334 4015 F (1) 859 334 4005 E-mail: robert.soehner@ge.com http://www.geaviation.com/services/ maintenance/ows/	CFM56-All CF34-All CF6-All GE90-All GEnx-All GP7000-All	HSI, MC HSI, MC HSI, MC HSI, MC HSI, MC HSI, MC	N/A
GE Aviation, Services	On-Wing Support Dallas 3010 Red Hawk Drive. Suite 100-A Grand Prairie Texas 75052 USA	Joel Corbitt Business leader T (1) 214 960 3323 http://www.geaviation.com/services/ maintenance/ows/	CFM56-All CF34-All CF6-All GE90-All GEnx-All GP7000-All	HSI, MC HSI, MC HSI, MC HSI, MC HSI, MC HSI, MC	N/A
Honeywell Aerospace	1300 West Warner Road 2101-2N Tempe, AZ† 85284 USA	Bill Wright Director technical sales Air Transport and Regional T (1) 480 592 4182 E-mail: bill.wright@Honeywell.com	ALF502 ALF507 ATF3 CFE738 TFE731 TPE331 HTF7000 Honeywell APUs	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	28 test cells
Pratt & Whitney Engine Services (Cheshire Engine Center)	500 Knotter Drive MS 303-01 Cheshire CT 06410 USA	Kevin Kearns General sales manager T (1) 203 250 4457 F (1) 860 755 9959 E-mail: kevin.r.kearns@pw.utc.com www.pw.utc.com	F117/PW2000 all PW4000 all	HSI, MC, MO, OH HSI, MC, MO, OH	Eight test cells
Pratt & Whitney Engine Services (Columbus Engine Center)	8801 Macon Road PO Box 84009 Columbus GA 31908 USA	Sean Treacy General sales manager T (1) 860-565-3922 F (1) 860 353 1304 E-mail: sean.treacy@pw.utc.com www.pw.utc.com	V2500-A1, A5	HSI, MC, MO, OH	Test cell
Pratt & Whitney Canada	St Hubert Service Center 7007 Chemin de la Savane St-Hubert Quebec J3Y 3X7 Canada	Jean-Luc Couderc Global sales manager T 450 468 7730 F 450 468 7807 E-mail: jean-luc.couderc@pwc.ca www.pwc.ca	PT6A, B, C, T PW100 PW150A PW200 ST6 ST18	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cell
Snecma America Engine Services	Acceso IV no.6 Int. A Fracc. Industrial Benito Juarez 76120 CP Queretaro Mexico	Wilfried Theissen GM T (52) 442 296 5600 F (52) 442 296 5624 E-mail: wilfried.theissen@sames.com.mx www.snecma.com	CFM56-5A, CFM56-5B, CFM56-7B	HSI, MC, MO, OH	Test cell
Rolls-Royce Brazil	Rua Dr. Cincinato Braga, 47 Bairro Planalto S„o Bernardo do Campo - S„o Paulo CEP09890-900 Brazil	Alessandro David Cinto Customer business director T (55) 11 4390 4804 F (55) 11 4390 4898	AE3007 All M250-All TAY650-15 T56 Series II,III Trent 700	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC	Three test cells
Rolls-Royce Canada	9500 CÙte de Liesse Road Lachine, PQ, QuÈbec H8T 1A2 Canada	Diana Hargrave VP programmes T (1) 514 828 1647 F (1) 514 828 1674 diana.hargrave@rolls-royce.com www.rolls-royce.com	AE3007 BR710 Spey Tay V2500	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	
Rolls Royce On Wing Care Services (in field, on/off-wing maintenance)	2135 Hoffman Road Indianapolis, IN 46241 USA	Rick Pataky Programme manager & GM Tel: 317-240-1221 Tel: 317-213-0164 rick.pataky@rolls-royce.com	AE2100 AE3007 all BR 700 Series, 710,715,725 RB211 all Tay 611 Trent 500,700,800,900,1000	HSI, MC, HSI, MC, HSI, MC, HSI, MC, HSI, MC, HSI, MC,	Nil

Engine overhaul directory — worldwide (cont...)

Company	Address	Contact details	Types (commercial)	Checks	Test cells
THE AMERICAS - AIRLINES					
American Airlines (AA Maintenance Services)	3900 N. Mingo Road Tulsa, OK USA	David Smith Manager, powerplant marketing T (1) 918 292 2567 M (1) 918 289 7368 F (1) 918 292 6734 E-mail: david.smith@aa.com www.aa-mro.com	JT8D-217/219 CF6-80A/-80C2 CFM56-7 Honeywell APUs	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH OH	Four engine test cells Two APU test cells
BizJet International (subsidiary of Lufthansa Technik)	3515 North Sheridan Tulsa OK 74115-2220 USA	Pete DuBois VP sales and marketing T (1) 918 831 7628 F (1) 918 832 8627 E-mail: pdubois@bizjet.com www.bizjet.com	TFE731 JT15D CF34 CJ610 CF700 Spey Tay	HSI. HSI, MC, MO, OH HSI. HSI, MC, MO, OH HSI, MC, MO, OH Repair, Mid-life, OH Repair, Mid-life, OH	Two test cells
Delta TechOps	Dept 460 1775 Aviation Blvd Atlanta Hartsfield International Airport, Atlanta GA 30320 USA	Jack Turnbill VP, technical sales and marketing T (1) 404 773 5192 F (1) 404 714 5461 E-mail: TechSales.Delta@delta.com www.deltatechops.com/	CFM56-3 CFM56-5 CFM56-7 CF34-3A/B CF34-8C CF6-80C2B1/B1F CF6-80C2B2/B2F CF6-80C2B4/B4F CF6-80C2B6/B6F CF6-80C2B7F CF6-80C2B8F CF6-80C2D1F JT8D-219 PW2000 PW4000-94 GTCP 131-9B GTCP 131-200	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Four engine test cells APU test cell
Lufthansa Technik AERO Service Center Tulsa	3515 North Sheridan Road Tulsa Oklahoma OK 74115 USA	Andreas Kehl VP marketing and sales Raimund Schnell VP marketing and sales T (918) 605 1883 F (918) 831 9095 E-mail: sales@lhaero.com www.lhaero.com	PW100 series PW 150 series CF34-3 series CF34-8 series CF34-10 series	HSI, MC, MO HSI, MC, MO HSI, MC, MO HSI, MC, MO	1 test cell
TAP Maintenance and Engineering Brazil	Estrada das Canarias, 1862 21941-480 Rio de Janeiro / RJ Brazil	Ricardo Vituzzo Sales GM Tel: (+55 21) 3383 2782 Fax: (+55 21) 3383 2047 E-mail: ricardo.vituzzo@tapme.com.br www.tapme.com.br	PW118/A/B PW120/A PW121 PW125B PW127 T56	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Two test cells
United Services	United Services Maint. Center San Francisco Intíl Airport Building 74 - SFOUS San Francisco CA 94128 USA	Paul Lochab MD sales and services T (1) 650 634 4104 F (1) 650.634.5926 E-mail: mro@unitedsvcs.com www.unitedsvcs.com	PW2000 PW4000 (all)	HSI, MC, MO, OH HSI, MC, MO, OH	Two test cells (all listed engines)
THE AMERICAS - INDEPENDENTS					
Aveos Fleet Performance	7171 Cote Vertu Ouest Zip 8040 Dorval (QuÈbec) H4S 1Z3 Canada	Jim Andrews VP and GM, engine solutions T (1) 514 828-3517 F (1) 514 945-3830 jim.r.andrews@aveos.com business@aveos.com www.aveos.com	CF34-3 series CF34-8 series CFM56-2 series CFM56-3 series CFM56-5 series JT9D-7 (A-J), JT9D-7R4 (D/E) GTCP85-129 GTCP331-200	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Two test cells
Aeromaritime America (ITP)	4927 E. Falcon Drive Mesa AZ 85215-2545 USA	Anita L. Goodwin GM T (1) 480 830 7780 F (1) 480 830 8988 E-mail: agoodwin@aeromarusa.com www.aeromarusa.com	RR M250-All series PW200	HSI, MC, MO, OH Servicing	Test cell N/A
APECS Engine Center	13642 SW 142nd Avenue Miami FL 33186 USA	Fred Laemmerhirt Director T 305 255 2677 F 305 255 0277 E-mail: Fred@a-pecs.com www.a-pecs.com	JT8D (all) JT8D-7B JT8D-9A JT8D-15, -15A JT8D-17, -17A, -17AR JT8D-200 series	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH Gearbox overhaul	Test cells available On-wing repairs C7 blade blending Hushkit installations QEC Installs/swaps
Atech Turbine Components	1 St Mark Street Auburn MA 01501 USA	Jay Kapur GM T (1) 508 721 7679 F (1) 508 721 7968 E-mail: jayk@atechturbine.com www.atechturbine.com	JT15D PT6 PW100 PW200 PW500	OH OH OH OH OH	N/A - component OH & repair only

Engine overhaul directory — worldwide (cont...)

Company	Address	Contact details	Types (commercial)	Checks	Test cells
Aviation Engine Service	8050 NW 90th St Miami FL 33166 USA	Guillermo Galvan President T (1) 305 477 7771 F (1) 305 477 7779 E-mail: Galvan@aviationengine.com	JT3D JT8D-1-17R JT8D-200	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cells available
CD Aviation Services	2707 E. 32nd Street Suite #2 PO Box 2367 Joplin MO 64803 USA	Rick Gibbs GM T (1) 417 206 2327 F (1) 417 206 2336 E-mail rick.gibbs@cdaviationservices.com www.cdaviationservices.com support@cdaviationservices.com	TPE331 TFE731	HSI, MC, MO, OH HSI, MC	
Complete Turbine Service	Turbine Engine Services 3300 SW 13th Avenue Ft. Lauderdale Florida 33315 USA	Konrad J. Walter President/member Ed Blyskal VP marketing and sales Mike Bartosh VP-Mtc operations T (1) 954 764 2616 F (1) 954 764 2516 www.completeturbine.com	CF6 series CF34 Series CFM56 series JT3D series JT8D series JT9D series PW2000 series PW4000 series RB211 Series RR Tay Series RR BR710 V2500 Series Honeywell Series APU	BSI, EMG, FS, HIS, MC, MPA, OH, QEC, TCI BSI, EMG, FS, HIS, MPA, MC, QEC, TCI BSI, EMG, FS, HIS, MC, MPA, QEC, TCI, BSI, FS, HSI, MC, TCI EMG, MPA, QEC BSI, EMG, FS, HSI, MC, MPA, QEC, TCI BSI, EMG, FS, HSI, MC, MPA, QEC, OH, TCI BSI, EMG, FS, MPA, QEC BSI, EMG, FS, MC, MPA, QEC BSI, EMG, FS, MC, MPA, QEC BSI, EMG, MPA, QEC BSI, EMG, MPA BSI, EMG, FS, MPA, QEC	
Dallas Airmotive (BBA Aviation)	900 Nolen Drive Suite 100 Grapevine TX 76051 USA	Christopher Pratt Dir. marketing & strategic planning T (1) 214 956 2601 F (1) 214 956 2825 E-mail: turbines@BBAAviationERO.com www.BBAAviationERO.com	PW100 PT6A & T JT15D TFE731 RR model 250/T63/T703 Spey Tay ALF502 CFE738 CF34 CJ610/J85 HTF7000 RE100 PW300 PW500 GTCP model 36 APU	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC HSI, MC HSI, MC, MO, OH MC MC HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	7 test cells in Dallas, TX 4 test cells in Neosho, MO Test cell in Charlotte, NC Five test cells in Portsmouth, UK
FJ Turbine Power	8195 West 20th Ave. Hialeah Florida 33014 USA	Jose Gomez de Cordova CEO E-mail: fjturbinepower@aol.com Manny Castanedo VP E-mail: mannyfjtp@aol.com Vernon Craig VP Marketing E-mail: vcraig@fjturbinepower.net T (1) 305-820-8494 F (1) 305-820-8495 C (1) 954-593-9988 www.fjturbinepower.net	CFM56-3 (all series) JT8D-7, -7B, -9A,-15, -15A JT8D-17, -17A, -17AR JT8D-209, -217, -217A, -217C JT8D-219 JT8D gearboxes	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	One test cell (JT8D) 24/7 AOG field for customers
ITR	Acceso IV No 6 Zona Industrial Benito Ju·rez CP 76120 QuerÈtaro, Qro. MÈxico	Emilio Otero CEO E-mail: itr@itrmexico.com.mx Julio RamÌrez Commercial director E-mail: dircom@itrmexico.com.mx T (52 + 442) 296 3915 / 00 F (52 + 442) 296 3906 / 08 www.itrmexico.com.mx	JT8D-STD JT8D-200 TPE-331	HS1, ESV1/2, EHM, MO, MC, OH HS1, ESV1/2, EHM, MO, MC, OH HSI, CAM, MO, MC	Two test cells
Kelly Aviation Center	3523 General Hudnell Drive San Antonio Texas 78226 USA	Frank Cowan Director, business development T (1) 210 928 5052 C (1) 210 827 5275 F (1) 210 928 5470 E-mail: frank.cowan@lmco.com www.kellyaviationcenter.com	CF6-50	HSI, MC, MO, OH	Four large engine turbofan cells with one capable of afterburner operation, Four turboprop/ turboshaft cells
Marsh Aviation	5060 East Falcon Drive Mesa AZ 85215-2590 USA	Ed Allen GM T (1) 480 832 3770 F (1) 480 985 2840 E-mail: allen-e@marshaviation.com www.marshaviation.com	TPE331 T76	HSI, OH HSI, OH	TPE331 T76
MTU Maintenance Canada	6020 Russ Baker Way Richmond BC V7B 1B4 Canada	Ralf Schmidt CEO and president T (1) 604 233 5755 F (1) 604 233 5719 E-mail: info@mtucanada.com www.mtu-canada.com	CF6-50 CFM56-3	HSI, MC, MO, OH MC	Test cell

Engine overhaul directory — worldwide (cont...)

Company	Address	Contact details	Types (commercial)	Checks	Test cells
NewJet Engine Services	13945 SW 139 Court Miami FL 33186 USA	Muazzi L. Hatem VP sales T (1) 305 256 0678 F (1) 305 256 0878 E-mail:muazzih@newjet.net www.newjet.net	JT8D-7B, -9A, -11, -15, -15A JT8D-17, -17A, -17AR JT8D-209 JT8D-217, -217A, -217C JT8D-219	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cells available
Patriot Aviation Services	9786 Premier Parkway Miramar FL 33025 USA	Virgil Pizer T (1) 954 462 6040 F (1) 954 462 0702 E-mail: virgil@patriotaviation.com www.patriotaviation.com	JT3D series JT8D series JT8D-200 series JT9D series CF6 series CFM56 series CF34 series V2500 series PW2000 series PW4000 series TAY series RB211 series BR700 series T56 series AE2100 series APU/GTC all series	HSI, MO, OH, Global capability HSI, MO, OH HSI, MO, OH HSI, MO, OH HSI, MO, OH HSI, MO, OH HSI, MO, QEC HSI, MO, QEC HSI, MO, QEC HSI, MO, QEC HSI, MO, QEC HSI, MO, QEC HSI, MO, QEC HSI, MO, QEC, BSI HSI, MO, QEC, BSI BSI	
Prime Turbines	630 Barnstable Road Barnstaple Municipal Airport Hyannis MA 02601 USA	Jack Lee Customer service manager T (1) 508 771 4744 F (1) 508 790 0038 E-mail: pt6@prime-turbines.com www.prime-turbines.com	PT6 all	HSI, OH	Test cell
StandardAero	Corporate Offices 1524 West 14th Street #110 Tempe Arizona 85281-6974 USA	Mike Turner Director marketing and corp comm. T (1) 480 377-3195 F (1) 480 377-3171 E-mail: mike.turner@standardaero.com www.standardaero.com	AE2100 AE3007 CF34-3/-8 CFM56-7 GTCP 36, GTCP85, RE220, APS2300 Model 250 PT6A PW100 PW600 T56/501D TFE731 TPE331	MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH Full MRO cap. HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cells for all displayed engine types available
Texas Aero Engine Services (JV, American Airlines and Rolls-Royce)	2100 Eagle Parkway Fort Worth TX 76177 USA	Jim Holmes Senior manager, customer business T (1) 817 224 1042 F (1) 817 224 0043 E-mail: j.holmes@taesl.com www.taesl.com	Trent 800 RB211-535	HSI, MC, MO, OH HSI, MC, MO, OH	Trent 800 RB211-535
TIMCO Engine Center	3921 Arrow Street Oscoda MI 48750 USA	Dennis Little GM T (1) 989 739 2194 ext 8532 F (1) 989 739 6732 E-mail (1): Dennis.Little@TIMCO.Aero E-mail (2): David.Koffs@TIMCO.Aero www.timco.aero	JT8D series JT8D-200 series JT8D series JT8D-200 series CFM56-3/-5/-7	HSI, MC, MO, OH HSI, MC, MO, OH On wing On wing On wing	Test cell for JT8D series JT8D-200 series
Timken Overhaul Services	3110 N Oakland St Mesa, Az 85215-1144 USA	Larry Batchelor Sr Product Sales Manager T (1) 480 606 3011 F (1) 480 635 0058 E-mail: larry.batchelor@timken.com www.timken.com/mro	PT6A Series PT6T Series T53	HSI, MC, MO, OH HSI, MC, MO, OH	Test cell for all listed eng Fuel control overhaul
United Turbine	8950 NW 79 Ave. Miami FL 33166 USA	Ali Mozzayanpour President T (1) 305 885 3900 F (1) 305 885 0472 E-mail: pt6@unitedturbine.com www.unitedturbine.com	PT6A & T	HSI, MC, MO, OH	Dynamometer Test cell
Vector Aerospace Engine Services - Atlantic	PO Box 150 Hangar 8 Slemon Park Summerside PE Canada C1N 4P6	Tim Cox VP engine & component sales T (1) 817 416 7926 F (1) 817 421 2706 E-mail: sales.esa@vectoraerospace.com www.vectoraerospace.com	PW100 PT6A JT15D 307A 308A/C	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cells available
Wood Group Turbopower	4820 NW 60th Ave Miami Lakes FL 33014 USA	Rana Das VP, GM T (1) 305 423 2300 F (1) 305 820 0404 E-mail: rana.das@woodgroup.com www.woodgroupturbopower.com	T56/501D PT6A PT6T ST6 APU	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	T56/501D PT6A prop cell PT6T dyno cell T56 prop cell 90,000ft2 facility

Engine overhaul directory — worldwide (cont...)

Company	Address	Contact details	Types (commercial)	Checks	Test cells
EUROPE - AIRLINES					
Air France Industries (AFI KLM E&M)	BP7 Le Bourget Aeroport 93352 Le Bourget Cedex France	Rob Pruim VP Sales International T (31) 20 649 1100 F (31) 20 648 8044 E-mail: rm.pruim@klm.com www.afiklmem.com	CFM56-5A, -5B, -5C CFM56-3, CFM56-7 CF6-50 CF6-80A, -80C2, -80E1 GE90	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cell up to 100,000lb CFM56 CF6 GE90
Alitalia Maintenance Systems	Leonardo da Vinci Airport Piazza Almerico da Schio 00050 Rome-Fiumicino Italy	Oreste Murri Manager of marketing & sales T (39) 06 6543 5236 F (39) 06 6543 5111 M†(39) 335 7389 719 E-mail: murri.oreste@alitaliaservizi.it E-mail: ams@alitaliaservizi.it www.alitaliamaintenancesystems.it	CF6-50 C2/E2 CF6-80 C2 CFM56-5B	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	CF6 test cell
Finnair Engine Services	Finnair Technical Services Helsinki-Vantaa Airport DE/83 01053 FINNAIR Finland	Mika H‰nninen VP sales and marketing T (358) 9 818 6443 F (358) 9 818 6900 mika.hanninen@finnair.com www.finnairtechnicalservices.com	CFM56-5B CF6-80C2 PW2037/2040	HSI, MC, MO, OH HSI, MC, MO, OH MC	Turbofan up to 100,000lb
Iberia Maintenance	Madrid-Barajas Airport La MuÒoza. Edif. Motores E-28042 Madrid Spain	JosÈ Luis QuirÛs Cuevas Commercial & development director T (34) 91 587 5132 F (34) 91 587 5884 E-mail: jlquirosc@iberia.es www.iberiamaintenance.com	CFM56-5A, -5B, -5C CFM56-7B CF34-3A1, -3B1 JT8D-217, -219 RB211-535E4, -535C37	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Three test cells 1 up to 100,000lb 2 for JT8D
KLM Engineering & Maintenance (AFI KLM E&M)	Dept SPL / TQ PO Box 7700 Schiphol Airport 1117 ZL Amsterdam Netherlands	Rob Pruim VP sales international T (31) 20 649 1100 F (31) 20 648 8044 E-mail: rm.pruim@klm.com www.afiklmem.com	CFM56-5A, -5B, -5C CFM56-3, CFM56-7 CF6-50 CF6-80A, -80C2, -80E1 GE90	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cell up to 100,000lb CFM56 CF6 GE90
Lufthansa Technik	HAM TS Weg beim Jaeger 193 Hamburg D-22335 Germany	Walter Heerdt SVP marketing & sales T (49) 405070 5553 F (49) 405060 8860 E-mail: marketing.sales@lht.dlh.de www.lufthansa-technik.com	JT9D JT15 PW4000 ALF502/LF507 CF6-80C2 CF6-80E1 CFM56-2, -3, -5, -7 V2500 CF34 PW100 PW150 Trent 500 Trent 700 Trent 900 Spey Tay	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Six test cells up to 100,000lb Airline support teams Total engine support Spare engine coverage On-spot borescope Engine lease HSPS
Lufthansa Technik AERO Alzey	Rudolf-Diesel-Strasse 10 D-55232 Alzey Germany	Andreas Kehl VP Marketing and Sales Raimund Schnell VP Marketing and Sales T +49 (0) 6731 4970 F +49 (0) 6731 497333 E-mail: sales@lhaero.com www.lhaero.com	PW100 series PW 150 series CF34-3 series CF34-8 series CF34-10 series	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	1 test cell
Lufthansa Technik Airmotive Ireland	Naas Road Rathcoole Co. Dublin Ireland	Paul Morgan Commercial manager T (353) 1 401 1109 F (353) 1 401 1344 E-mail: paul.morgan@ltai.ie www.ltai.ie	JT9D-7A/F/J JT9D-7Q CFM56-2, -3, -7 V2500	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	JT9D JT9D CFM56
Lufthansa Technik Switzerland	P.O. Box CH-4002 Basel Switzerland	Thomas Foth Director sales & marketing T (41) 61 568 3070 F (41) 61 568 3079 thomas.foth@lht-switzerland.com www.lht-switzerland.com	ALF502/LF507	HSI, MC, MO, OH	
N3 Engine Overhaul Services	Gerhard-Hoeltje Str. 1 D-99310 Arnstadt Germany	Wolfgang Kuehnhold GM T (49) 3628 5811 211 F (49) 3628 5811 8211 E-mail: wolfgang.kuehnhold@n3eos.com www.n3eos.com	Trent 500 Trent 700 Trent 900	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cell for Trent 500/700/900 up to 150,000lb
TAP Maintenance & Engineering	Marketing & Sales P.O. Box 50194 1704-801 Lisbon Portugal	Pedro Pedroso GM engine sales T (+351) 218 415 430 F (+351) 218 415 913 E-mail: ppedroso@tap.pt www.tapme.pt	CFM56-3 CFM56-5A/5B/5C CFM56-7B JT8D (standard) RB211-524B4 RB211-524D4	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cell up to 100,000lb

Engine overhaul directory — worldwide (cont...)

Company	Address	Contact details	Types (commercial)	Checks	Test cells
Turkish Engine Center	Sabiha Gokcen Int/l Airport 34912 Pendik Istanbul Turkey	Aykut Tutucu Sales, Mkng and Cust. Supp. Dir T (90) 216 585 4810 F (90) 216 585 4805 aykut.tutucu@pw.utc.com	CFM56-3/-5/-7 series V2500 series	Maint., Repair, OH Maint., Repair, OH	Uses Turkish Technic's test cell
Turkish Technic	Turkish Technic Inc. Ataturk Intîl Airport Gate B 34149 Yesilkoy Istanbul Turkey	Altug Sokeli Technical marketing & sales mgr T (90) 212 463 63 63 ext. 9223 F (90) 212 465 25 21 asokeli@thy.com techmarketing@thy.com www.turkishtechnic.com	CFM56-3 Series CFM56-5A/ -5B/ -5C Series CFM56-7B CF6-80A Series CF6-80C2 LF507-1F V2500	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cells for all listed engines
EUROPE - INDEPENDENTS					
Aeromaritime Mediterranean (ITP)	7, Industrial Estate Hal Far BBG 06 MALTA	Mario Mazzola MD T (356) 21 65 1778 F (356) 21 65 1782 E-Mail: mario.mazzola@aeromaritime.com www.aeromaritime.com	M250-all series	HSI, MC, MO, OH	One test cell
Air Atlanta Aero Engineering	Shannon Airport Co. Clare Ireland	Martin O'Boyle T (353) 61 717780 F (353) 61 717709 E-mail: moboyle@airatlanta.ie www.airatlanta.ie	CF6-80 JT8D CFM56 RR Tay RB211 JT9D	On-wing repairs On-wing repairs On-wing repairs On-wing repairs On-wing repairs On-wing repairs	
Avio	Avio - MRO Division Commercial Aeroengines Viale Impero 80038 Pomigliano dÌArco Napoli Italy	Werner Schroeder VP Avio MRO Division T (39) 081 316 3268/3809 F (39) 081 316 3716 E-mail: armando.murolo@aviogroup.com www.aviogroup.com	PW100 (120,121,124B,127, 127E,127F,127B,120A, PW123, PW123AF,127G JT8D-200 Engine Family CFM56-5B, -7B	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	No. 8 up to 100,000lb thrust
CRMA (Construction reparation material aÈronautique) Subsidiary of Air France	14 avenue Gay-Lussac ZA clef de st-Pierre F 78990 Elancourt France	Luc Bornand CEO T (33) 1 3068 37 01 F (33) 1 3068 3620 E-mail:luc.bornand@crma.fr www.crma.fr	CF6-80C2, CF6-80E1 CFM56-3 / -5 / -7 GE90, GP7200	MO and repair parts MO and repair parts MO and repair parts	None
EADS SECA	1 boulevard du 19 mars 1962 BP 50064 95503 Gonesse Cedex France	Jean-Jacques Reboul VP sales & marketing T (33) 1 30 18 53 13 F (33) 1 30 18 54 90 jean-jacques.reboul@seca.eads.net www.seca.eads.net	PW100 series PT6A JT15D TFE731 series CF700 PW300 series	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Four test cells
Euravia Engineering	Euravia House Colne Road Kelbrook Lancashire BB18 6SN UK	Steve Clarkson Director customer services T (44) 1282 844 480 F (44) 1282 844 274 E-mail: steve.clarkson@euravia.aero www.euravia.aero	PT6A Series PT6T Series ST6L GTCP 165 Artouste Mk 120-124 Rover Mk 10501	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cells for all listed engines
H+S Aviation (BBA Aviation)	Airport Service Road Portsmouth, Hamphsire PO3 5PJ UK	Steve Bull Territorial sales director T: (+44) 23 9230 4256 F: (+44) 23 9230 4020 steve.bull@hsaviation.co.uk www.BBAAviationERO.com	CT7-2 through -9 JT15D PT6T RR250/T63/T703 T700 GTCP 36-100/150 APU GTCP 331-200/250 APU PW901 APU T40-1 APU	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Five test cells
Industria de Turbo Propulsores (ITP) Ajalvir	M-108, Ctra. Torrejon-Ajalvir 28864 - Ajalvir Madrid PostBox: Apdo. 111 28850 - Torrejon de Ardoz Madrid Spain	Jose Luis Zubeldia In service support executive director T (34) 91 205 4611 F (34) 91 205 4650 E-mail: joseluis.zubeldia@itp.es www.itp.es	ATAR 9K50, F404-400, EJ200 TFE731-2/3/4/5, CF700 PW100 (123AF, 127G) PT6T-3, TPE331-All, T55, T53 LM2500 TP400, MTR390-E BR715	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH (WIP) Parts repair only	Seven test cells Two turbofan cells Up 25.000lb Two turboshaft cells Up to 5,000shp One Turboprop cell (Prod) Up to 20,000shp Two Turboshaft (Prod)
Industria de Turbo Propulsores (ITP) Albacete	Parque Aeron·utico y LogÌstico Ctra. de las PeÒas 02006 - Albacete PostBox: Apdo. 7036 02080 - Albacete Spain	Santiago Tellado ISS business commercial director T (34) 91 205 4592 F (34) 91 205 4650 E-mail: santiago.tellado@itp.es www.itp.es	CT7 TP (-5, -7A, -9C) CT7 TS (-2A, -8A, -8E, -8F5) PW206 A/B/B2/C/E PW207 C/D/E T700-GE-401/C, -701A/C/D	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	One Test Cell Up to 5,000 hp
MTU Maintenance Berlin-Brandenburg	Dr.-Ernst-Zimmermann-Str. 2 D-14974 Ludwigsfelde Germany	T (49) 3378 824 0 F (49) 3378 824 300 E-mail: ludwigsfelde@mtu.de www.mtu-berlin.com	CF34-3, CF34-8, CF34-10 PT6A, PW200, PW300 PW500	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Four test cells

Engine overhaul directory — worldwide (cont...)

Company	Address	Contact details	Types (commercial)	Checks	Test cells
MTU Maintenance Hannover	Muenchner Str. 31 D-30855 Langenhagen Germany	Dr. Martin Funk President & CEO T (49) 511 7806 0 F (49) 511 7806 2111 E-mail: hannover@mtu.de www.mtu-hannover.de	CF6-50, -80C2 CFM56-7 PW2000 series PW6000 V2500-A1, -A5, -D5	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Two test cells 150,000 lb
OGMA	2615-173 Alverca Portugal	M·rio Lobato Faria VP aviation services T (351) 21 958 1000 F (351) 21 957 9010 E-mail: com_engine@ogma.pt www.ogma.pt	AE2100/D3, AE3007 T56/501 series Turmo Artouste	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Six test cells 30,000 lb
Vector Aerospace Engine Services UK	12 Imperial Way Croydon Surrey CR9 4LE UK Fleetlands Building 110 Fareham Road Gosport Hampshire PO13 OAA UK	Philip Self Director - sales UK T (44) 20 8688 7777 F (44) 20 8688 6603 E-mail: philip.self@vectoraerospace.com www.vectoraerospace.com	ALF502/ LF 502 PW 307/308 RR T56/501D series RR 250 series RR Conway & Dart series Hamilton 54H60 Propellers	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	T/fan cell up to 40,000lb T/shaft cell up to 10,000 shp
SR Technics	Zurich Airport CH-8058 Switzerland	Sean O'Connor EVP sales (acting) T (41) 43 812 13 01 F (41) 43 812 97 98 E-mail: sean.oconnor@srtechnics.com www.srtechnics.com	CFM56-5B/C, -7 PW4000 (94 & 100 fan)	HSI, MC, MO, OH HSI, MC, MO, OH	One test cell 100,000lb
Summit Aviation	Merlin Way Manston Kent CT12 5FE UK	Bruce Erridge Commercial director T (44) 1843 822444 F (44) 1843 820900 E-mail: Bruce@summit-aviation.co.uk	JT3D JT8D-Std All Series JT8D-200 Series	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	One test cell 40,000lb
Turbine Motor Works (TMW)	Hangar 1, Upwood Airpark Ramsey Road Bury, Cambridge PE26 2RA UK	David Billington Director of sales and marketing T (44) 1487 711650 F (44) 1487 710777 E-mail: david.billington @turbinemotorworks.com www.turbinemotorworks.com	CF6-50 CF6-80 JT9D JT3D	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	
ASIA, AFRICA, MIDDLE EAST, AUSTRALASIA					
Abu Dhabi Aircraft Technologies	PO Box 46450 Abu Dhabi International Airport Abu Dhabi UAE	Kirubel Tegene VP marketing and sales commercial T: (+971) 2 5057 234 F: (+971) 2 5757 263 E-mail: commercial@adat.ae www.adat.ae	CF6-50C/E CF6-80C2 series CFM56-5A series PT6 series Trent 500 (planned) Trent 700 V2500A5 (planned) GTCP331-200, -250, -350 series	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH MC & TEST (planned MO,OH) HSI, MC, MO, OH HSI, MC, MO, OH	100,000lb
Ameco Beijing	PO Box 563 Capital International Airport Beijing China 100621	Mr Teng Bin/Mr Olaf Albrecht Senior directors, marketing & sales T: (+86) 10 6456 1122 X 4100/4101 F: (+86) 10 6456 1823 E-mail: sales@ameco.com.cn www.ameco.com.cn	PW4000-94 RB211-535E4	HSI, MC, MO, OH HSI, MC, MO, OH	100,000lb (one cell)
Bedek Aviation	Engines Division Bedek Aviation Group Israel Aircraft Industries Ben-Gurion Airport 70100 Israel	Michel Levy GM T: (+972) 3 935 7064 F: (+972) 3 935 8740 E-mail: milevy@iai.co.il www.iai.co.il	CFM56-2/-3/-5-7 JT3D-3B/-7 JT8D-7 to -17R JT8D-217/-219- JT9D-7A/-7F/-7J JT9D-59A/-70A/-7Q/-7R4/ -7R4G2/-7R4D/E T53-13/-703 T56/501 PW4000-94 PT6A-27 to -42/-50/T V2500-A5	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HIS, MC	Four jet engines One turboprop Three turboshaft
Ethiopian Airlines	PO Box 1755 Bole International Airport Addis Ababa Ethiopia	Zemene Nega Director tech. sales and marketing T: (+251) 11 6651192 F: (+251) 11 6651200 / 11 6611474 E-mail: Zemenen@ethiopianairlines.com www.ethiopianairlines.com	JT8D JT9D PW2000 PT6 PW120, PW121,	HSI, MC, MO, OH HSI, MC HSI, MC HSI, MC, MO, OH HSI, MC, MO, OH	One 100,000lb test cell Two turboshaft test cells
GE Aviation, Services	GE Aviation, Services - Malaysia MAS Complex A-AA1802 SAAS Airport 47200 Subang, Selangor D.E Malaysia	Alan Jones GM T (603) 5039 4502 F (603) 5039 4702 E-mail: alan.jones1@ge.com www.geaviation.com	CFM56-3, -5 PW4056, PW4168	HSI, MC, MO, OH HSI, MC, MO, OH	One test cell

Engine overhaul directory — worldwide (cont...)

Company	Address	Contact details	Types (commercial)	Checks	Test cells
GE Aviation, Services	On-Wing Support Korea Aircraft Maintenance B Area Incheon International Airport 2840 Woonseo-Dong, Jung-Ku Incheon 400-430 South Korea	DY Kwon (acting) Business leader T (82) 32 744 5971 F (82) 32 744 5979 E-mail: dongyeon.kwon@ge.com http://www.geaviation.com/services/maintenance/ows/	CFM56-All CF34-All CF6-All GE90-All GEnx-All V2500 PW4000	HSI, MC HSI, MC HSI, MC HSI, MC HSI, MC HSI, MC HSI, MC	
GE Aviation, Services	On-Wing Support Xiamen No. 3 Road of Xiamen Aviation Industry Xiamen, 361006 P.R. China	Li Jun Business leader T (86) 592 573 1501 F (86) 592 573 1605 E-mail: jun4.li@ge.com http://www.geaviation.com/services/maintenance/ows/	CFM56-All CF34-3 CF34-10 (Planned) GE90-All (Planned) GEnx-All (Planned)	HSI, MC HSI, MC	
GMF-AeroAsia Indonesia	Marketing building Soekarno-Hatta International Airport PO Box 1303, BUSH 19130 Cengkareng, Jakarta Indonesia	Bimo Agus VP Bus. development & cooperation T (62) 21 550 8609, 550 8670 F (62) 21 550 2489 E-mail: marketing@gmf-aeroasia.co.id www.gmf-aeroasia.co.id	CFM56-3B1, 3C1 Spey 555 ser	HSI, MC, MO, OH HSI, MC, MO, OH	120,000lb
HAESL	70 Chun Choi Street Tseung Kwan O Industrial Est New Territories Hong Kong	David Radford Customer business manager T: (852) 2260 3264 F: (852) 2260 3277 E-mail: david.radford@haesl.com www.haesl.com	RB211-524 C2/D4 RB211-524G/H-T Trent 500 Trent 700 Trent 800	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	130,000lb
Honeywell Aerospace Singapore	161 Gul Circle Singapore 629619 Singapore	Bob Norazni GM/ISC director T: (65) 6861 4533 F: (65) 6861 2359 E-mail: bob.norazni2@honeywell.com www.honeywell.com	TPE331	HSI, OH	TPE331
IHI	229, Tonogaya Mizuh-Machi Nishitama-Gun Tokyo 190-1297 Japan	Kazuo Satou GM sales group T: (81) 425 68 7103 F: (81) 425 68 7073 E-mail: kazuo_satou www.ihi.co.jp	CFM56-3 CF34-3/-8 V2500	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Two test cells capable of 115,000lb and 60,000lb
Jordan Airmotive (JALCo)	Queen Alia International Airport (QAIA) PO Box 39180 Code 11104 Amman Jordan	Qassem Omari Vice chairman/GM T: (962) 6445 1181 F: (962) 6445 2620 E-fax: 1 801 340 6924 E-mail: qomari@rja.com.jo www.jalco.com.jo	JT3D-7/-3B JT8D standard RB211-524 series CF6-80C2 CFM56-5	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH Partial repair - mod. cap. QEC build-up	100,000lb JT3D JT8D RB211-524 CF6-80C2
LTQ Engineering (formerly Jet Turbine Services, JV of Lufthansa Technik and Qantas)	70-90 Garden Drive Tullamore VIC 3043 Australia	Marek Wernicke CEO T: (61) 3 8346 2002 F: (61) 3 8346 2111 E-mail: marek.wernicke@ltq.com.au	CFM56-3 CFM56-7B CF6-80C2 CF6-80E1	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	

Engine overhaul directory — worldwide (cont...)

Company	Address	Contact details	Types (commercial)	Checks	Test cells
Lufthansa Technik Philippines	MacroAsia Special Economic Zone Villamor Air Base Pasay City Metro Manila 1309 Philippines	Richard Haas VP marketing & sales T: (63) 2855 9310 F: (63) 2855 9309 E-mail: richard_haas@ltp.com.ph Emaill: sales@ltp.com.ph www.ltp.cpm.ph	CF6-80C2 CF6-80E1 CFM56-3 CFM56-5B/-5C	QEC build-up, minor repairs QEC build-up, minor repairs QEC build-up, minor repairs QEC build-up, minor repairs	
MTU Maintenance Zhuhai	1 Tianke Road Free Trade Zone Zhuhai, 519030 P.R. China	Holger Sindemann President & CEO T (86) 756 8687806-177 F (86) 756 8687910 E-mail: holger.sindemann@mtuzhuhai.com www.mtu-zhuhai.com	V2500-A5 CFM56-3 CFM56-5B CFM56-7	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	150,000 lb
Pratt & Whitney Engine Services (Eagle Services Asia)	Eagle Services ASIA 51 Calshot Road Singapore 509927	Ulrico Zubler General sales manager T (65) 65 48 29 25 F (65) 65 49 46 54 E-mail: ulricho.zubler@pw.utc.com www.pw.utc.com	JT9D-7Q, 7R4, 7A, 7J PW4000-94, 100	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cells for all listed engines
Pratt & Whitney Engine Services (Christchurch Engine Center)	Christchurch Engine Centre 634 Memorial Ave Christchurch International Airport	Steven Robinson General sales manager T (64) 3 374 7007 F (64) 3 374 7001 E-mail: steve.robinson@pw.utc.com www.pw.utc.com	JT8D-STD, -200 V2500 A1, A5, D5 RR Dart All	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Test cells for all listed engines
Pratt & Whitney Engine Services (Shanghai Engine Center)	Shanghai Pratt&Whitney Aircraft Engine Maintenance No.8 Block1 8228 Beiqing Road Qingpu District Shanghai Post Code:201707 PR China	Stephen Sun General sales manager T (86) 21-3923-0023 F (86) 21-3923-0088 E-mail: steven.sun@pw.utc.com www.pw.utc.com	CFM56-3, -5B, -7B	HSI, MC, MO, OH	Test cells for listed engines
SAA Technical	Room 309, 3rd floor Hangar 8 Jones Road Gauteng Johannesburg International Airport 1627 South Africa	Ismail Randeree Executive mgr mkg & cust. support T: (27) 11 978 9993 F: (27) 11 978 9994 E-mail: satmarketing@flysaa.com www.flysaa.com	JT8D-7/-7A/-9/-9A/-15/-15A/-17/-17A JT9D-7R4G2/-7F/-7J RB211-524G/H V2500 CFM56-3/-5B/-7B	HSI, MC, MO, OH HSI, MC, MO, OH MC MC MC	Test cell for JT8D, JT9D, CF6-50C2, RB211-524G/H
Sichuan Snecma Aero-engine Maintenance	Shuangliu Airport Sichuan Province 610201 Chengdu Chine	Jean-Louis Sauvetre DG T : +86 28 8 572 16 93 F: +86 28 8 572 16 96 jean-louis-sauvetre@ssamc.com.cn	CFM56-3 CFM56-5B CFM56-7B	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Two tests cells
Snecma Morocco Engine Services	BP87 Mohammed V Airport Nouasser - Casablanca Morocco	Alexandre Brun GM T : +212 2 253 69 00 F: +212 2 253 98 42	CFM56-3, CFM56-5B and CFM56-7 (piece part level)	HSI, MO, OH	one test cell
ST Aerospace	501 Airport Road Paya Lebar Singapore 539931	Yip Hin Meng VP/GM (STA Engines) T: (65) 6380 6788 F: (65) 6282 3010 E-mail: yiphm@stengg.com www.staero.aero	CFM56-3/-5/-7 JT8D all F100 F404 J85 T53 T56/501 series Makila 1A/1A1	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH	Five test cells
Thai Airways	Tech marketing and sales dept. Technical department Suvarnabhumi Airport Bangphli Samut Prakarn 10540 Thailand	Bunloo Varasarin Dir. tech. mktg. & sales dept. T: (662) 137 6300 F: (662) 137 6942 E-mail: bunloo.v@thaiairways.com www.thaiairways.com	CF6-50 CF6-80C2 PW4158 Trent 800	MC, Mo, OH MC, Mo, OH MC MC	CF6-50/-80C2 PW4158 Trent 800
Turbomeca Africa	Atlas Road PO Box 7005 Bonearo Park 1622 South Africa	Robert Bonarius Manager sales & customer service T: (27) 11 927 2000 F: (27) 11 927 2956 E-mail: info@turbomeca.co.za www.turbomeca.co.za	Turmo 3C4, 4C Makila 1A, 1A1, 1A2, 1K2 Arrius 2K2, 2K1, 2B1, 2B2 Arriel series Adour	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH MC MC	Turmo Makila Arrius Adour

Abbrevations
HIS: hot section inspection
MC:module change
OH:full engine overhaul
MO: module overhaul

If you wish to be listed in next year's EYB contact jason.holland@ubmaviation.com

APU overhaul directory 2011

Company	Address	Contact details	APU types	Capabilities
Abu Dhabi Aircraft Technologies	PO Box 46450, Abu Dhabi International Airport Abu Dhabi UAE	Kirubel Tegene VP Sales & Marketing T (971) 2 505 7530 F (971) 2 575 7263 E-mail: commercial@adat.ae www.adat.ae	GTCP331-200 GTCP331-250 GTCP331-350	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Aerotec International	3007 E Chambers St Phoenix AZ 85040 USA	Colin Fairclough Director of sales T (1) 602 253 4540 F (1) 602 252 0395 E-mail: inquiries@aerotecinternational.com www.aerotecinternational.com	GTCP36-150RR/RJ GTCP85-98 GTCP85-129 GTCP131-9A/B/D GTCP331-200 GTCP331-250 GTCP331-500 GTCP660 TSCP700-4B/5/7E RE220 APS500 APS2000 APS2300 APS3200	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Air Asia Company	Tainan Airfield # 1000, Sec. 2 Ta-Tung Rd. Tainan 7025 Taiwan	Glenn C.L. Lee Director, Marketing T (886) 6 268 1911 Ext. 205 / 260-5907 E-mail: 346264@mail.airasia.com.tw	GTCP85-98 GTCP85-129	HSI, MC, MO, OH HSI, MC, MO, OH
Aircraft Power & Service	2415 W, Arkansas Street Durant OK 74701 USA	Dale Owens Senior VP T (1) 580 920 0535 F (1) 580 920 1235 E-mail: dowens@apsmro.com	GTCP85	HSI, MC, MO, OH
Air India	Engineering Department Old Airport Mumbai 400029 India	S.S.Katiyar Deputy GM (Eng.) T (91)-22-2626 3237 F (91) 22-2615 7068 / 2615 7046 E-Mail: SS.Katiyar@airindia.in	PW901 GTCP331-250H GTCP131-9B	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Air New Zealand Engineering Services (ANZES)	Geoffrey Roberts Road PO Box 53098 Auckland International Airport, 1730 Auckland New Zealand	Paul Chisholm Account manager APU marketing, sales M (+61) 0417790059 F (+64) 3 374 7319 E-mail: paul.chisholm@airnz.co.nz www.airnz.co.nz	GTCP85-129 GTCP95 GTCP331-200 GTCP331-250	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Ameco Beijing	P.O. Box 563 Beijing Capital Intl. Airport 100621 Beijing P.R.China	Christian Reck Executive Director Sales & Supply T (86) 10 6456 1122-4000 F (86) 10 6456 7974 E-Mail: reck@ameco.com.cn	GTCP85	HSI, MC, MO, OH
American Airlines Maintenance & Engineering Center	3900 N Mingo Rd MD 21 Tulsa OK 74166 USA	Bobby Bigpond Senior contract account manager T (1) 918 292 2582 F (1) 918 292 3864 E-mail: bobby.bigpond@aa.com	GTCP85-98DHF GTCP131-9 GTCP131-9B GTCP331-200 GTCP331-500B	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Alturdyne	660 Steele Street El Cajon CA 92020 USA	Frank Verbeke President T (1) 619 440 5531 F (2) 619 442 0481 fverbeke@alturdyne.com www.alturdyne.com	T62 Series	HSI, MC, MO, OH One test cell
Aveos Fleet Performance	2311 Alfred-Nobel Boulevard, Zip 8060 Ville Saint-Laurent, (QC) H4S 2B6 Canada	Brenda Stevens Market Intelligence Analyst T (1) 514 856-7158 brenda.stevens@aveos.com business@aveos.com www.aveos.com	GTCP36-300	HSI, MC, MO, OH
CD Aviation Services	2707 E. 32nd Street Suite #2 PO Box 2367 Joplin MO 64803 USA	Rick Gibbs GM T (1) 417 206 2327 F (1) 417 206 2336 E-mail rick.gibbs@cdaviationservices.com www.cdaviationservices.com support@cdaviationservices.com	GTCP30 GTCP36 RE100 RE220	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Coastal Aerospace	21419 Fair Oaks Rd Melfa VA 23410 USA	T (1) 757 787 3704 F (1) 757 787 4704 E-mail: coastalaerospace@verizon.net www.coastalaerospace.com	GTCP85 GTC85 GTCP95	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Chase Aerospace	4493 36th Street Orlando Florida 32811 USA	Brad Scarr Managing Director T (1) 407 812 4545 F (1) 407 812 6260 www.chaseaerospace.com	GTCP36 GTCP85 GTCP331	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH

APU overhaul directory 2011 (cont...)

Company	Address	Contact details	APU types	Capabilities
Chromalloy	391 Industrial Park Road San Antonio Texas 78226 USA	James Furguson VP & GM T (1) 210 331 2405 E-mail: cpssatx@chromalloy.com	GTCP85 GTCP331-200 GTCP331-250	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Dallas Airmotive (BBA Aviation)	900 Nolen Drive, STE 100 Grapevine TX 76051 USA	Christopher Pratt Director of Marketing T (1) 214 956 3001 F (1) 214 956 2810 E-mail: turbines@BBAAviationERO.com www.BBAAviationERO.com	GTCP36 RE100	HSI, MC, MO, OH MC
Delta TechOps	Dept 460 1775 Aviation Blvd Atlanta Hartsfield International Airport, Atlanta GA 30320 USA	Jack Turnbill VP technical sales T (1) 404 773 5192 F (1) 404 714 5461 E-mail: TechSales.Delta@Delta.com www.deltatechops.com	GTCP131-9 GTCP331	HSI, MC, MO, OH HSI, MC, MO, OH
Euravia Engineering	Euravia House Colne Road Kelbrook Lancashire BB18 6SN UK	Steve Clarkson Director customer services T (44) 1282 844 480 F (44) 1282 844 274 E-mail: steve.clarkson@euravia.aero www.euravia.aero	ST6L GTCP165	HSI, MC, MO, OH HSI, MC, MO, OH
El Al Israel Airlines	PO Box 41 Ben Gurion International Airport Tel Aviv 70100 Israel	Eli Uziel Marketing & sales manager T (972) 3 9717278 F (972) 3 9717205 E-mail: uziele@elal.co.il www.elaltech.com	GTCP85 GTCP331 GTCP331-200 GTCP331-500B GTCP660 GTCP660-4 GTCP131	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
EPCOR (subsidiary of Air France KLM)	Bellsingel 41 1119 NT Schiphol-Rijk Netherlands	Paul Chun MD T (31) 20 316 1740 F (31) 20 316 1777 E-mail: sales@epcor.nl www.epcor.nl	GTCP331-350 GTCP131-9 GTCP331-500 APS 2300	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Finnair	Finnair Technical Services Helsinki-Vantaa Airport DE/83 01053 FINNAIR Finland	Mika H‰nninen Vice President, Sales and marketing T (358) 9 818 6443 F (358) 9 818 6900 mika.hanninen@finnair.com www.finnairtechnicalservices.com	APS 3200	HSI, MC, MO, OH
GMF AeroAsia (Garuda Indonesia Group)	Marketing Building Soekarno Hatta Intíl Airport Cengkareng 19130 Indonesia	Winston T. Milner VP sales & marketing T (62) 21 550 8609 F (62) 21 550 2489 E-mail: marketing@gmf-aeroasia.co.id www.gmf-aeroasia.co.id	GTCP36-4A GTCP85-129 series GTCP85-184/185 TSCP700-4B/E	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
H+S Aviation (BBA Aviation)	H+S Aviation APU centre Airport Service Rd Portsmouth, Hants PO3 5PJ UK	Steve Bull Sales director T (44) 23 9230 4256 F (44) 23 9230 4020 steve.bull@hsaviation.co.uk www.hsaviation.com	PW901A GTCP36-100/-150 GTCP331-200/250 T-62T-40-1	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Honeywell Aerospace (Germany)	Frankfurter Str. 41-65 D-65479 Raunheim Germany	Volker Wallrodt T: (49) 6142 405 201 F: (49) 6142 405 390 E-mail: volker.wallrodt@honeywell.com www.honeywell.com	GTCP36 GTCP85 GTCP131-9 GTCP331 GTCP660 RE220 TSCP700	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Honeywell Aerospace (Singapore)	161 Gul Circle Singapore 629619	Bob Norazni GM T (65) 686 14 533 F (65) 686 12 359 E-mail: bob.norazni2@honeywell.com www.honeywell.com	GTCP36 GTCP85 GTCP131-9 GTCP331 TSCP700	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Honeywell Aerospace (USA)	Engine Services 1944 East Sky Harbor Circle MS 2101-2N Phoenix 85034 Arizona USA	Brian Shurman Aftermarket Services, Mechanical T: 602-365-3279 F: 602-365-4029 E-mail: Brian.Shurman@honeywell.com www.honeywell.com	GTCP36 GTCP85 GTCP131-9 GTCP165-1B GTCP331 GTCP660-4 RE220 TSCP700	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Iberia	Iberia Maintenance Madrid-Barajas Airport. La MuÒoza. E-28042 Madrid Spain	Jose Luis QuirÛs Cuevas Commercial & Business Development director T (34) 91 587 5132 F (34) 91 587 4991 E-mail: jlquirosc@iberia.es www.iberiamaintenance.com	GTCP36-300 GTCP85-98DHF GTCP131-9A	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH

APU overhaul directory 2011 (cont...)

Company	Address	Contact details	APU types	Capabilities
Inflite (Southend) WAS (Components)	North Hangar Aviation Way Southend Essex SS2 6UN UK	Ken Tracy Commercial director T (44) 1702 348601 E-mail: sales@inflite-southend.co.uk www.inflite.co.uk	GTCP36-100M GTCP36-150M GTCP85-115 series GTCP85-129 series GTCP85-71 GTCP36-4A GTCP85-98 GTCP85-180/185 All associated LRUs	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Innotech Aviation	10225 Ryan Avenue Dorval Quebec H9P 1A2 Canada	Scott Mistine Director of Maintenance T (1) 514 420 2943 scott.mistine@innotech-excaire.com	GTCP36-100/-150	HSI, MC, MO, OH
IAI - Bedek Aviation	Israel Aerospace Industries Bedek Aviation Group Components Division Ben Gurion IntÌl Airport 70100 Israel	Tali Yoresh Director sales & customer service T (972) 3 935 7395 F (972) 3 935 7757 E-mail: tyoresh@iai.co.il www.iai.co.il	GTCP85 Series GTCP131-9B/D GTCP331-200 GTCP331-250 GTCP660	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Japan Airlines International	M1 Building Maintenance Centre 3-5-1 Haneda Airport, Ota-ku, Tokyo 144-0041 Japan	Masaaki Haga MD engineering & maintenance T (81) 3 3474 4134	GTCP331 GTCP660 TSCP700 PW601A	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
JAT Airways	JAT Tehnika Aerodrom Beograd 59 Beograd 11180 Serbia	Srdjan Miskovic VP engineering, maintenance & repair T (381) 11 2601475 E-mail: srdjan.miskovic@jat-tech.rs www.jat-tehnika.aero	GTCP85	HSI, MC, MO, OH
Korean Air Maintenance & Engineering	Maintenance Planning Dep. Korean Air 1370, Gonghang-dong Gangseo-gu Seoul, Korea 157-712	T (82) 2 2656 3574 F (82) 2 2656 8120 E-mail: selmph@koreanair.co.kr www.mro.koreanair.co.kr	GTCP331-250	HSI, MC, MO, OH
Lufthansa Technik Aero Alzey	Rudolf-Diesel-Strasse 10 D-55232 Alzey Germany	Andreas Kehl VP Maerketing and Sales Raimund Schnell VP Marketing & Sales T +49 (0) 6731 4970 F +49 (0) 6731 497333 E-mail: sales@lhaero.com www.lhaero.com	PW901A	HSI, MC, MO, OH
Lufthansa Technik	Dept HAM TS Weg beim Jäger 193 D-22335 Hamburg Germany	Walter Heerdt SVP marketing & sales T (49) 40 5070 5553 F (49) 40 5070 5605 E-mail: marketing.sales@lht.dlh.de www.lufthansa-technik.com	APS 2000 APS 2300 APS 3200 PW901A GTCP36-300 GTCP85-98/-129H GTCP131-9 GTCP331-200/-250/-350/-500/-600 GTCP660-4 TSCP700-4E	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Pakistan International Airlines	Engineering & Maint. Dept Quaid-E-Azam International Airport Karachi 75200 Pakistan	Tariq Farooq Chief Engineer Engineering Business Development, PIA T: (92) 21 9904 3574 F: (92) 21 9924 2104 E-mail: tariq.farooq@piac.aero	GTCP85-129 GTCP660-4 TSCP 700-5/4B GTCP331-250	OH OH OH OH
Piedmont Aviation Component Services	1031 East Mountain St Building #320 Kernersville North Carolina 27284 USA	Alan Haworth Director sales & marketing T (1) 336 776 6279 F (1) 336 776 6301 E-mail: alan.haworth@piedmontaviation.com	GTCP36 GTCP85 GTCP331	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Pratt & Whitney Canada (Canada)	St Hubert Service Center 1000 Marie-Victorin (05DK1) Longueil Quebec J4G 1A1 Canada	James Temple General sales manager T (1) 450 468 7730 F (1) 450 468 7807 E-mail: james.temple@pwc.ca www.pwc.ca	ST6L-73 APS3200	HSI, MC, MO, OH HSI, MC, MO, OH
Pratt & Whitney Canada (Singapore)	10 Loyang Crescent Loyang Industrial Estate Singapore 509010	Ron Norris Manager marketing & sales T (65) 6545 3212 F (65) 6542 3615 E-mail: ron.norris@pwc.ca www.pwc.ca	APS 3200	HSI, MC, MO, OH
Revima APU (Hamilton Sundstrand Power System subsidiary)	1 Avenue du Lathan 47 76490 Caudebec en caux France	Jean Michel Baudry Business development manager T (33) 2 35 56 35 82 F (33) 2 35 56 35 56	GTCP85-98 GTCP331-200/-250 PW901A/C PW980	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH

APU overhaul directory 2011 (cont...)

Company	Address	Contact details	APU types	Capabilities
Revima APU (cont...)		E-mail: jeanmichel.baudry@revima-apu.com www.hamiltonsundstrand.com Xavier Mornand T (33) 2 35 56 36 04 E-mail: xavier.mornand@revima-apu.com	TSCP700-5/-4B/-4E APS 2000 APS 3200 APS 500 APS 1000 GTCP131-9A/B	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
South African Technical	Private Bag X12 Room 212 Hangar 8 Johannesburg 1627 South Africa	Kobus Kotze Senior manager, APU T (27) 11 978 9513 E-mail: kobuskotze@flysaa.com www.flysaa.com	GTCP85 GTCP660	HSI, MC, MO, OH HSI, MC, MO, OH
SR Technics * in cooperation with partner companies	Sales Department 8058 Zurich Airport Switzerland www.srtechnics.com	sales@srtechnics.com	GTCP85 series* GTCP131 series* GTCP331 series* GTCP660 series* APS3200* ATSCP700-4E*	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
StandardAero Augusta	1550 Hangar Road Augusta Ga 30906-9684 USA	Tony Gay, engine shop manager T +(1) 706-771-5677 F +(1) 706-771-5628 Bill McIlwraith, APU customer support T +(1) 706-560-3356 F +(1) 706-790-5122 Greg Washburn, APU crew chief T +(1) 706-771-5631 F +(1) 706-790-5122	GTCP36-100 series GTCP-150 series GTCP-3092	HSI, MC, MO, OH HSI, MC, MO, OH HSI,
StandardAero Maryville	1029 Ross Drive Maryville Tennessee 37801 USA	Tim Fischer VP & GM T + (1) 865-981-4673 F + (1) 865-983-2092 Toll Free: + (1) 800-906-8726 from USA apu@standardaero.com	GTCP36 series GTCP85 RE220 APS2300	HSI, MC, MO, OH, LRU HSI, MC, MO, OH, LRU HSI, MC, MO, OH, LRU HSI, MC, MO, OH, LRU
TAP Maintenance & Engineering	Marketing and Sales Lisbon Airport 1704-801 Lisbon Portugal	Carlos Ruivo VP marketing & sales T (351) 21 841 5975 F (351) 21 841 5913 E-mail: marketing.me@tap.pt www.tapme.pt	GTCP85 series APS3200	HSI, MC, MO, OH HSI, MC, MO, OH
TAP Maintenance & Engineering Brazil	Estr das Canarias, 1862 Rio de Janeiro 21941-480 Brazil	Anderson Fenocchio Ricardo Vituzzo Marketing & sales E-mail: anderson.fenocchio@tapme.com.br E-mail: ricardo.vituzzo@tapme.com.br www.tapme.com.br	APS500 T62-T-40C11 GTCP85 GTCP36-150 GTCP660-4 GTCP331-200ER TSCP700-4B/-4E/-5 GTCP131-9B	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Triumph Air Repair	4010 S 43rd Place Phoenix AZ 85040-2022 USA	Jim Jackalone Vice President ñ Sales and Customer Support Phone 602-470-7231 Fax 602-470-7230 jjackalone@triumphgroup.com www.triumphgroup.com	GTCP85 GTCP131 GTCP331 GTCP660 PW901 TSCP700	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Triumph Aviation Services Asia	700/160 ñ Moo 1 T. Bankao, A. Pantong Chonburi 20160 Thailand	Dan McDonald VP Sales and Customer Support T (66) 38-465-070 F (66) 38-465-075 E-mail: dmcdonald@triumphgroup.com www.triumphgroup.com	GTCP85 GTCP131 GTCP331 GTCP660 PW901A TSCP700	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
Turkish Technic	Ataturk Intíl Airport Gate B 34149 Yesilkoy Istanbul Turkey	Altug Sokeli Technical marketing & sales manager T (90) 212 463 6363 X9223 F (90) 212 465 2121 E-mail: asokeli@thy.com techmarketing@thy.com www.turkishtechnic.com	APS 2000 APS 3200 GTCP85-98C/CK/DHF GTCP85-129H GTCP139-9B GTCP331-250F/H	HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH HSI, MC, MO, OH
United Services	United Services Maintenance Center San Francisco International Airport Building 74 Ò SFOUS San Francisco CA 94128-3800 USA	Paul Lochab MD supply chain, pma and sales, mktg & svcs T (1) 650 634-4269 F (1) 650 634 5926 E-mail: mro@unitedsvcs.com www.unitedsvcs.com	GTCP331 -200, -500 PW901	HSI, MC, MO, OH HSI, MC, MO, OH

Specialist engine repairs directory

Company name	Address	Contact	Component capabilites	Engine type	Specialist skills
NORTH AMERICA					
Aero Propulsion Support	108 May Drive Harrison Ohio 45030 USA	Allan Slattery President/CEO T (1) 513 367 9452 F (1) 513 367 7930 Email: aslattery@aeropropulsion.com	Honeycomb seals, compressor diffusers, compressor shrouds, turbine nozzles, turbine supports, engine sheet metal components, seals and abradable parts	All Honeywell APUs, Sundstrand APUs GTCP-331, GTCP-36, GTCP-131, TSCP-700, RR-250 all series, C30, C40,C47, C20,C28, PW901 APU, GE CT7	GTAW and resistance welding, vacuum and atmosph. furnace braze and heat treatment, precision machining, NDT, liquid penetrant, pressure test, plasma welding, EB welding
Aerospace Welding	890 Michele-Bohec Blainville Quebec Canada J7C 5E2	Michel Dussault Vice President Sales/General Mgr T (1) 450 435 9210 F (1) 450 435 7851 E-Mail: mdussault@aerospacewelding.com	Exhaust systems, jet pipes, heat shields, ducting (bleed pipes, de-icing), tubing, nose cowls (CL 600), tracks, rings, landing gear, fuel tanks, engine mounts, thrust reverser (CL 600)	JT3D, JT8D, JT9D, JT15D, PT6A, PW100, RB211, Dart, Avon, APUs, Garrett, Sunstrand	FPI, MPI, eddy current, fusion welding for robotic thermo spray cells (plasma, HVOF, thermo spray) full metallurgical lab conventional milling and turning equipment, computerised spot and seam welding, furnace brazing
Aerospace Component Services (P&WC)	1000 Marie-Victorin Longueuil Quebec Canada J4G 1A1	Dominique Dallaire GM T (1) 450 468 7896 F (1) 450 468 7786 E-mail: dominique.dallaire@pwc.ca	Accessory & Component repairs Gas Generator Cases (PW100), Liners, Life Cycle Parts, Fuel Controls, Flow Dividers, Fuel Nozzles, TSCU, EEC, Electrical, TSCU, AFU, Bleed Valves and Fuel Pumps	PT6, JT15D, PW100, PW150, PW200, PW300, PW500 and PW600	Manual brazing, brazing, Automatic Welding, CNC Machining, Manual Machining, no mechanical machining, blending balancing, vacuum furnace, pressure test, FPI, MPI, STI, X-Ray, eddy current pressure flush, water jet stripping, ultrasonic cleaning, plasma spray, painting, plating, TBC, manual &automatic peening (shot & glass), Nano-plating (Q4 2010)
Aircraft Ducting Repair	101 Hunters Circle Forney TX 75126 USA	Steve Alford President T (1) 972 552 9000 F (1) 972 552 4504 E-mail: repairs@acdri.com	Engine exhaust tailpipes, pneumatic ducts, tubes and manifolds, APU exhaust ducts	JT3D, JT8D, JT8D-200, CF6-50, CF6-80C2, CFM-56-3/-3B/-3C, CFM-56-7B, PW4000, V2500	TIG welding, NDT, CNC machining
Aircraft Power and Services	2415 West Arkansas Durant OK 74701 USA	Dale Owens VP, sales and customer services T (1) 580 920 0535 F (1) 580 920 1235 Email: dowens@apsmro.com	Overhaul of internal engine components for the P&W PT6, ST6, JT15D, JFTD12, JT8D, JT8D-200, JT3D and the Honeywell TPE 331, TFE 731, GTCP36 APU, GTCP85 and GTCP331 APU. Overhaul of the complete 85 series APU and its accessories and selected 36 series APU accessories	P&W PT6, ST6, JT15D, JFTD12, JT8D, JT8D-200 and JT3D and Honeywell TPE 331, TFE 731, GTCP36, GTCP85, GTCP331	TID, MIG and resistance welding, plasma spray, vacuum furnace braze, precision machining, NDT, liquid penetrant, MPI, heat treating, shotpeening, balancing, air flow mach precision hand blend, specialised coating, accescory test benches, APU test cell
AMETEK Aerospace and Defense (Reynosa Service Center)	1701 Industrial Boulevard Hidalgo Mukilteo TX 78557 USA (ship-to address)	Joe Lynch Aftermarket manager T (1) 978 988 4869 F (1) 215 323 9538 E-mail: joe.lynch@ametek.com	Fuel flowmeters, oil level sensors, temperature sensors, EGT, switches, speed sensors, wiring harnesses	CFM56, CF6, PW, GP7200, CF34 Honeywell engines	Intricate assembly, fuel flow calibration
APECS Engine Center	13642 South West 142nd Avenue Kendall FL 33186 USA	Nick Troonin Manager T (1) 305 255-2677 F (1) 305 255-0277 E-mail: NickT@a-pecs.com Web: a-pecs.com	Gearbox Overhaul & Exchange Certified insitu. blade blending (on-wing), line maintenance support, testing, trouble-shooting, vibration analysis, breather checks, digital video borescope inspections, field service repair team, gearbox and fan specialists, repair, modification, overhaul and sales of JT8D parts, piece parts and components	JT8D - 7B, -9A, -15, -15A, -17 JT8D - 209, -217A, -217C, -219	JT8D engine overhaul, repair and modifications. ASB: 6431 specialists, HPC exchanges for quick turn time, custom work scopes
Britt Metal Processing	15800 North West 49th Avenue Miami FL 33014 USA	Tim Waggoner Director of Mktg and Bus. Dev. T (1) 305 621 5200 F (1) 305 625 9487 E-mail: marketing@brittmetal.com	Stationary component repair - Supports, Scrolls, Diffusers, Compressor, Inlet, Diff. Hsngs. Hot section components Exotic materials	PUs: GTCP331, GTCP131-9 GTCP660, TSCP700, GTCP85 Pneumatics: Air Cycle Machine Air Turbine Starters, Valves & more Hydraulics: Hsngs, Adapter Blocks	Balancing, Vacuum Brazing, Plasma and Thermal Coatings Welding, NDT, Heat Treating CNC Machining, Paint and more

Specialist engine repairs directory (cont...)

Company name	Address	Contact	Component capabilites	Engine type	Specialist skills
Chromalloy	303 Industrial Park San Antonio TX 78226 USA	Tom van der Linden VP, Sales P +31 13 5328 423 F E-mail: tvanderlinden@chromalloy.com	Turbine engine modules, cases and frames, combustors, disks, shafts, hubs	CF6, CFM56, PW2000, PW4000, RB211-535, V2500	CNC grinding, CNC machining, CNC welding, coordinate measuring machine, electron beam welding, gas tungsten arc welding, heat treating, non-destructive inspection, plasma spray, vacuum brazing
Chromalloy	330 Blaisdell Road Orangeburg NY 10962	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	Aircraft and industrial gas turbine engines	PW4000, PW2000, V2500, JT9D, JT8D, V94, GG8, CF6, CFM56	CBN abrasive tip, customized repair development, EDM, full engineering analysis, grinding, heat treating, hydrogen flouride cleaning, laser drilling, LPW, metallurgical analysis, multiple axis machining, precision machining, tool design/ manufacture, vacuum brazing, welding
Chromalloy	30 Dart Road Newnan GA 30265 USA	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	HPC components	PW4000, 94" RCC, 100", 112", PW2000, JT9D, FT4, FT8, GG3, GG4, GG8, JT8D, RB211, RB211-524,RB211-535 E4, Trent 500, Trent 700, Trent 800, V2500, Mars, Titan, Taurus	Coating restoration, EDM, grinding, plasma spray, vacuum brazing, water jet stripping and cutting
Chromalloy	3636 Arrowhead Drive Carson City NV 89706 USA	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	HPT/LPT blades and vanes	LM1600, LM2500, LM5000, LM6000, CF6-50, CF6-6, CF6-80A, CF6-80C2, CF6-80E, CFM56-2, CFM56-3, CFM56-5A, CFM56-5B, CFM56-5C, CFM56-7, JT8D-200, PW2000	Acid strip, alkaline cleaning, atomic absorption analysis, automated TIG welding, belt sanding, braze pre-forms, braze sinter cake, brazing, CNC CO2 laser fusion, CNC machining, computerized airflow testing, computerized tomograph inspection, CMM, eddy current inspection, EDM, electro-stripping, FPI, fluoride-ion cleaning, glass bead peening, grinding, grit blast, investment casting, metallurgical analysis, SEM, welding
Chromalloy	1720 National Boulevard Midwest City OK 73110 USA	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	Gas turbine components	501K, 570/571K, 601K, CF34-3, CF700/CJ610, CT58, JT8D-200, JT9D-3/-20J, JT9D-7Q, PW2000, 501D, RB211-535E4	Atomic absorption analysis, braze pre-forms, chemical stripping/ cleaning, CNC welding, CMM, DDH, electro plating, electron beam welding, fluoride-ion cleaning, heat treating, laser drilling, laser machining, LPW, SEM, welding
Chromalloy	6161 West Polk Street Phoenix AZ 85043 USA	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	Gas turbine engine components	GTCP131, GTCP331-200/250, GTCP 331-350, GTCP36-100/150, GTCP36-280/300, GTCP660, GTCP85, LTS101, TFE731, TPE331, TSCP700	Acid strip, ATPS, aiflow testing, curvic grinding, DERs, eddy current inspection, EDM, electro-chemical grinding, electron beam welding
Chromallloy	2100 West 139th Srt. Gardena CA 90249 USA	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	High and low pressure turbine vanes	LM1600, LM2500, LM5000, LM6000, CF6-50, CF6-6, CF6-80A, CF6-80C2, CF6-80E, CFMI, Tf39/HT-90, F108, F404	TIG and laser weld, laser drilling, EDM, brazing, vacuum furnaces, CNC machining & grinding, high temperature diffusion coatings, air plasma spray, NDT: FPI, airflow and EMU assembly & set management
Chromalloy	1071 Industrial Place El Cajon CA 92020 USA	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	Gas turbine engine components	CF6-6, CF6-50, CF6-80A, CF6-80C2, LM2500, LM5000, LM6000, TF39, F101/F108/F110, CF34, TF34/9, JT3D, JT8D, JT9D, PW2000, PW4000, CFM56-2, CFM56-3, CFM56-5, CFM56-7, RB211-22B, RB211-524,RB211-535, TAY, V2500 (A1), V2500 (A5), V2500 (D5)	DER repairs, turbine seals repair, CNC welding, CMM, heat treating

Specialist engine repairs directory (cont…)

Company name	Address	Contact	Component capabilites	Engine type	Specialist skills
Chromalloy	1777 Stergios Road Calexico CA 92231 USA	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	High and low pressure turbine vanes and blades	LM2500, CF34-4, CF6-50, CF6-6, CF6-80A, CF6-80C2, LM6000, CFM56-3, CFM56-5A, CFM56-5B, CFM56-5C, CFM56-7, GG4, JT3D, JT8D, JT8D-200, JT9D-3/-20J, JT9D-7Q, JT9D-7R4D/E/H, JT9D-7R4G2, PW4000, GTCP331-200/250, GTCP331-350, GTCP-131-9, V2500A1,V2500A5/D5	CNC grinding, eddy current inspection, electro-chemical grinding, electro-discharge machining, electron beam welding, FPI, laser drilling/cutting, laser CO2 welding, machining, plasma spray, shot peening
Chromalloy	601 Marshall Phelps Road Windsor CT 06095 USA	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	Gas turbine engine components	GG3, GG4, GG6, CF6-80A, CF6-80C2, CFM56-2, CFM56-3, CFM56-5A, CFM56-5B, CFM56-5C, CFM56-7, V2500A5/D5, JT8D, JT8D-200, PW2000, PW4000-94"	Adhesive bonding, brazing, eddy current inspection, FPI, grinding, heat treatment, magnetic particle inspection, non-destructive testing, ultrasonic inspection, vacuum furnace, x-ray inspection
Chromalloy	14042 Distribution Way Dallas TX 75234	Tom van der Linden VP, Sales P +31 13 5328 423 F E-mail: tvanderlinden@chromalloy.com	Gas turbine engine components	CF34, TF39, CF6-6, CF6-50, CF6-80A, CF6-80C2, LM2500, LM5000, CFM56-2, CFM56-3, CFM56-5A, CFM56-5B, CFM56-7B, V2500-A1, V2500-A5, V2500-D5, JT8D-1/17AR, JT8D-209/219, PT6/ST6, PW2000, PW4000, RB211-22B, RB211-524, RB211-535C, RB211-535E4	CMM, EDM, FPI, heat treatment & furncace braze, horizontal milling, lathe turning, profiling system, radiographic inspection, surface grinding, TIG welding, vertical milling, vibro super polishing
Component Repair Technologies	8507 Tyler Blvd Mentor Ohio 44060 USA	Rich Mears Sales manager T (1) 440 255 1793 F (1) 440 225 4162 E-mail: richmears@componentrepair.com	Cases, shafts, bearing housings, frames	JT8D, JT8D-200, CFM56, CF6-6, -50, -80A, -80C2, CT7, CF34, PW2000, PW4000, V2500	Chemical stripping, plating, HVOF, EBW, CNC machining, vacuum furnace, NDT, X-ray, eddy current
ETI	8131 East 46th Street Tulsa OK 74145 USA	Andy Clark Sales and customer service T (1) 918 627 8484 F (1) 918 627 8446 E-mail: andy.clark@etitulsa.com	VSV bushings, lever arms, anti-vortex tubes, gangnut channels, bearing housings, shoulder studs, air seals, guide plates, comb. retaining blots, air inlet screens	JT8D, JT9D, PW2000, PW4000, PT6, CFM56, CF34, CF6, V2500	Wet and dry abrasive cleaning, grinding, heat treating, machining, surface treatment, TIG, welding, brazing, vacuum brazing, SWET NDT,FPI, dimensional inspection
GE Aviation, Services - Cincinnati Aviation Component Service Center	201 W. Crescentville Rd Cincinnati OH 45246-1733	24/7 AOG Hotline +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com	Cases, frames, structures, combustors, LLP HPT shrouds, LPT & HPT nozzles	CFM56, CF6, GE90, CF34, LM (Industrial Engines)	Cleaning/surface treatments Non-destructive testing Welding/brazing Coatings, CNC and adaptive milling Robotic metal spray Wire and CNC EDM systems Lean induction furnace
GE Aviation, Services - Strother Field	Strother Field Industrial Park Arkansas City KS 67005	24/7 AOG Hotline +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com		CF34-3/-8/-10 CFM56-2/-3/-5B/-7 CT7, T700	
GE Aviation, Services - McAllen	6200 South 42nd St McAllen TX 78503	24/7 AOG Hotline +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com	LPT nozzles and blades LPT vanes HPC supports and hangers HPC vane sectors & stationary seals	CF6-50, CF6-80A/C/E, CFM56-2/-3/-5/-7/-7B CF34-3/-8/-10 LM2500/5000/6000 GE90-94B/-115B	Superior LPT yield programs Salvation reviews Kitting and assembly programs, Accessory repairs
GE Aviation, Services - Tri-Reman	3390 East Locust St Terre Haute IN 47803	24/7 AOG Hotline +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com	Structures/honeycomb Frames/cases	CFM56-2/-3/-5/-7 LM1600/2500/5000/6000 CF6-6/-50/-80 GE90 CF34	Honeycomb seal & segment repairs, LPT cases and frames, honeycomb replacement, weld repair, plasma spray, honeycomb manufacturing, TIG and EG welding, vacuum brazing and heat treating, balancing, NDT,TBC, plasma spray, SVPA, electrochemical grinding, laser cutting and drilling, EDM
GE Aviation, Services - Symmes Road	3024 Symmes Road Hamilton OH 45014-1334	24/7 AOG Hotline +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com	Cases, frames, structures Combustors, LLP HPT blades & shrouds LPT & HPT nozzles	CF34-3/-8/-10 CFM56-2/-3/-5B/-7 CT7, T700	Cleaning/surface treatments Non-destructive testing Welding/brazing Coatings, CNC and adaptive milling, Robotic metal spray Wire and CNC EDM systems Lean induction furnace

Specialist engine repairs directory (cont...)

Company name	Address	Contact	Component capabilites	Engine type	Specialist skills
GKN Aerospace - Chem-tronics	Box 1604 1150 West Bradley Ave El Cajon CA 92022 USA	Steve Pearl GM T (1) 619 258 5220 F (1) 619 448 6992 E-mail: steve.pearl@usa.gknaerospace.com	Fan blades, fan discs, fan cases, compressor blades, compressor cases	JT9D, PW2037, PW4000, RB211-524, -535, Trent, AE3007,CFM56-2, -3, -5A, -5B, -5C, -7,CF6-50, -80A, -80C, CF34, ALF502, 507, TFE731, V2500	Chemical stripping, EBW, HVOF/plasma, waterjet technology, high speed optical inspection, precision airfoil recontouring, automated airfoil machining and finishing
Honeywell Aerospace - Phoenix (Engine accessories)	1944 East Sky Harbor Circle Phoenix AZ 85034 USA	Bill Wright Technical sales APU/propulsion T 480 592 4182 E-mail: bill.wright@honeywell.com	Engine generators/IDG/CSD Fuel/oil coolers and heaters Fuel control units and components All engine related accessories	All Honeywell engines / APUs JT8, JT9, JT10, JT11, JT15D, CF6, CT7, CFM56, CF34, PT6, P108, PW100, PW100, PW4000, RB211, RR250	
Honeywell Aerospace (Engine piece part advanced repair)	1944 East Sky Harbor Circle Phoenix AZ 85034 USA	Bill Wright Technical sales APU/propulsion T 480 592 4182 E-mail: bill.wright@honeywell.com	Complete cold section part restoration including gear boxes, cases, knife edge seals,impellers, blisks, fan blades, compressor blades	V2500, CF34, PW100, PT6, JT15D, T56, 501K, TFE731, TPE331, all small 36 series APU, large 36 series APU, 331-200/250, 331-350, 331-500, 131-9	EBW, CNC, TIG, FPI, MPI, CMM, HVOF, NDT, EBM, LPPS, EDM, waterjet
Honeywell Aerospace (Engine piece part advanced repair)	85 Beeco Road Greer SC 29652 USA	Bill Wright Technical sales APU/propulsion T 480 592 4182 E-mail: bill.wright@honeywell.com	Complete hot section part restoration, fan blades, compressor blades, stator vanes, combustors, NGVs, turbine blades, cases, seals	V2500, CF34, PW100, PT6, JT15D, T56, 501K, TFE731, TPE331, all small 36 series APUs, large 36 series APUs, 331-200/250, 331-350, 331-500, 131-9, T53, T54, AGT 1500	EBW, CNC, TIG, FPI, MPI, CMM, HVOF, NDT, EBM, LPPS, EDM, waterjet, EBPVD, laser welding, fluoride ion cleaning, "jet fix" crack restoration, platinum aluminide coatings, full brazing and heat treat
Honeywell Aerospace (Engine accessories)	3475 North Wesleyan Boulevard Rocky Mount North Carolina, 27804 USA	Bill Wright Director, technical sales Mechanical T 480 592 4182 E-mail: bill.wright@honeywell.com	Mechanical and hydraulic actuators, hydromechanical fuel controls, pneumatic fuel controls	All Honeywell engines	
Honeywell Aerospace (Engine accessories)	6930 North Lakewood Avenue Tulsa, Oklahoma 74117 USA	Bill Wright Director, technical sales Mechanical T 480 592 4182 E-mail: bill.wright@honeywell.com	Aircraft heat exchangers, precoolers, ozone converters, valves, water separators, fuel heaters, oil coolers	All Honeywell engines / APUs JT8, JT9, JT10, JT11, JT15D, CF6, CT7, CFM56, CF34, PT6, P108, PW100, PW100, PW4000, RB211, RR250, Spey, Tay, T64, T76	
Honeywell Aerospace (Engine accessories)	Hangar 8, Slemon Prk Summerside Prince Edward Island, COB 2A0 Canada	Bill Wright Director, technical sales Mechanical T 480 592 4182 E-mail: bill.wright@honeywell.com	Fuel controls, flow dividers, fuel pumps, fuel nozzles propeller governors, pumps electronics, electronic engine controls (EEC), torque signal conditioners, electrical equipment, generators harnesses	All Honeywell engines PW100, PW4000	
Jet Aviation Specialists	3373 North West 107th Street Miami Florida 33167 USA	Andrew Walmsley VP, sales and marketing T (1) 305 681 0160 F (1) 305 681 7356 E-mail: awalmsley@jas-inc.com	Combustion assemblies, turbine cases, stators, supports, spinner cones	JT8D, JT8D-200, CF6-6, CF6-50, CF6-80A, CF6-80C2 CFM56-3, CF34, T56, TF33	Plasma spray, paint, welding, brazing, precision machining, grinding NDT, heat treatment
Liburdi Turbine Services	400 Highway 6 North Dundas Ontario L9H 7K4 Canada	Scott Hastie Engineering Manager T (1) 905 689 0734 F (1) 905 689 0739 E-mail: shastie@liburdi.com	Industrial turbine blades, buckets, NGVs, vane stators, fuel nozzles	Industrial Avon, Marine Spey, Industrial RB211, ALF502, A501K, LM2500, LM1600, authorised Rolls-Royce industrial repair vendor	Coatings, HVOF and air plasma, heat treat, GDAW, PAW and laser welding, EDM, NDT, X-ray
Nordam Repair Division	11200 East Pine St. Tulsa OK 74116 USA	Thomas Henning Director, marketing T (1) 918 878 6313 F (1) 918 878 6796 E-mail: thenning@nordam.com	Exhaust nozzles, sleeves, plugs, centrebodies, fairings, ducts, thrust reversers	CF6-50, CF6-80, CFM56, JT8D, JT9D, PW2000, PW4000, V2500, RB211	Vacuum brazing and bonding
PAS Technologies	1234 Atlantic Street North Kansas City MO 64116-4142 USA (other facilities at Hillsboro, OH; Miramar, FL; Phoenix, AZ, Singapore and Ireland)	Marsha Farmer Communications director T (1) 816 556 4600 F (1) 816 556 4615 E-mail: marsha_farmer@pas-technologies.com	Commercial fan blades, carbon seals, military fan blades, compressor blades, variable guide vanes, rotor assemblies, bevel gears, seal seats, housings, honeycomb, feltmetal, shrouds	JT8D, JT9D, CF6, CFM56, PW2000, PW4000, F117, V2500, JT15D, F100, GG4, TF39, PW100, PW300, PW901, RB211, Spey, Tay	Inspection, machining, grinding, finishing, lapping, CNC milling, welding, vacuum and atmospheric heat treatment, automated glass and ceramic shot peening, plasma and D-gun coating, full NDT, EBW, airfoil straightening and blending, electrolytic, chemical and mechanical stripping, grit blasting, vibratory finishing, plating, HVOF, TIG, FPI, MPI, CMM, LPPS, EDM

Specialist engine repairs directory (cont...)

Company name	Address	Contact	Component capabilites	Engine type	Specialist skills
Pratt & Whitney Canada Accessories and Component Services	1000 Marie-Victorin Longueuil Quebec Canada J4G 1A1	Dominique Dallaire GM T (1) 450 468 7896 F (1) 450 468 7786 E-mail: dominique.dallaire@pwc.ca	Component repairs	All P & WC engine series	
Pratt & Whitney Canada Accessories and Component Services	3101 Hammon Road Wichita Falls, TX, USA	Robert Kirsh General Manager T (1) 940-761-9200 F (1) 940-761-9292 E-mail: robert.kirsh@pwc.ca	Component repairs	All P & WC engine series hot section engine components	
Pratt & Whitney Canada Accessories and Component Services	1000 Marie Victorin Blvd Longueuil, Quebec, Canada J4G 1A1	Eric MacIntyre Marketing & Customer Service Mgr T (1) 450-442-6802 F (1) 450-442-6810	Accessory Repair and Overhaul for all P&WC engine models		
Pratt & Whitney Component Solutions	4905 Stariha Drive Muskegon, MI, USA	Pete Gibson General Manager T (1) 231-798-8464 F (1) 231-798-0150 E-Mail: pete.gibson@pwc.ca	Rotable exchange support and serviceable parts sales for all P&WC engine models		
Pratt & Whitney Engine Services Accessories and Component Services	1525 Midway Park Rd Bridgeport, WV, USA	Jeff Powell Manager T (1) 304-842-1207 F (1) 304-842-1229 E-mail: jeff.powell@pwc.ca	Component repairs	PT6A, PT6T, JT15D, PW300, PW500	
Propulsion Technologies Int'l (A JV of Snecma Services cleaning, diamond grinding, and Technology Corp.)	15301 SW 29th Street Miramar Florida 33027 USA	Oscar Molina oscar.molina@ptcgrp.com T: (1) 786 999 0672 Web: www.snecma-services.com	CFM56, CF6-50, CF6-80, JT8D and V2500	For parts repair only	
Timken Aftermarket Solutions	3110 N Oakland St Mesa, Az 85215-1144 USA	Larry Batchelor Sr Product Sales Manager Tel:- +1-480-606-3011 Fax:- +1-480-635-0058 Email:- larry.batchelor@timken.com www.timken.com/mro	Bearing Repair Component repair Fuel Control	All platforms, all manufacturers A250, PT6, T53 PT6, T53	Bearing Inspection, Repair & Test Compressor case & turbine nozzle repair and exchange Repair, Overhaul & Exchange
TCI - Turbine Controls	5 Old Windsor Road Bloomfield CT 06002 USA	David Tetreault VP, sales T (1) 860 761 7533 F (1) 860 761 7591 E-mail: dtetreault@tcimro.com	Engine component support of discs, shafts, hubs, seal ring holders, air seals, bearing housings, supports, spools, MGB and AGB housings and gears, engine accessory support of fuel, oil and pnuematice components, i.e. pumps, actuators, valves, starters	CFM56, CF6, CF34, PW4000, PW2000, V2500, F100. GG4, GG8, LM Series	CMM, NDT, FPI, MPI, chemical cleaning, EBW, dabber tig, heat treat, 6-axis robotic plasma and thermal spray, shot peen, grit blast, paint, CNC turning, milling & grinding, engine accessory repair and overhaul fuel, oil, hydraulic, pneumatic testing
Turbine Components TCI	8985 Crestmar Point San Diego, CA 92121 USA	Raffee Esmailians T (1) 858 678 8568 F (1) 858 678 0703 M 858 442 6045 E-mail: Raffee@turbinecomponents.com	Turbine Component repairs; Combustion Liners, Housings, Compressor Cases, Turbine Hsg. Honeycomb Exh. Nozzles/Sleeves, Exh. Ducts, Nozzles, Stators, Hot Section Components & more Major component repair/overhaul:	Honeywell APU series P&WC PT6, PW100, JT15 series PWA PW4000, PW2000, JT9 series PWA JT12/JFTD12 Hamilton Sundstrand APU series Honeywell TFE731, TPE331, GE CF34, RR T56/501 PT6, PW1000, JT8, JT9	EBW, Vacuum Furnace Brazing & Heat Treating, EDM, CNC Mach./Milling Centers, CMM, 6-Axis Robotic Plasma/Thermal and HVOF Coating, Micro Plasma Arc Welding Waterjet Machining, NDT and Repair Development Engineering FAA, EASA, ISO 9000
Whyco Finishing Technologies	670 Waterbury Road Thomaston CT 06787 USA	Peter Masella Director of Sales and Marketing T (1) 860 283 5826 F (1) 860 283 6153 E-mail: peterm@whyco.com Web: www.whyco.com	Chromium, copper, nickel, plating, abrasive blasting specialised cheming cleaning, chemical removal of coatings and braze alloys, chemical stripping HVOF coatings	All makes, all models	
(Windsor Airmotive, Connecticut) Barnes Aerospace Aftermarket	7 Connecticut South Dr. East Granby CT 06026 USA	William Gonet VP, Sales T (1) 860 325 1125 F (1) 860 653 0397 E-mail: wgonet@barnesaero.com	Casings and Frames, Rotating Air Seals, Discs, Drums, Spacers, OGVs, Bearing Housings	JT8D, JT9D, PW2000, PW4000, RB211, Trent 700, Trent 800, Trent 500, Trent 900, CFM56, CF6, Tay, GE90 LM2500, LM6000, LM5000, GG4/8 Avon, 501K	EBW and Automatic TIG welding; High Pressure Water Jet; CNC Milling, Turning, and Grinding; Plasma and Wire Arc Coating; Heat Treat, Thermal Processing, and Vacuum Brazing; X-ray, FPI, Eddy Current and Ultrasonic Testing; EDM; Rotable Pool Support
(Windsor Airmotive, Ohio) Barnes Aerospace Aftermarket	9826 Crescent Park Dr. West Chester OH 45069 USA	William Gonet VP, Sales T (1) 860 325 1125 F (1) 860 653 0397 E-mail: wgonet@barnesaero.com	High Pressure Turbine Shrouds honeycomb Seals	CFM56, GE90, CF6, CF34, Tay RB211	CNC Grinding and Turning; Laser Drilling; Vacuum Brazing and Heat Treat; EDM; FPI; Several Coatings includ-ing SVPA; Rotable Pool Support

Specialist engine repairs directory (cont...)

Company name	Address	Contact	Component capabilites	Engine type	Specialist skills
Woodward Aircraft Engine Systems	One Woodward Way PO Box 405 Rockton Ill 61072-0405 USA	Tony Dzik Manager, cust. support and bus. dev. T (1) 815 639 6983 F (1) 815 624 1929 E-mail: adzik@woodward.com	Fuel controls, actuators, fuel nozzles, augmenters and fuel manifolds	GE90, CF6, CFM56, F110, RB211, V2500, CF34, BR700, TPE331, PT6, PW4000, PW206, PW207, PW2000, FJ44, JT8, JT9, CT7, CT700	Heat treating, brazing, welding, surface coating, advanced machining, EBW, laser welding, TIG welding, EDM, plasma coating, vacuum brazing
EUROPE					
1Source Aero Services	P.O. Box 163 32009 Schimatari Greece	Greg Ferguson GM T (30) 226 204 9301 F (30) 226 204 9422 Email: g.ferguson@1source-aero.com	Most types of engine accessories, including fuel, oil, pneumatic, actuators, and electrical	CFM56, CFM53, CFM55, CFM57 V2500 A1, A5, D5 PW2000 F-100	Component and accessory MRO, FPI, MPI, full accessory test capability, EB welding, plasma spray, parts balance
Chromalloy - France	BP 7120 Ave Des Gros Chevaux Z I du Vert Galant F-94054 France	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	AL and CR coatings, blades, vane segments, vane rings, honeycomb seal repairs, manufacturing of honeycomb and felt	All PWA, all GE, all CFM series	Chemical stripping and plating, TIG, MIG and EB welding, laser drilling, pack and vapour phase deposition, LPPS, HVOF, EDM, ECG, CNC turning and milling
Chromalloy - Netherlands	Siriusstraat 55 5015 BT Tilburg Netherlands	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	Honeycomb seals, shrouds, frames, cases, supports, fan discs and spools, NGVs	CF6-50, CF6-80A, CF6-80C2, CF6-80E, CF34, LM1600, LM2500, LM5000, LM6000, V2500, 131B, CFM56-2, CFM56-3, CFM56-5A, CFM56-5B (P), CFM56-5C, CFM56-7B, PW4000, A250, BR700	High speed grinding, laser drilling, Tungsten inert gas & EB welding, EDM, eddy current
Chromalloy - UK	1 Linkmel Road Eastwood, Nottingham NG16 3RZ	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	Small engine component repair, large engine component and Honeycomb repair, IGT blade repair	501K, AVON, 501D, Dart, RB211-22B, RB211-524B/C/D, RB211-524G/H, RB211-535C, RB211-535E4, Tay, Trent 500/700/800, AL5512, ALF502/LF507, PW100, PW901	Acid strip, blending, CNC milling and turning, CMM, degreasing, eddy current inspection, EDM, electron beam welding, FPI, grinding, LPW, vacuum brazing, vibro super polishing
CRMA	14 Avenue Gay-Lussac ZA Clef de Saint-Pierre F-78990 Elancourt France	Yves Cosaque Marketing, sales and development GM T (33) 1 3068 3702 F (33) 1 3068 8819 E-mail: yves.cosaque@crma.fr Web: www.crma.fr	Combustion chambers, casings, HPT supports, booster vanes, turbine centre frame (TCF) rotating & stationary seals, spools, QEC accessories, harnesses, sensors, VBV mechanism	CF6-80C2, CF6-80E1, CFM56-5A, CFM56-5B, CFM56-5C, CFM56-7B, GE90 series, GP7200 military engines	CFM56-5C, CFM56-7B, laser drilling, cutting and welding, thermal spray, heat treatment, brazing, EDM NDT inspection, CMM and CNC machining,multi colling holes drilling, airflow test
GE Engine Services - Hungary	Levai utca 33 Veresegyhaz 2112 Hungary	24/7 AOG Hotline T +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com	Pipe repair & kitting Liner panels Honeycomb	CF6-6/-50/-80A/-80C/-80E CFM56-2/-3 GE90 RB211 CF34	Chemical cleaning, anodize and alodine, CNC shotpeening and dry blasting, machining, NDT inspection, CNC unicoat plasma spraying, CNC resist-ance spot welder, vacuum brazing and heat treatment, TIG and orbital welding
GE Engine Services - Wales	Caerphilly Road, Nantgarw Cardiff, South Glamorgan South Wales, UK CF15 7YJ	24/7 AOG Hotline T +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com		GE90, GP7000 CFM56-3/-5/-7	
Goodrich Engine Control Systems	The Radleys Marston Green Birmingham B33 0HZ UK	Niki Court Marketing Co-ordinator T (44) 121 788 5000 F (44) 121 779 5712 E-mail: niki.court@goodrich.com ECEPSservices@goodrich.com	Fuel metering controls, fuel pumping systems, electronics controls (software and hardware), afterburner systems, fuel driven actuation controls, engine health monitoring systems, variable geometry actuation control, microprocessors, variable displacement vane pumps	EJ200, Argo APU, F404, F414, CF34-1, CF34-3, CF6-50/80A, CT2106 APU, V2500, TFE 1042, LF507, TF55, LT101, GTCP36-170, PW305/6, Pegasus, RB211-524G/H, RB211-535, Spey, Tay, Trent 700/800, Trent 500, Viper, AE2100, AE3007, T406, A250-C40, C20/R2, C47B, BR710	Engine control systems supplier, engine control equipment, tailored support contracts
Honeywell Aerospace Raunheim (Engine Accessories)	Frankfurterstrasse 41-65 Raunheim D-65479 Germany	Bill Wright Director, technical sales Mechanical T 480 592 4182 E-mail: bill.wright@honeywell.com	Engine generators/IDG/CSD Fuel/oil coolers and heaters Fuel control units and components	All Honeywell engines / APUs JT8, JT9, JT10, JT11, JT15D, CF6, CT7, CFM56, CF34, PT6, P108, PW100, PW100, PW4000, RB211, RR250, Spey, Tay, T64, T76, All Honeywell engines and APUs	

Specialist engine repairs directory (cont...)

Company name	Address	Contact	Component capabilites	Engine type	Specialist skills
Honeywell Aerospace Bournemouth (Engine Accessories)	Bournemouth International Airport Christchurch, Dorset BH23 6NW UK	Bill Wright Director, technical sales Mechanical T 480 592 4182 E-mail: bill.wright@honeywell.com	Environmental control, cabin pressure control, heat transfer compressor, starter, oxygen hydraulics, electronic systems and equipment		
Jet Technology Centre	Ridgewell House Hollywood, Ballyboughal Co. Dublin Ireland	Michael O Connell Sales & Marketing Manager T (353) 1 8432 221 F (353) 1 8433 849 E-mail: michael.oconnell@jtc.ie Web: www.jtc.ie	Fuel nozzles, MECs, FCUs, pumps EVC/EVBC, fuel, air, oil and hydraulic accessories, safety equipment, slides, vests, rafts, airframe structural	JT3D, JT8D, JT9D, CFM56, CF6-50, CF6-80, 707/727/737/747/757/767 DC8/9/10 MD80, MD11 A300/310/320/330/340	Overhaul, repair, test, Part Sales Exchange Rotables
LPW Technology	PO Box 768 Altrincham Cheshire WA15 5EN UK	Phil Carroll Technical support T (44) 845 539 0162 F (44) 845 539 0163 E-mail: phil.carroll@lpwtechnology.com	Specialist laser cladding/ deposition consultancy, supplier of thermal spray and welding wire and powder	All engine types	Application and process development, process optimisation, enclosure and fixture design, supply of specialist laser, cladding gas and plasma, atomised powders, powder handling and process
Lufthansa Technik Intercoat	Kisdorfer Weg 36-38 D-24568 Kaltenkirchen Germany	Sebastian David Sales manager T (49) 4191 809 100 F (49) 4191 2826 E-mail: sales@lht-intercoat.de	Fuel pump housings, hydraulic housings, oil pump housings, Arkwin actuators, Boeing and Airbus hydraulic parts	JT8-D, JT9-D, CFM56-3, -5, -7 CF6-50, CF6-80, RB211, Trent 500 V2500, PW2000, PW4000 Boeing and Airbus components	Interfill, FPI, CMC measuring, CNC machining
PWA International	Naas Road Rathcoole Co. Dublin Ireland	Vince Gaffney International sales manager T (353) 1 4588100 F (353) 1 4588106 E-mail: vince.gaffney@pw.utc.com	Case overhaul (all models)	JT9D, PW2000, PW4000, V2500	NDT, EBW, TIG, CNC machining, plasma, HVOF, grinding, vacuum furnace, EDM, shot peen, press test, R&D cell
Rösler	Unity Grove School Lane Knowsley Business Park Prescot L34 9GT UK	Stephen Lewis-Brammer GM T (44) 151 482 0444 F (44) 151 482 4400 E-mail: rosler@rosleruk.com	Surface finishing of aero engine blades and vanes (in both compressor and turbine section), vane assemblies and multi-span components, supply of machines, consumables, subcontract and Keramo process	All engine types	Keramo finishing to <10 microinches (<0.25 micrometres) Ra, shot peening and shot blasting
Summit Aviation	Merlin Way, Manston, Kent, UK CT12 5FE	Bruce Erridge Commercial director T (44) 1843 822444 F (44) 1843 820900 E-mail: bruce@summit-aviation.co.uk	QEC removal and installation	Pratt and Whitney JT8D (STD) / 217 / 219 Pratt and Whitney JT3D (All Series)	Complete overhaul, repair and test
TAMRO	Hangar 3, Upwood Airpark Ramsey Road Bury, Cambridge PE26 2RA UK	David Billington Director, sales and marketing T (44) 1487 711650 F (44) 1487 710777 E-mail: David.Billington@turbinemotorworks.com Web: www.turbinemotorworks.com	MRO airframe and engine accessories, fuel, hydraulic pneumatic, oil, electrical, wheel and brake, safety, airframe structural wide and narrow body airframes and respective engine types	CF6-50/80, CFM56, JT9D, JT8D, JT3D ALF502, ALF507	Complete overhaul, repair and testing components
Turbine Component Repair (TCW)	Hangar 2, Upwood Airpark Ramsey Road Bury, Cambridge PE26 2RA UK	David Billington Director, sales and marketing T (44) 1487 711650 F (44) 1487 710777 E-mail: David.Billington@turbinemotorworks.com Web: www.turbinemotorworks.com	Compressor and turbine airfoils, frames and cases, air seals and other rotating parts and Combustors	CF6-50/80, JT9D, JT3D	Airframe types: 747, 777, 767, 757, 737NG, 737, 717, 707 MD-11, DC-10, MD-80, DC-9 RJ85, RJ100, BAE146 A340, A330, A321, A320, A319, A300
TRT	Bramble Way Clovernook Industrial Estate, Somercotes Derbyshire DE55 4RH UK	Andrew Adams Marketing and contracts manager T (44) 1773 524400 F (44) 1773 836327 Email: aadams@trt-ltd.com www.trt-ltd.com	HP, IP, LP blades, HP, IP, LP nozzle guide vanes, nozzle guide vane, assemblies	T500 - T700 - T800 RB211-524-535 (All varients)	TIG and lazer welding vacuum furnace brazing, heat treatment NDT, FPI, X-Ray, EDM CNC machining, precision grinding
TWI	Granta Park Great Abingdon Cambridge CB16AL UK	T: (44) 1223 891162 F: (44) 1223 892588	Engineering solutions incl welding, joining and associated technologies, technology transfer consultancy and project support. Contract R&D, training and qualification	All engine types	Arc, gas and resisitance welding, plasma spray, cold spray, vacuum furnace braze, laser cladding and deposition, NDT, liquid penetrant, MPI, eddy current and ultrasonic inspections, EBW, laser welding and cutting
Woodward Aircraft Engine Systems	5 Shawfarm Road Prestwick Ayrshire KA9 2TR UK	Jim Houston General Manager T (44) 1292 677 633 F (44) 1292 677 612 E-mail: jhoust@woodward.com	Repair and overhaul, fuel control, propellor governer unit test stands	CFM56-2/-3, CFM56-5, CF34-3, CF6-6/-50, RB211-535E4, PT6, PW100, CT7, Allison 250, TPE331, V2500	

Specialist engine repairs directory (cont...)

Company name	Address	Contact	Component capabilites	Engine type	Specialist skills
REST OF WORLD					
Chromalloy	25 Moo 5 Bungkhampoi Lamlukka, Pathumthani Thailand 12150	Tom van der Linden VP, Sales P +31 13 5328 423 E-mail: tvanderlinden@chromalloy.com	Gas turbine engine parts	CFM56-2B/-2C, CFM56-3, CFM56-5A/5B/5C, CFM56-7B, CF6-50, CF6-80A, CF6-80C2, CF6-80E1, LM2500, LM5000, LM6000, PW4000 94/100"	Blending, chemical plating, CMM, ECG, EDM, furnace brazing, gas tungsten arc welding, grinding, heat treating, instruction brazing, metallurgical analysis, steel shot peening, vacuum brazing, welding
GE Aviation, Service - ATI	62 Loyang Way Singapore 508770	Jimmy Tan MD T (65) 543 7818 F (65) 543 7839 E-mail: jtan@airfoiltech.com	HPC blades and vanes, fan blades, HPC cases	CF6, CFM56, GE90, CF34, LM, Honeywell	HPC airfoils repair, service management, new make manufacturing, automatic chemical stripping line, micro plasma automated welding, coining and stamping, net shape machining and grinding (2D & 3D airfoil), RD305 leading edge inspection & leading edge re-profiling
GE Aviation, Services - Singapore	23 Loyang Singapore 508726	24/7 AOG Hotline T +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com	Combustors, HPT blades & nozzles, LPT blades & nozzles	CF6-6/-50/-80A/-80C/-80E GE90 CF34 CFM56-2/-3/-5/-7 LM2500/5000/6000 RB211-535C	Rejuvenation/enhanced rejuvenation, nozzle fabrication repair, shank coating strip, Al Green coating, EB weld repair, laser cladding, NDT - FPI, radioscopic inspection, current, airflow testing, special processes, machine shop
GE Celma	Rua Alice Herve, 356 Bingen Petropolis RJ, CEP: 25669-900 Brazil	24/7 AOG Hotling T +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com		CF6-50, CF6-80C2 CFM56-3/-7	
GE Engine Services Malaysia	MAS Complex A-AA1802 SAAS Airport 47200 Subang Selangor D.E. Malaysia	24/7 AOG Hotling T +1-513-552-3272 Toll Free in USA: 1-877-432-3272 Email: geae.csc@ge.com		CFM56-3/-5B	
Honeywell Aerospace Singapore (Engine accessories)	17 Changi Business Park Central 1 Singapore 486073 Singapore	Paul David Director, technical sales Mechanical T 480 592 4089 E-mail: paul.david@honeywell.com	Engine generators/IDG/CSD Fuel/oil coolers and heaters, fuel control units and components, all engine related accessories	All Honeywell engines / APUs CT7, CF6, CF34, CFM56, JT8, JT9, JT10, JT11, JT15D, PT6, P108, PW100, PW4000, RB211, RR250, Spey, Tay	
Honeywell Aerospace - Xiamen (APU and Propulsion)	Xiamen Gaoqi Int'l Airport Xiamen Fujian 361006 China	Bill Wright Technical sales APU/Propulsion T 480 592 4182 E-mail: bill.wright@honeywell.com	Technical expertise in APUs APU accessories, engine starters, heat exchangers	APU GTCP 85 series APU 85, 331-200/250 series	
Honeywell Aerospace - Melbourne (Engine accessories)	34 Fraser Street, Airport West Victoria, Melbourne, 3042 Australia	Paul David Director technical sales Mechanical T 480 592 4089 E-mail: paul.david@honeywell.com	Air turbine starters bleed air and pneumatic valves, cooling turbines, electro-mechanical actuators		
Windsor Airmotive Asia Barnes Aerospace Aftermarket	21 Loyang Lane 508921 Singapore	Sebastian Lim Sales Manager, Asia T (65) 6541 9222 F (65) 6542 9364	Casings and Frames, Honeycomb Seals, TOBI Ducts, OGVs, Rotating Air Seals, Disks	JT8D, JT9D, PW4000, Trent 700,Trent 800, Trent 500, Trent 900 RB211, CFM56	EBW and Auto TIG Welding; High Pressure Water Jet; CNC Milling, Turning, Grinding; Plasma and Wire Arc Coating; Heat Treat, Thermal processing and Vacuum Brazing; X-ray, FPI, Eddy Current and Ultrasonic testing; EDM; Several Coatings including SVPA; Rotable Pool Support

Directory of major commercial aircraft turboprops

Manufacturer	Designation	Max Mech SHP	Max Shaft RPM	Dry Weight (lb)	Length (in)	Comp stages	Turb stages	Aircraft applications
General Electric	T64-P4D	3400		1188	110	14 axial	2H, 2L	C-27A Spartan
	CT7-5A2	1735		783	96	6 axial	2H, 2L	Saab 340
	CT7-7A	1700		783	96	6 axial	2H, 2L	CN235
	CT7-9B/C	1870		805	96	6 axial	2H, 2L	Saab 340, CN 235
	CT7-9D	1940		805	96	6 axial	2H, 2L	
	CT64-820-4	3133		1145	110	14 axial	2H, 2L	
Honeywell	LPT101-700A-1A	700		335	37	1 axial, I cent		Piaggio P.166-DL3
	T35-L-701	1400		693	59	5 axial, 1 cent	1H, 1L	OV-1 Mohawk
	T76-G-400			341	44			OV-10 Bronco
	TPE331-5/-5A/-6	840		360		2 cent	3	Ayres S2R-G6, Dornier 228, Mu-2, Beech King Air B100
	TPE331-8	715		370		2 cent	3	Cessna Conquest
	TPE-10/-10R/-10U	1000		385	46	2 cent	3	Ayres S2R-G10, Jetstream 31, Merlin III, Commander 690
	TPE331-11U	1000		405	46	2 cent	3	Merlin 23, Metro 23
	TPE331-12U/-12JR	1100		407	46	2 cent	3	C-212-400, Metro 23, Jetstream Super 31
	TPE331-14A/B	1645		620	53	2 cent	3	PA-42-100 Cheyenne
	TPE331-14GR/HR	1960		620	53	2 cent	3	Ayres Vigilante, Jetstream 41
	TPE331-25/61	575		335		2 cent	3	MU-2B
Pratt & Whitney Canada	PT6A-11	550	2200	328	62	3 axial, 1 cent	1H, 1L	Piper Cheyenne 1A, Piper T1040
	PT6A-11AG	550	2200	330	62	3 axial, 1 cent	1H, 1L	Air tractor AT 402A/B, Schweizer G-164B AG-Cat Turbine
	PT6A-15AG	680	2200	328	62	3 axial, 1 cent	1H, 1L	Air tractor AT 402A/B, AT 502B, Ayres Turbo Thrush T-15, Frakes Turbo Cat Model A/B/C, Schweizer G-164B AG-Cat Turb.
	PT6A-21	550	2200	328	62	3 axial, 1 cent	1H, 1L	Raytheon Beech King Air C90A/B/SE
	PT6A-25	550	2200	353	62	3 axial, 1 cent	1H, 1L	Raytheon Beech T-34C
	PT6A-25A	550	2200	343	62	3 axial, 1 cent	1H, 1L	FTS Turbo Firecracker, Pilatus Turbo Trainer PC-7, PZL-Okecie PZL-130 TE Turbo-Orlik, Raytheon Beech T-44A
	PT6A-25C	750	2200	346	62	3 axial, 1 cent	1H, 1L	Embraer EMB-312 Tucano, Pilatus Turbo Trainer PC-7 MK II
	PT6A-27	680	2200	328	62	3 axial, 1 cent	1H, 1L	CATIC/HAIG Y-12, deHavilland DHC-6 Twin Otter Series 300, Embraer Bandeirante EMB-110, LET L410, Raytheon Beech 99A, Ratheon Beech B99
	PT6A-28	680	2200	328	62	3 axial, 1 cent	1H, 1L	Piper Cheyenne II, Raytheon Beech 99A, Raytheon Beech King Air A100/E90
	PT6A-34/34AG	750	2200	331	62	3 axial, 1 cent	1H, 1L	Air Tractor AT 502B, Ayres Turbo Thrush T-34, CROPLEASE Fieldmaster, Embraer Bandierante EMB-110/-111, Embraer Caraja, Frakes Mallard, Frakes Turbo Cat Model A/B/C, JetPROP DLX, Pacific Aero Cresco 750, PZL-Okecie PZL-106 Turbo-Kruk, Schweizer G-164B AG-Cat Turbine, Schweizer G-164D AG-Cat Turbine, Vazar Dash 3 Turbine Otter
	PT6A-36	750	2200	331	62	3 axial, 1 cent	1H, 1L	Raytheon Beech C99 Airliner
	PT6A-112	500	1900	326	62	3 axial, 1 cent	1H, 1L	Cessna Conquest I, Reims F406 Caravan II
	PT6A-114	600	1900	345	62	3 axial, 1 cent	1H, 1L	Cessna 208/208B Caravan 1
	PT6A-114A	675	1900	350	62	3 axial, 1 cent	1H, 1L	Cessna 208/208B Caravan 1
	PT6A-121	615	1900	326	62	3 axial, 1 cent	1H, 1L	PIAGGIO P-166-DL3
	PT6A-135A	750	1900	338	62	3 axial, 1 cent	1H, 1L	Cessna Conquest I, Embraer EMB-121 XINGU II, Piper Cheyenne IIXL, Raytheon Beech King Air E90-1, Vazar Dash 3 Turbine Otter
	PT6A-42	850	2000	403	67	3 axial, 1 cent	1H, 2L	Raytheon Beech C12F, Raytheon Beech King Air B200
	PT6A-42A	850	2000	403	67	3 axial, 1 cent	1H, 2L	Piper Malibu Meridian
	PT6A-50	1120	1210	607	84	3 axial, 1 cent	1H, 2L	deHavilland DHC-7 Dash 8
	PT6A-60A	1050	1700	475	72	3 axial, 1 cent	1H, 2L	Raytheon Super Beech King Air 300/350
	PT6A-60AG	1050	1700	475	72	3 axial, 1 cent	1H, 2L	Air Tractor AT 602, Ayres Model 660
	PT6A-61	850	2000	429	68	3 axial, 1 cent	1H, 2L	Piper Cheyenne IIIA
	PT6A-62	950	2000	456	71	3 axial, 1 cent	1H, 2L	Pilatus Turbo Trainer PC-9
	PT6A-64	700	2000	465	70	4 axial, 1 cent	1H, 2L	Socata TBM700
	PT6A-65AG	1300	1700	486	75	4 axial, 1 cent	1H, 2L	Air Tractor AT 602, AT 802/802A/802AF/802F, Ayres Turbo Thrush T-65, CROPLEASE Fieldmaster, CROPLEASE Firemaster
	PT6A-65AR	1424	1700	486	75	4 axial, 1 cent	1H, 2L	AMI DC-3, Shorts C-23B Super Sherpa
	PT6A-65B	1100	1700	481	75	4 axial, 1 cent	1H, 2L	Polish Aviation Factory M28 Skytruck, Raytheon Beech 1900/1900C
	PT6-65R	1376	1700	481	75	4 axial, 1 cent	1H, 2L	Shorts 360/360-300
	PT6A-66	850	2000	456	70	4 axial, 1 cent	1H, 2L	PIAGGIO Avanti P-180
	PT6A-66A	850	2000	450	70	4 axial, 1 cent	1H, 2L	Ibis Aerospace Ae 270 HP
	PT6A-67	1200	1700	506	74	4 axial, 1 cent	1H, 2L	Pilatus Turbo Porter PC-6, Raytheon Beech RC-12K
	PT6A-67A	1200	1700	506	74	4 axial, 1 cent	1H, 2L	Raytheon Beech Starship
	PT6A-67AF	1424	1700	520	76	4 axial, 1 cent	1H, 2L	Conair Aviation - S2 Turbo-Firecat
	PT6A-67AG	1350	1700	520	76	4 axial, 1 cent	1H, 2L	Air Tractor AT 802/802A/802AF/802F
	PT6A-67B	1200	1700	515	76	4 axial, 1 cent	1H, 2L	Pilatus PC-12
	PT6A-67D	1271	1700	515	74	4 axial, 1 cent	1H, 2L	Raytheon Beech 1900D
	PT6A-67R	1424	1700	515	76	4 axial, 1 cent	1H, 2L	Basler Turbo BT-67, Greenwich Aircraft DC-3, Shorts 360/360-300
	PT6A-68	1250	2000	572	72	4 axial, 1 cent	1H, 2L	Raytheon T-6A Texan II

Directory of major commercial aircraft turboprops (cont...)

Manufacturer	Designation	Max Mech SHP	Max Shaft RPM	Dry Weight (lb)	Length (in)	Comp stages	Turb stages	Aircraft applications
	PT6A-68B/68C	1600	2000	572	72	4 axial, 1 cent	1H, 2L	Pilatus PC-21
	PW118	1800	1300	861	81	2 cent	1H, 1L	Embraer EMB120
	PW118A	1800	1300	866	81	2 cent	1H, 1L	Embraer EMB120
	PW118B	1800	1300	866	81	2 cent	1H, 1L	Embraer EMB120
	PW119B	2180	1300	916	81	2 cent	1H, 1L	Fairchild Dornier 328-110/120
	PW119C	2180	1300	916	81	2 cent	1H, 1L	Fairchild Dornier 328-110/120
	PW120	2000	1200	921	84	2 cent	1H, 1L	Aerospatiale/Alenia ATR42-300/320
	PW120A	2000	1200	933	84	2 cent	1H, 1L	Aerospatiale/Alenia ATR42-400/500, Bombardier Aerospace Q100
	PW121	2150	1200	936	84	2 cent	1H, 1L	Aerospatiale/Alenia ATR42-300/320, Bombardier Aerospace Q100
	PW121A	2200	1200	957	84	2 cent	1H, 1L	Aerospatiale/Alenia ATR42-400/500
	PW123	2380	1200	992	84	2 cent	1H, 1L	Bombardier Aerospace Q300
	PW123AF	2380	1200	992	84	2 cent	1H, 1L	Canadair CL-215T/CL-415
	PW123B	2500	1200	992	84	2 cent	1H, 1L	Bombardier Aerospace Q300
	PW123C	2150	1200	992	84	2 cent	1H, 1L	Bombardier Aerospace Q200
	PW123D	2150	1200	992	84	2 cent	1H, 1L	Bombardier Aerospace Q200
	PW123E	2380	1200	992	84	2 cent	1H, 1L	Bombardier Aerospace Q300
	PW124B	2500	1200	1060	84	2 cent	1H, 1L	Aerospatiale/Alenia ATR 72-200
	PW125B	2500	1200	1060	84	2 cent	1H, 1L	Fokker 50/High Performance
	PW126A	2662	1200	1060	84	2 cent	1H, 1L	Jetstream Aircraft ATP
	PW127	2750	1200	1060	84	2 cent	1H, 1L	Aerospatiale/Alenia ATR 72-210/500
	PW127B	2750	1200	1060	84	2 cent	1H, 1L	Fokker 50/High Performance, Fokker 60 Utility
	PW127C	2750	1200	1060	84	2 cent	1H, 1L	XIAN Y7-200A, Ilyushin Il-114, Socata HALE
	PW127E	2400	1200	1060	84	2 cent	1H, 1L	Aerospatiale/Alenia ATR42-400/500
	PW127F	2750	1200	1060	84	2 cent	1H, 1L	Aerospatiale/Alenia ATR 72-210A
	PW127G	2920	1200	1060	84	2 cent	1H, 1L	CASA C295
	PW127H	2750	1200	1060	84	2 cent	1H, 1L	Ilyushin IL-114-100
	PW127J	2880	1200	1060	84	2 cent	1H, 1L	XIAN Aircraft Co. MA-60
	PW150A	5071	1020	1521	95	3 axial, 1 cent	1H, 1L	Bombardier Aerospace Q400
	PW150B	5071	1020	1521	95	3 axial, 1 cent	1H, 1L	AVIC II Y8F600
Rolls-Royce	Dart RDa7 Mk536	2280		1257	98	2 cent	3	Fokker F-27
	Dart RDa7 Mk529	2250		1257	98	2cent	3	Gulfsteam 1
	Dart RDa10 Mk542	3060		1397	99	2 cent	3	Convair 660, YS 11
	Dart Mk552	2465		1303	98	2 cent	3	Super HS 748-2B, F27
	Tyne Rty 20 Mk 515	5730		2275	109	6L, 9H	1H, 3L	CL44
	Tyne Rty 20 Mk 21/22	6,100		2394	115	6L, 9H	1H, 3L	Transall C.160
	Tyne Rty 20 Mk 801	4860				6L, 9H	1H, 3L	
Rolls-Royce USA	250-B17	420	50,970	195	45	6 axial, 1 cent		Nomad
(Allison)	250-B17B, B17C/D	420	50970	198	45	6 axial, 1 cent		Nomad, Turbine Islander, Turbostar, Viator, Fuji T-5, SF260TP, AS 202/32TP, Redi Go, Siai Marchetti, Turbo Pillan
	250-B17F, B17F/1, B17F/2	450	50970	205	45	6 axial, 1 cent		Beech 36, Cessna P210, Nomad, Canguro, Redi Go, SF260TP, Ruschmeyer 90-420AT, Turbine Trilander, Defender 4000, Fuji T7, Grob G140, Beechcraft A36
	AE2100A	4152	15,375	1578	116	14 axial	2H, 2L	Saab 2000
	AE2100C	3600	15375	1578	116	14 axial	2H, 2L	N-250-100
	AE2100D	4591	14268	1655	116	14 axial	2H, 2L	LMATTS C-27J, Lockheed C-130J, Lockheed L-100F
	AE2100J	4591	14268	1655	116	14 axial	2H, 2L	ShinMaywa
	501-D22	4050	13820	1835	146	14 axial	2H, 2L	L-100
	501-D22A/C/G	4910	13820	1890	147	14 axial	2H, 2L	Convair 580A, L100-20/-30



Directory of major commercial aircraft turbofans

Manufacturer	Designation	Takeoff thrust (lb)	Flat rate temp (°F)	Bypass ratio	Length (in)	Fan tip dia (in)	Basic weight(lb)	Comp stages	Turb stages	Aircraft applications
CFM	CFM56-2-C1	22,000	86	6	95.7	68.3	4,635	1F + 3L, 9H	1H, 4L	DC-8-71, -72, -73
	CFM56-2A-2/3	24,000	90/95	5.9	95.7	68.3	4,820	1F + 3L, 9H	1H, 4L	E-3, E6, E-8B KE-3
	CFM56-2B-1	22,000	90	6	95.7	68.3	4,671	1F + 3L, 9H	1H, 4L	KC-135R C-135FR
	CFM56-3-B1	20,000	86	5	93	60	4,276	1F + 3L, 9H	1H, 4L	B737-300, -500
	CFM56-3B-2	22,000	86	4.9	93	60	4,301	1F + 3L, 9H	1H, 4L	B737-300, -400
	CFM56-3C-1	23,500	86	5	93	60	4,301	1F + 3L, 9H	1H, 4L	B737-300, -400, -500
	CFM56-5-A1	25,000	86	6	95.4	68.3	4,995	1F + 3L, 9H	1H, 4L	A320
	CFM56-5A3	26,500	86	6	95.4	68.3	4,995	1F + 3L, 9H	1H, 4L	A320
	CFM56-5A4	22,000	86	6	95.4	68.3	4,995	1F + 3L, 9H	1H, 4L	A319
	CFM56-5A5	23,500	86	6	95.4	68.3	4,995	1F + 3L, 9H	1H, 4L	A319
	CFM56-5B1	30,000	86	5.5	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A321
	CFM56-5B2	31,000	86	5.5	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A321
	CFM56-5B3	33,000	86	5.4	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A321
	CFM56-5B4	27,000	86	5.7	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A320
	CFM56-5B5	22,000	86	6	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A319
	CFM56-5B6	23,500	86	5.9	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A319
	CFM56-5B7	27,000	86	5.9	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A319, A319CJ
	CFM56-5B8	21,600	86	6	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A318
	CFM56-5B9	23,300	113	6	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A318
	CFM56-5C2	31,200	86	6.6	103	72.3	8,740	1F + 4L, 9H	1H, 5L	A340-200, -300
	CFM56-5C3	32,500	86	6.5	103	72.3	8,740	1F + 4L, 9H	1H, 5L	A340-200, -300
	CFM56-5C4	34,000	86	6.4	103	72.3	8,740	1F + 4L, 9H	1H, 5L	A340
	CFM56-5B1/3	30,000	86	5.5	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A321
	CFM56-5B2/3	31,000	86	5.5	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A321
	CFM56-5B3/3	33,000	86	5.4	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A321
	CFM56-5B4/3	27,000	86	5.7	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A320
	CFM56-5B5/3	22,000	86	6.0	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A319
	CFM56-5B6/3	23,500	86	5.9	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A319
	CFM56-5B7/3	27,000	86	5.9	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A319, A319CJ
	CFM56-5B8/3	21,600	86	6.0	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A318
	CFM56-5B9/3	23,300	113	6.0	102.4	68.3	5,250	1F + 4L, 9H	1H, 4L	A318
	CFM56-7B18	19,500	86	5.5	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-600
	CFM56-7B20	20,600	86	5.4	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-600, -700
	CFM56-7B22	22,700	86	5.3	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-600, -700
	CFM56-7B24	24,200	86	5.3	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-700, -800, -900
	CFM56-7B26	26,300	86	5.1	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-800, -900
	CFM56-7B27	27,300	86	5.1	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-800, -900
	CFM56-7B20/3	20,600	86	5.4	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-600, -700
	CFM56-7B22/3	22,700	86	5.3	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-600, -700
	CFM56-7B24/3	24,200	86	5.3	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-700, -800, -900
	CFM56-7B26/3	26,300	86	5.1	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-800, -900
	CFM56-7B27/3	27,300	86	5.1	103.5	61	5,257	1F + 3L, 9H	1H, 4L	B737-800, -900
General Electric	CJ610-5-6	2,950	59		40.5	17.6	403	8	2	Learjet 24D, 25B, 25C, Westwind 1121
	CJ610-8-9	3,100	59		40.5	17.6	411	8	2	Westwind 1123
	CJ610-8A	2,950	59		40.5	17.6	411	8	2	Learjet Century III
	CF700-2D2	4,500	59		75.6	33.1	767	8	2	Falcon 20, Rockwell Sabre 75A
	CF34-1A	8,650	59	6.2	103	49	1,625	1F, 14H	2H, 4L	Challenger 601
	CF34-3A	9,220	70	6.2	103	49	1,625	1F, 14H	2H, 4L	Challenger 601
	CF34-3A1	9,220	70	6.2	103	49	1,625	1F, 14H	2H, 4L	Challenger 601 Canadair Regional Jet
	CF34-3B	9,220	86	6.2	103	49	1,670	1F, 14H	2H, 4L	Challenger 604
	CF34-3B1	9,220	86	6.2	103	49	1,670	1F, 14H	2H, 4L	Canadair Regional Jet
	CF34-8C1	13,790	86	4.9	128.5	52	2,350	1F, 10H	2H, 4L	Canadair CRJ-700
	CF34-8C5	14,500	86	4.9	128.5	52	2,470	1F, 10H	2H, 4L	Canadair CRJ-900
	CF34-8E	14,500	86	4.9	128.5	52	2,470	1F, 10H	2H, 4L	Embraer ERJ-170/175
	CF34-10A	18,050	86	5	90	53	3,800	3L,9H	1H, 4L	ACAC ARJ21
	CF34-10E	18,500	86	5	90	53	3,800	3L, 9H	1H, 4L	ERJ-190/195
	CF6-6D	40,000	88	5.72	188	86.4	8,176	1F + 1L, 16H	2H, 5L	DC-10-10
	CF6-6D1A	41,500	84	5.76	188	86.4	8,966	1F + 1L, 16H	2H, 5L	DC-10-10

Directory of major commercial aircraft turbofans (cont...)

Manufacturer	Designation	Takeoff thrust (lb)	Flat rate temp (°F)	Bypass ratio	Length (in)	Fan tip dia (in)	Basic weight(lb)	Comp stages	Turb stages	Aircraft applications
	CF6-45A2	46,500	97	4.64	183	86.4	8,768	1F + 3L, 14H	2H, 4L	B747-100B SR
										B747SP
	CF6-50C	51,000	86	4.26	183	86.4	8,966	1F + 3L, 14H	2H, 4L	DC-10-30
										A300-B2,-B4
	CF6-50E	52,500	78	4.24	183	86.4	9,047	1F + 3L, 14H	2H, 4L	B747-200
	CF6-50C1	52,500	86	4.24	183	86.4	8,966	1F + 3L, 14H	2H, 4L	DC-10-30
										A300-B2, -B4
	CF6-50E1	52,500	86	4.24	183	86.4	9,047	1F + 3L, 14H	2H, 4L	B747-200
	CF6-50C2	52,500	86	4.31	183	86.4	8,966	1F + 3L, 14H	2H, 4L	DC-10-30
										A300-B2, -B4
	CF6-50C2R	51,500	86	4.31	183	86.4	8,966	1F + 3L, 14H	2H, 4L	DC-10-30
	CF6-50E2	52,500	86	4.31	183	86.4	9,047	1F + 3L, 14H	2H, 4L	B747-200
	CF6-50C2B	54,000	79	4.25	183	86.4	8,966	1F + 3L, 14H	2H, 4L	DC-10-30
	CF6-50C2R	51,000	79	4.25	183	86.4	8,966	1F + 3L, 14H	2H, 4L	DC-10-30
	CF6-50E2B	54,000	86	4.24	183	86.4	9,047	1F + 3L, 14H	2H, 4L	B747-200
	CF6-80A	48,000	92	4.66	166.9	86.4	8,760	1F + 3L, 14H	2H, 4L	B767-200
	CF6-80A1	48,000	92	4.66	166.9	86.4	8,760	1F + 3L, 14H	2H, 4L	A310-200
	CF6-80A2	50,000	92	4.59	166.9	86.4	8,760	1F + 3L, 14H	2H, 4L	B767
	CF6-80A3	50,000	92	4.59	166.9	86.4	8,760	1F + 3L, 14H	2H, 4L	A310-200
	CF6-80C2-A1	59,000	86	5.15	168.4	93	9,480	1F + 4L, 14H	2H, 5L	A300-600
	CF6-80C2-A2	53,500	111	5.31	168.2	93	9,480	1F + 4L, 14H	2H, 5L	A310-200/ -300
	CF6-80C2-A3	60,200	86	5.09	168.3	93	9,480	1F + 4L, 14H	2H, 5L	A300-600
										A310-300
	CF6-80C2-A5	61,300	86	5.05	168.3	93	9,480	1F + 4L, 14H	2H, 5L	A300-600
	CF6-80C2-A5F	61,300	86	5.05	168.3	93	9,860	1F + 4L, 14H	2H, 5L	A300-600
	CF6-80C2-A8	59,000	95	5.09	168.3	93	9,480	1F + 4L, 14H	2H, 5L	A310-300
	CF6-80C2-B1	56,700	86	5.19	168.3	93	9,670	1F + 4L, 14H	2H, 5L	B747-200, -300
	CF6-80C2-B1F	58,000	90	5.19	168.3	93	9,790	1F + 4L, 14H	2H, 5L	747-400
	CF6-80C2-B2	52,500	90	5.31	168.3	93	9,670	1F + 4L, 14H	2H, 5L	B767-200/-ER/-300
	CF6-80C2-B2F	52,700	86	5.31	168.3	93	9,790	1F + 4L, 14H	2H, 5L	B767-300ER
	CF6-80C2-B4	58,100	90	5.14	168.3	93	9,790	1F + 4L, 14H	2H, 5L	B767-200ER/-300ER
	CF6-80C2-B4F	58,100	77	5.14	168.3	93	9,790	1F + 4L, 14H	2H, 5L	B767-300ER
	CF6-80C2-B5F	60,800	77	5.14	168.3	93	9,790	1F + 4L, 14H	2H, 5L	B767-300ER
	CF6-80C2-B6	60,800	86	5.06	168.3	93	9,670	1F + 4L, 14H	2H, 5L	B767-300ER
	CF6-80C2-B8F	60,800	86	5.06	168.3	93	9,790	1F + 4L, 14H	2H, 5L	B767-300ER
	CF6-80C2-D1F	51,250	86	5.03	168.3	93	9,790	1F + 4L, 14H	2H, 5L	C-5M
	CF6-80E1-A2	65,800	86	5.1	173.5	96.2	11,225	1F + 4L, 14H	2H, 5L	A330
	CF6-80E1-A3	69,800	86	5.1	173.5	96.2	10,627	1F + 4L, 14H	2H, 5L	A330-200
	CF6-80E1-A4	68,100	86	5	168.4	96.2	9,790	1F + 4L, 14H	2H, 5L	A330-200
	GE90-76B	76,000	86	8.7	287	123	16,644	1F + 3L, 10H	2H, 6L	B777-200
	GE90-77B	77,000	86	8.7	287	123	16,644	1F + 3L, 10H	2H, 6L	B777-200
	GE90-85B	84,700	86	8.7	287	123	16,644	1F + 3L, 10H	2H, 6L	B777-200
	GE90-90B	90,000	86	8.7	287	123	16,644	1F + 3L, 10H	2H, 6L	B777-200/-200ER/-300
	GE90-94B	93,700	86	8.7	287	123	16,644	1F + 3L, 10H	2H, 6L	B777-200ER/-300
	GE90-110B1	110,100	92	7.2	287	128.2	18,260	1F + 3L, 9H	2H, 6L	B777-200LR
	GE90-115B	115,300	86	7.2	287	128.2	18,260	1F + 3L, 9H	2H, 6L	B777-300ER
	GEnx-1B54	53,200	86	9	184.7	111.1	18,822	1F + 4L, 10H	2H, 7L	B787-3
	GEnx-1B64	63,800	86	8.8	184.7	111.1	18,822	1F + 4L, 10H	2H, 7L	B787-8
	GEnx-2B67	66,500	86	7.4	169.7	104.2	18,822	1F + 3L, 10H	2H, 7L	B747-8
	GEnx-1B70	69,800	86	8.6	184.7	111.1	18,822	1F + 4L, 10H	2H, 7L	B787-9
GE-P&W Alliance	GP7270	70,000	86	8.7	187	116	12,906	1F + 5L, 9H	2H, 6L	A380
	GP7277	77,000	86	8.7	187	116	12,906	1F + 5L, 9H	2H, 6L	A380
Honeywell	AS907	6,500	85	4.2	92.4	46.3	1364	1F + 4L, 1CF	2H, 3L	Continental Jet
	AS977-1A	7,092	85	4.2	92.4	49.9	1,364	1F + 4L, 1CF	2H, 3L	Avro RJX and BAe 146
	ALF502L	7,500	59	5	56.8	41.7	1,311	1F + 1L,7H + 1CF	2H, 2L	Canadair 600 Challenger
	ALF502R-3A/5	6,970	71	5.6	58.6	41.7	1,336	1F + 1L, 7H + 1CF	2H, 2L	BAe 146
	ALF502R-6	7,500	71	5.6	58.6	41.7	1,375	1F + 1L, 7H + 1CF	2H, 2L	BAe 146
	LF507-1F	7,000	74	5	58.6	41.7	1,385	1F + 2L,7H + 1CF	2H, 2L	Avro RJ
	LF507-1H	7,000	74	5	58.6	41.7	1,385	1F + 2L,7H + 1CF	2H, 2L	BAe 146
	TFE731-2	3,500	72	2.5	49.7	28.2	743	1F + 4L,1H	1H, 3L	Dassault Falcon 10
										CASA C101
										Learjet 31/35
										AT-3, IA-63
	TFE731-2A/B/J/L/N	3,600	73.4	2.56	49.7	28.2	750	1F + 4L, 1CF	1H, 3L	K-8

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Manufacturer	Designation	Takeoff thrust (lb)	Flat rate temp (°F)	Bypass ratio	Length (in)	Fan tip dia (in)	Basic weight(lb)	Comp stages	Turb stages	Aircraft applications
	TFE731-3	3,700	76	2.67	49.7	28.2	742	1F + 4L, 1CF	1H, 3L	731 Jetstar, Jetstar II CASA 101 Dassault Falcon 50 Hawker 400/700 Westwind Sabreliner 65
	TFE731-3A	3,700	76	2.66	49.7	28.2	766	1F + 4L, 1H	1H, 3L	Learjet 55 Astra
	TFE731-3B	3,650	70	2.65	49.7	28.2	760	1F + 4L, 1H	1H, 3L	Citation III, VI
	TFE731-3C	3,650	70	2.65	49.7	28.2	777	1F + 4L, 1H	1H, 3L	Citation III, VI
	TFE731-4	4,060	76	2.4	58.15	28.2	822	1F + 4L, 1H	1H, 3L	Citation V11
	TFE731-5	4,304	73.4	3.33	54.7	29.7	852	1F + 4L, 1H	1H, 3L	Hawker 800 CASA C101
	TFE731-5A	4,500	73.4	3.15	67.8	29.7	884	1F + 4L, 1H	1H, 3L	Dassault Falcon 900 Dassault Falcon 20-5
	TFE731-5B	4,750	77	3.2	67.8	29.7	899	1F + 4L, 1H	1H, 3L	Dassault Falcon 900B Dassault Falcon 20-5 Hawker 800XP
	TFE731-20	3,500	93	3.1	59.65	34.2	895	1F + 4L, 1H	1H, 3L	Learjet 45
	TFE731-40	4,250	77	2.9	51	28.2	895	1F + 4L, 1H	1H, 3L	Falcon 50EX Astra SPX
	TFE731-60	5,000	89.6	3.9	72	30.7	988	1F + 4L, 1H	1H, 3L	Falcon 900EX
IAE	V2500-A1	25,000	86	5.4	126	63	5,210	1F + 3L, 10H	2H, 5L	A320, ACJ
	V2522-A5	23,000	131	4.9	126	63.5	5,210	1F + 4L, 10H	2H, 5L	A319
	V2524-A5	24,500	131	4.9	126	63.5	5,210	1F + 4L, 10H	2H, 5L	A319
	V2525-D5	25,600	86	4.9	126	63.5	5,610	1F + 4L, 10H	2H, 5L	MD-90
	V2527-A5	26,600	115	4.8	126	63.5	5,210	1F + 4L, 10H	2H, 5L	A320
	V2528-D5	28,600	86	4.7	126	63.5	5,610	1F + 4L, 10H	2H, 5L	MD-90
	V2530-A5	30,400	86	4.6	126	63.5	5,210	1F + 4L, 10H	2H, 5L	A321-100
	V2533-A5	32,000	86	4.5	126	63.5	5,210	1F + 4L, 10H	2H, 5L	A321-200
PowerJet	SaM146	13,750	TBA	4.43	81.49	48.2	TBA	3L, 6H	1H, 3L	Superjet 100-75B
	SaM146	15,650	TBA	4.43	81.49	48.2	TBA	3L, 6H	1H, 3L	Superjet 100-75LR/-95
Pratt & Whitney	JT3C-6	11,200 dry	?	?	138.6	38.8	4,234	9L, 7H	1H, 2L	B707-120 DC-8-10
	JT3C-7	12,000 dry	?	?	136.8	38.8	3,495	9L, 7H	1H, 2L	B720
	JT3C-12	13,000 dry	?	?	136.8	38.8	3,550	9L, 7H	1H, 2L	B720
	JT3D-1, -1A	17,000 dry	?	1.4	136.3	53.1	4,145	2F + 6L, 7H	1H, 3L	B720B B707-120B DC-8-50
	JT3D-1 & -1A -MC6	17,000 dry	?	1.4	145.5	53.1	4,540	2F + 6L, 7H	1H, 3L	B707-120B
	JT3D-1 & -1A-MC7	17,000 dry	?	1.4	145.5	53	4,165	2F + 6L, 7H	1H, 3L	B720B
	JT3D-3B, -3C	18,000 dry	84	1.4	136.6	53.1	4,340	2F + 6L, 7H	1H, 3L	DC-8-50,-61,-61F,-62,-63 B707-120B, -320B, -C B720B, VC-137C
	JT3D-7, -7A	19,000 dry	84	1.4	136.6	53.1	4,340	2F + 6L, 7H	1H, 3L	B707-320B, C , F DC-8-63, -63F
	JT4A-3, -5	15,800	N/K	N/A	144.1	43	5,020/4,815	8L, 7H	1H, 2L	B707-320 DC-8-20
	JT4A-9, -10	16,800	N/K	N/A	144.1	43	5,050/4,845	8L, 7H	1H, 2L	B707-320 DC-8-20
	JT4A-11, -12	17,500	N/K	N/A	144.1	43	5,100/4,895	8L, 7H	1H, 2L	B707-320 DC-8-20, -30
	JT8D-1, -1A, -1B	14,000	N/K	1.1	123.5	42.5	3,155	2F + 4L, 7H	1H, 3L	B727-100, -100C DC-9-10, -20, -30 Caravelle 10B, 10R
	JT8D-7, -7A, -7B	14,000	84	1.1	123.5	42.5	3,205	2F + 4L, 7H	1H, 3L	Caravelle 10B, 10R, 11R DC-9-10/-30 B727, B737
	JT8D-9, -9A	14,500	84	1.04	123.5	42.5	3,377	2F + 4L, 7H	1H, 3L	Caravelle 12 B727-200 B737-200

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Manufacturer	Designation	Takeoff thrust (lb)	Flat rate temp (°F)	Bypass ratio	Length (in)	Fan tip dia (in)	Basic weight(lb)	Comp stages	Turb stages	Aircraft applications
										DC-9-20, -30, -40
										T-43A, C-9A, C-9B, VC-9C
	JT8D-11	15,000	84	1.05	123.5	42.5	3,389	2F + 4L, 7H	1H, 3L	DC-9-20/-30/-40
	JT8D-15, -15A	15,500	84	1.03/1.04	123.5	42.5	3,414/3,474	2F + 4L, 7H	1H, 3L	B727-200
										B737-200
										DC-9-30,-40, -50
										Mercure
	JT8D-17, -17A	16,000	84	1.01/1.02	123.5	42.5	3,430/3,475	2F + 4L, 7H	1H, 3L	B727-200
										DC-9-30, -50
										B737-200
	JT8D-17R	17,400	77	1	123.5	42.5	3,495	2F + 4L, 7H	1H, 3L	B727-200
	JT8D-17AR	16,400	77	1	123.5	42.5	3,600	2F + 4L, 7H	1H, 3L	B727-200
	JT8D-209	18,500	77	1.78	154.2	49.2	4,435	1F + 6L, 7H	1H, 3L	MD-81
	JT8D-217	20,850	77	1.73	154.2	49.2	4,470	1F + 6L, 7H	1H, 3L	MD-82
	JT8D-217A	20,850	84	1.73	154.2	49.2	4,470	1F + 6L, 7H	1H, 3L	MD-82, MD-87
	JT8D-217C	20,850	84	1.81	154.2	49.2	4,515	1F + 6L, 7H	1H, 3L	MD-82, -83, -87, -88
	JT8D-219	21,700	84	1.77	154.2	49.2	4,515	1F + 6L, 7H	1H, 3L	MD-82, -83, -87, -88
	JT9D-3A	43,600 dry	80	5.2	154.2	95.6	8,608	1F + 3L, 11H	2H, 4L	B747-100
	JT9D-7	45,600 dry	80	5.2	154.2	95.6	8,850	1F + 3L, 11H	2H, 4L	B747-100/-200B, C, F
										B747 SR
	JT9D-7A	46,250 dry	80	5.1	154.2	95.6	8,850	1F + 3L, 11H	2H, 4L	B747-100/-200B, C, F
										B747 SR, SP
	JT9D-7F	48,000 dry	80	5.1	154.2	95.6	8,850	1F + 3L, 11H	2H, 4L	B747-200B, C, F,
										B747 SR, SP
	JT9D-7J	50,000 dry	80	5.1	154.2	95.6	8,850	1F + 3L, 11H	2H, 4L	B747-100, -200B, C, F,
										B747 SR, SP

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Manufacturer	Designation	Takeoff thrust (lb)	Flat rate temp (°F)	Bypass ratio	Length (in)	Fan tip dia (in)	Basic weight(lb)	Comp stages	Turb stages	Aircraft applications
	JT9D-20	46,300 dry	84	5.2	154.2	95.6	8,450	1F + 3L, 11H	2H, 4L	DC-10-40
	JT9D-59A	53,000	86	4.9	154.2	97	9,140	1F + 4L, 11H	2H, 4L	B747-200
										A300-B4-100/-200
	JT9D-70A	53,000	86	4.9	154.2	97	9,155	1F + 4L, 11H	2H, 4L	B747-200
	JT9D-7Q, -7Q3	53,000	86	4.9	154.2	97	9,295	1F + 4L, 11H	2H, 4L	B747-200B, C, F
	JT9D-7R4E, E1	50,000	86	5	153.6	97	8,905	1F + 4L, 11H	2H, 4L	B767-200, -200ER, -300
										A310-200,-300
	JT9D-7R4E4, E3	50,000	86	4.8	153.6	97	9,140	1F + 4L, 11H	2H, 4L	B767-200ER,-300
										A310-200, -300
	JT9D-7R4H1	56,000	86	4.8	153.6	97	8,885	1F + 4L, 11H	2H, 4L	A300-600
	PW2037	38,250	87	6	141.4	78.5	7,300	1F + 4L, 12H	2H, 5L	B757-200
	PW2040	41,700	87	6	141.4	78.5	7,300	1F + 4L, 12H	2H, 5L	B757-200, -200F
	PW2043	43,000	87	6	141.4	78.5	7,300	1F + 4L, 12H	2H, 5L	B757-200, -300
	PW4050	50,000	92	5	153.6	97	9,213	1F + 4L, 12H	2H, 5L	B767-200, -200ER
	PW4052	52,200	92	5	132.7	94	9,213	1F + 4L, 11H	2H, 4L	B767-200, -200ER, -300
	PW4056	56,000	92	4.9	132.7	94	9,213	1F + 4L, 11H	2H, 4L	B767-200, -200ER, -300
	PW4056	56,750	92	4.9	132.7	94	9,213	1F + 4L, 11H	2H, 4L	B747-400
	PW4060	60,000	92	4.8	132.7	94	9,332	1F + 4L, 11H	2H, 4L	B767-300, -300ER
	PW4062	62,000	86	4.8	132.7	94	9,400	1F + 4L, 11H	2H, 4L	B767-300
	PW4062	62,000	86	4.8	132.7	94	9,400	1F + 4L, 11H	2H, 4L	B747-400
	PW4074	74,000	86	6.4	191.7	112	14,995	1F + 6L, 11H	2H, 7L	B777-200
	PW4077	78,040	86	6.4	191.7	112	14,995	1F + 6L, 11H	2H, 7L	B777-200
	PW4084	84,600	86	6.4	191.7	112	14,995	1F + 6L, 11H	2H, 7L	B777-200
	PW4090	91,790	86	6.4	191.6	112	15,741	1F + 6L, 11H	2H, 7L	B777-200, -300
	PW4098	98,000	86	6.4	194.7	112	16,170	1F + 7L, 11H	2H, 7L	B777-300
	PW4152	52,000	108	5	132.7	94	9,332	1F + 4L, 11H	2H, 4L	A310-300
	PW4156	56,000	92	4.9	132.7	94	9,332	1F + 4L, 11H	2H, 4L	A300-600, A310-300
	PW4158	58,000	86	4.8	132.7	94	9,332	1F + 4L, 11H	2H, 4L	A300-600, -600R
	PW4164	64,000	86	5.1	163.1	100	11,700	1F + 5L, 11H	2H, 5L	A330
	PW4168	68,000	86	5.1	163.1	100	11,700	1F + 5L, 11H	2H, 5L	A330
	PW4460	60,000	86	4.8	132.7	94	9,332	1F + 4L, 11H	2H, 4L	MD-11
	PW4462	62,000	86	4.8	132.7	94	9,400	1F + 4L, 11H	2H, 4L	MD-11
	PW6122A	22,100	86	4.8	108	56.6	4,840	1F + 4L, 5H	1H, 3L	A318
	PW6124A	23,800	86	5	108	56.6	4,840	1F + 4L, 5H	1H, 3L	A318
P & W Canada	JT15D-1, -1A, -1B	2,200	59	3.3	56.6	27.3	514/519	1F + 1CF	1H, 2L	Cessna Citation 1
	JT15D-4	2,500	59	2.6	60.4	20.8	557	1F + 1CF	1H, 2L	A»rospatiale Corvette
										Cessna Citation II
										Mitsubishi Diamond 1
	JT15D-4C	2,500	59	2.6	60.4	20.8	575	1F + 1CF	1H, 2L	Agusta S211
	JT15D-5	2,900	80	2	60.4	20.5	632	1F + 1CF	1H, 2L	Beechjet 400A
										Cessna T-47A
	JT15D-5A	2,900	80	2	60.4	27	632	1F + 1CF	1H, 2L	Cessna Citation V
	JT15D-5B	2,900	80	2	60.4	27	643	1F + 1CF	1H, 2L	Beech T-1A Jayhawk
	JT15D-5C	3,190	59	2	60.4	27	665	1F + 1CF	1H, 2L	Agusta S211A
	JT15D-5D	3,045	80	2	60.6	27	627	1F + 1CF	1H, 2L	Cessna Citation V Ultra
	JT15D-5F	2,900	80	2	60.4	27	635	1F + 1CF	1H, 2L	Raytheon Beech
	PW305A	4,679	93	4.3	81.5	30.7	993	1F, 4H + 1CF	2H, 3L	Learjet Model 60
	PW305B	5,266	74.3	4.3	81.5	30.7	993	1F, 4H + 1CF	2H, 3L	Raytheon Hawker 1000
	PW306A	6,040	89	4.5	75.6	31.7	1,043	1F, 4H + 1CF	2H, 3L	Gulfstream G-200
	PW306B	6,050	95	4.5	75.6	31.7	1,062	1F, 4H + 1CF	2H, 3L	Fairchild 328JET
	PW306C	5,770	91.4	4.3	75.726	31.7	1,150	1F, 4H + 1CF	2H, 3L	Cessna Citation Sovereign
	PW307A	6,405	92.1	4.31	86.02	32.7	1,242	1F, 4H + 1CF	2H, 3L	Falcon 7X
	PW308A	6,904	98.6	4	84.2	33.2	1,365	1F, 4H + 1CF	2H, 3L	Raytheon Hawker Horizon
	PW308C	7,002	100.4	4	84.2	33.2	1,375	1F, 4H + 1CF	2H, 3L	Dassault Falcon 2000EX
	PW530A	2,887	73	3.2	60	27.6	616	1F, 2H + 1CF	1H, 2L	Cessna Citation Bravo
	PW535A	3,400	81	3.7	64.8	29	697	1F + 1L, 2H + 1CF	1H, 3L	Cessna Encore Ultra
	PW545A	3,804	83	4	75.7	32	815	1F + 1L, 2H + 1CF	1H, 3L	Cessna Citation Excel
	PW610F-A	950	97	1.83	45.4	14.5	259.3	1F, 1H + 1C	1H, 1L	Eclipse Aviation E500
	PW615F-A	1,390	77	2.8	49.5	16.03	310	1F, 1H + 1C	1H, 1L	Citation Mustang
	PW617F-E	1,780	68	2.7	52.6	17.7	366	1F, 1H + 1C	1H, 1L	Embraer Phenom 100
	PW800	10,000 to 20,000	TBA	TBA	TBA	TBA	TBA	TBA	TBA	
Rolls-Royce	AE3007A	7,580	86	5.3	106.5	38.5	1,608	1L , 14H	2H, 3L	Embraer EMB-135/145
	A3007C	6,495	86	5.3	106.5	38.5	1,586	1L, 14H	2H, 3L	Citation X

Directory of major commercial aircraft turbofans (cont...)

Manufacturer	Designation	Takeoff thrust (lb)	Flat rate temp (°F)	Bypass ratio	Length (in)	Fan tip dia (in)	Basic weight(lb)	Comp stages	Turb stages	Aircraft applications
	BR710-A1-10	14,750	86	4.2	134	51.6	3,520	1L, 10H	2H, 2L	Gulfstream V
	BR710-A2-20	14,750	86	4.2	134	51.6	3,600	1L, 10H	2H, 2L	Global Express
	BR710-C4-11	15,385	86	4.2	134	51.6	3,520	1L, 10H	2H, 2L	Gulfstream V-SP
	BR715-58	22,000	50	4.4	142	62.2	4,660	1 + 2L, 10H	2H, 3L	B717
	RB211-22B	42,000	84	4.8	119.4	84.8	9,195	1L, 7I, 6H	1H, 1I, 3L	L-1011-1, -100
	RB211-524B & B2	50,000	84	4.5	119.4	84.8	9,814	1L, 7I, 6H	1H, 1I, 3L	L-1011-200/-500 B747-200/SP
	RB211-524B4D/ B4 improved	50,000	84	4.4	122.3	85.8	9,814	1L, 7I, 6H	1H, 1I, 3L	L-1011-250/500
	RB211-524C2	51,500	84	4.5	119.4	84.8	9,859	1L, 7I, 6H	1H, 1I, 3L	B747-200/SP
	RB211-524D4	53,000	86	4.4	122.3	85.8	9,874	1L, 7I, 6H	1H, 1I, 3L	B747-200/SP
	RB211-524D4 upgrade	53,000	86	4.4	122.3	85.8	9,874	1L, 7I, 6H	1H, 1I, 3L	B747-200/-300
	RB211-524G	58,000	86	4.3	125	86.3	9,670	1L, 7I, 6H	1H, 1I, 3L	B747-400/B767-300
	RB211-524H	60,600	86	4.1	125	86.3	9,670	1L, 7I, 6H	1H, 1I, 3L	B747-400/B767-300
	RB211-524G-T	58,000	86	4.3	125	86.3	9,470	1L, 7I, 6H	1H, 1I, 3L	B747-400
	RB211-524H-T	60,600	86	4.1	125	86.3	9,470	1L, 7I, 6H	1H, 1I, 3L	B747-400/B767-300
	RB211-535C	37,400	84	4.4	118.5	73.2	7,294	1L, 6I, 6H	1H, 1I, 3L	B757-200
	RB211-535E4	40,100	84	4.3	117.9	74.1	7,264	1L, 6I, 6H	1H, 1I, 3L	B757-200/-300
	RB211-535E4B	43,100	84	4.3	117.9	74.1	7,264	1L, 6I, 6H	1H, 1I, 3L	B757-200/-300, Tu 204
	Spey 511-8	11,400	74	0.64	109.6	32.5	2,483	5L, 12H	2H, 2L	Gulfstream GI, II, III
	Spey 512-5W/-14DW	12,550 (wet)	77	0.71	109.6	32.5	2,609	5L, 12H	2H, 2L	Trident 2E/3B BAC 1-11-475, -500
	Tay 611	13,850	86	3.04	94.7	44	2,951	1 + 3L, 12H	2H, 3L	Gulfstream IV
	Tay 620	13,850	86	3.04	94.7	44	3,185	1 + 3L, 12H	2H, 3L	F100, F70
	Tay 650	15,100	86	3.06	94.7	45	3,340	1 + 3L, 12H	2H, 3L	F100
	Tay 651	15,400	82.4	3.07	94.7	45	3,380	1 + 3L, 12H	2H, 3L	B727
	Trent 553	53,000	86	7.7	154	97.4	10,400	1L, 8I, 6H	1H, 1I, 5L	A340-500
	Trent 556	56,000	86	7.6	154	97.4	10,400	1L, 8I, 6H	1H, 1I, 5L	A340-600
	Trent 768	67,500	86	5.1	154	97.4	10,550	1L, 8I, 6H	1H, 1I, 4L	A330-300
	Trent 772	71,100	86	5	154	97.4	10,550	1L, 8I, 6H	1H, 1I, 4L	A330-300
	Trent 772B	71,100	100	5	154	97.4	10,500	1L, 8I, 6H	1H, 1I, 4L	A330-200, -300, Freighter
	Trent 875	74,600	86	6.2	172	110	13,100	1L, 8I, 6H	1H, 1I, 5L	B777-200
	Trent 877	77,200	86	6.1	172	110	13,100	1L, 8I, 6H	1H, 1I, 5L	B777-200, -200ER
	Trent 884	84,950	86	5.9	172	110	13,100	1L, 8I, 6H	1H, 1I, 5L	B777-200/-200ER/-300
	Trent 892	91,600	86	5.8	172	110	13,100	1L, 8I, 6H	1H, 1I, 5L	B777-200ER/-300
	Trent 892B	91,600	86	5.8	172	110	13,100	1L, 8I, 6H	1H, 1I, 5L	B777-200ER/-300
	Trent 895	95,000	77	5.8	172	110	13,100	1L, 8I, 6H	1H, 1I, 5L	B777-200ER/-300
	Trent 970	70,000	86	8.7	179	116	14,190	1L, 8I, 6H	1H, 1I, 5L	A380-800
	Trent 972	72,000	86	8.6	179	116	14,190	1L, 8I, 6H	1H, 1I, 5L	A380-800
	Trent 977	76,500	86	8.5	179	116	14,190	1L, 8I, 6H	1H, 1I, 5L	A380-F
	Trent 1000-A	63,800	86	11	160	112	11,924	1L, 8I, 6H	1H, 1I, 6L	B787-8
	Trent 1000-C	69,800	86	11	160	112	11,924	1L, 8I, 6H	1H, 1I, 6L	B787-8, -9
	Trent 1000-D	69,800	95	11	160	112	11,924	1L, 8I, 6H	1H, 1I, 6L	B787-8, -9
	Trent 1000-E	53,200	86	11	160	112	11,924	1L, 8I, 6H	1H, 1I, 6L	B787-3, -8
	Trent 1000-G	67,000	86	11	160	112	11,924	1L, 8I, 6H	1H, 1I, 6L	B787-8, -9
	Trent 1000-H	58,000	86	11	160	112	11,924	1L, 8I, 6H	1H, 1I, 6L	B787-3, -8
	Trent 1000-J	73,800	86	11	160	112	11,924	1L, 8I, 6H	1H, 1I, 6L	B787-9
	Trent 1000-K	73,800	91	11	160	112	11,924	1L, 8I, 6H	1H, 1I, 6L	B787-9
	Trent XWB-74	74,000	TBA	TBA	TBA	118	TBA	1L, 8I, 6H	1H, 2I, 6L	A350-800 XWB
	Trent XWB-83	83,000	TBA	TBA	TBA	118	TBA	1L, 8I, 6H	1H, 2I, 6L	A350-900 XWB
	Trent XWB-92	92,000	TBA	TBA	TBA	118	TBA	1L, 8I, 6H	1H, 2I, 6L	A350-1000 XWB