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# REPORT

MTU Aero Engines www.mtu.de

# Pioneering new core engine technologies



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# Editorial

Dear Readers:

MTU Aero Engines' products and services are among the finest to be found in the global marketplace. The company excels in particular in the areas of low-pressure turbines and high-pressure compressors, as well as repair and manufacturing processes. These core competencies make us a must-have partner in the engine industry. Our success is the result of decades of intensive research work performed both in-house and in cooperation with partners from industry and academe. To remain at the top of the game, we are continuing to invest in R&D. In 2010, we will spend 230 million euros, which is around ten million more than in the year before. For it is only through innovation that we will be able to maintain our position as a technology leader. With this approach we intend to secure the company's competitiveness long-term and to help make air travel cleaner in the future.

Under its three-stage Claire technology program, MTU has succeeded in making a major contribution towards the development of the propulsion concept of the future. It bases on the geared turbofan (GTF), which we are building in partnership with Pratt & Whitney and which features a high-speed low-pressure turbine. Our key areas of research are low-pressure turbines and high-pressure compressors. But apart from these, we are also dedicating significant technological efforts to the further development of the overall engine system, for example, by highly advanced thermodynamic cycles with markedly improved thermal efficiencies. In the process, we closely cooperate with other companies, with universities and research institutes at a regional, national and European level.

One of the most important projects pursued is the MTU-led European NEWAC (New Aero Engine Core Concepts) technology program. The results of the four years of intensive research work performed under the program were announced just recently. The efforts to develop new core engine concepts have yielded an impressive combination of technical innovations and environmentally sound technologies, and the outcome is also tangible proof of how successful joint research can be. Such programs, sponsored by the European Commission, are vital to all industry players in Europe, because they provide a platform for blazing new trails in engine technology.

The above examples go to show that MTU is continuously investing in novel products and engine services. Thus, we make sure that the company remains a driver of innovation and a valued and reliable partner in the engine industry.

Sincerely yours,

Dr. Rainer Martens
Member of the Board of Management,
Chief Operating Officer

Active compressor on MTU's rig 260.

# Pioneering new core engine technologies

By Denis Dilba

Four years of research conducted as part of the New Aero Engine Core Concepts technology program—NEWAC for short—have produced results that once again illustrate just how much can be achieved when industry and research partners work together on a European level. With active systems, heat management and advanced combustors, the newly developed core engine concepts feature an impressive mix of technical innovations and environmentally sound technologies.

The Advisory Council for Aeronautics Research in Europe (ACARE) wants the aviation industry to explore radically new technologies as it works to meet environmental standards for the next generations of aircraft. A glance at the figures shows that the industry will need to halve fuel consumption, $CO_2$ emissions and noise levels by 2020 relative to year-2000 aircraft, while also slashing emissions of oxides of nitrogen by 80 percent. Regarding noise and $NO_X$ emissions future engines will need to contribute the lion's share and in terms of fuel consumption some 20 percent of these improvements. All this obviously comes as no surprise to the engine manufacturers, who have spent years ploughing resources into research programs such as EEFAE, VITAL and DREAM with the goal of finding technological solutions to achieve the drastic cuts in consumption and emissions that are required over today's engines.

The recent presentation on the five-year NEWAC project, which is co-funded by the European Commission under the Sixth Framework Programme for Research and Technology Development, provided the perfect opportunity to judge how far manufacturers have already come. Under the leadership of MTU Aero Engines, 40 partners were working towards cutting $CO_2$ emissions by six percent and $NO_X$ emissions by 16 percent by making improvements to the core engine. The NEWAC project is split into five key areas of research—four core engine concepts plus a sub-project to investigate lean combustion processes—and testing has already been successfully completed in some areas.

The greatest potential for cutting fuel consumption and thus reducing $CO_2$ emissions lies in the combined use of heat exchangers (recuperators) and intercoolers in the engine. "The idea here is that the recuperator elements use the residual heat from the exhaust gas stream to pre-heat the air entering the combustor," says Stefan Donnerhack, technical expert at MTU Aero Engines in Munich and head of the Intercooled Recuperative Aero-Engine (IRA) research team. The approach makes it possible to achieve the same turbine entry temperature as in a conventional engine, but with less fuel.

Blade profile aspiration being tested at EPFL (École Polytechnique Fédérale de Lausanne).

Abrasive coatings were tested on a Sulzer test facility.

Snecma compressor rig.

Donnerhack says their previous work under the Clean project had already confirmed they were on the right track with their chosen concept of a profiled-tube recuperator: "Our work on the IRA focuses on the optimum arrangement of the recuperator modules in the exhaust gas stream and the development of a new radial compressor." There were two good reasons for a new radial compressor, adds the MTU expert: It is well suited for an engine with a comparatively low overall pressure ratio of between 20:1 and 25:1 in the IRA cycle, and it also discharges the air radially outward, as its name suggests, which is precisely where it needs to go anyway in order to be routed past the combustor and reach the recuperator.

Intercooled engine intercase prototypes.

NEWAC partner Turbomeca, a French manufacturer of engines for aircraft and helicopters and a specialist in the field of radial compressors, has managed to reduce the weight of the new compressor more than ten percent while boosting efficiency by approximately one percent. Donnerhack is confident that improvements to the airflow through the recuperator will help reduce IRA fuel consumption by a further two percentage points in addition to the 16 percent already achieved under Clean. He also notes that the overall IRA engine system will be around one percent lighter. Final rig tests are scheduled to take place over the next few months.

Rolls-Royce researcher Nick Baker, who heads up the Intercooled Core (IC) project of NEWAC, has developed an intercooler that could also be used in a modified form in the IRA. "The main advantage of the Intercooled Core concept is that it is not quite as complex as the IRA," says Baker. Nonetheless, the task of developing the IC is far from simple. The intercooler needs to be ultra-compact and as lightweight as possible, which is what prompted Baker and his NEWAC partners to use a rapid prototyping technique to produce an intercooler in titanium. Its corrugated sheet structure has already demonstrated impressive performance in initial trials, according to Baker. The job to be done now is to make it even smaller.

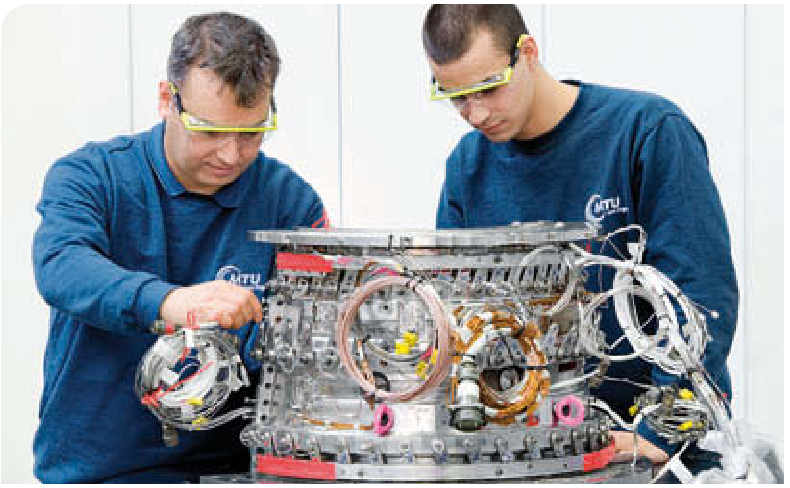
Baker's project team has also been working on the design of the flow ducts that feed air to the intercooler modules and then back to the high-pressure compressor. Minimizing the pressure losses in this area has been challenging, Baker explains. Integrating the intercooler has also required the team to optimize the compressors and make the engine casing more rigid. Although efforts are still ongoing to meet the goal of four percent reduced fuel consumption relative to a conventional engine, Baker says: "NEWAC is already the most successful EU project I have ever worked on."

The Rolls-Royce expert is confident that the targets will be met within a year or so. "And we will keep working on these new technologies even after NEWAC comes to an end," he adds. The first technologies developed under NEWAC are likely to appear in production engines from 2020 at the earliest. "But for engine manufacturers like us that feels like no time at all," states Wolfgang Sturm, who works at MTU and heads up research into the Active Core concept, emphasizing the importance of this research work. Sturm explains that one of the key elements of his active core engine is a smart compressor that adapts itself to varying operating conditions. To pull off this impressive feat of engineering, his team developed an active clearance control system. The sensors in this system continuously monitor the clearance and use actuators to adjust the casing so that the compressor is constantly working at optimum efficiency.

Setup for testing of the active clearance control system.

Advanced compressor rotor.

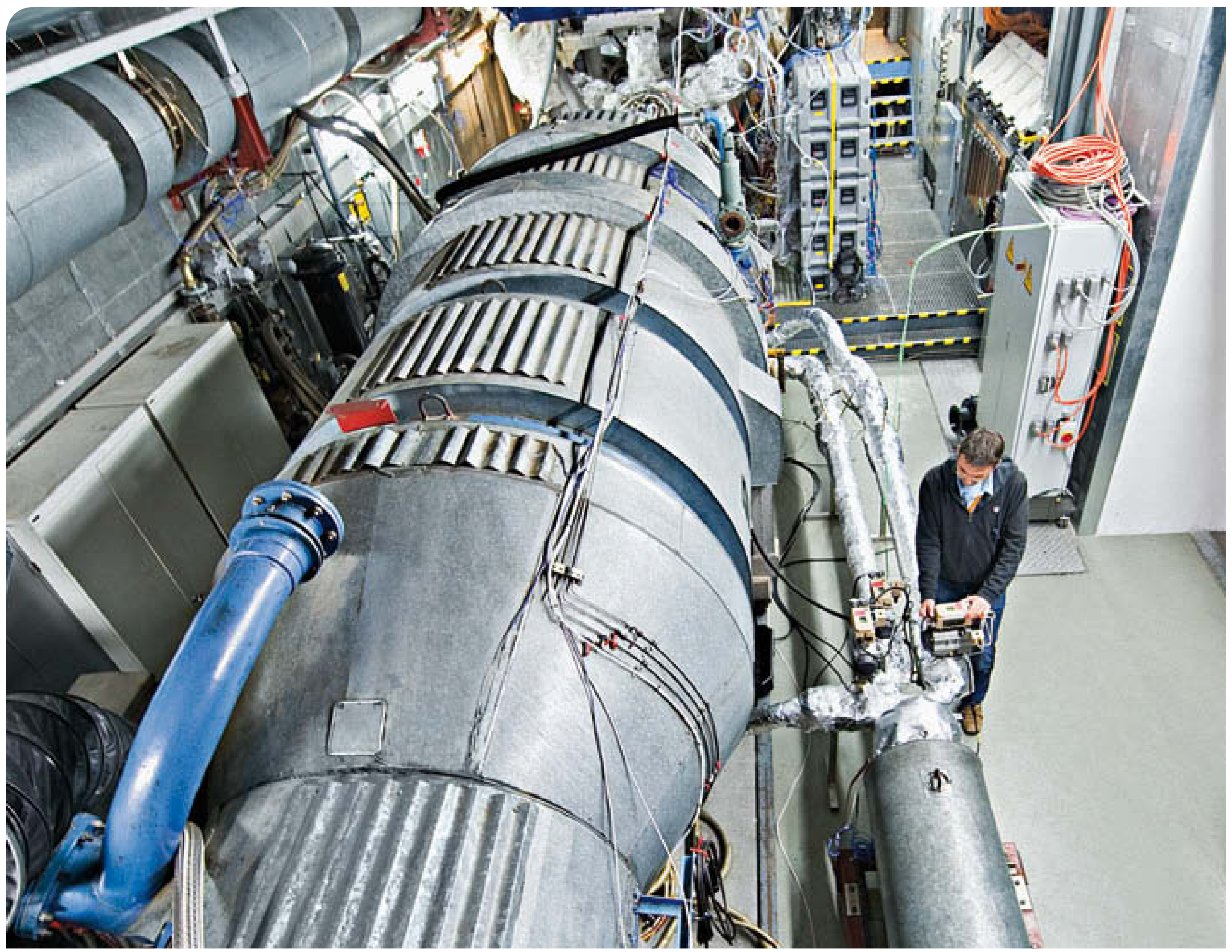
The team also developed what is known as a tip injection system. "That's where we addi-



Two MTU employees are fitting the instrumentation for the experimental compressor.

tionally blow air from the outside into the forward compressor stages," says Sturm, explaining that this helps improve stability at part load conditions. The third key aspect of the active core engine is cooling air cooling. If the cooling air is colder than in today's engines, significantly less air is needed for the remaining cooling tasks in the engine, such as turbine blade cooling. "And that boosts the engine's efficiency," says Sturm. But everything is a question of balance. If the difference in temperature between the cooling air and the hot gas in the turbine becomes too great, the turbine's service life will drop markedly. Sturm and his NEWAC colleagues therefore had to design a system to actively control the temperature of the cooling air.

The result was a 1.5 percent drop in fuel consumption and 0.5 percent increase in the efficiency of the high-pressure turbine with enhanced cooling. The active core engine now requires some 20 percent less cooling air overall than before, says Sturm, and the technologies used in the smart high-pressure compressor have improved its efficiency by two percent. "We have only just finished our rig tests and we still have to analyze and assess all the data," the MTU expert adds, "but it is already clear that these technologies offer great potential for the future." Sturm and his team are obviously keen to continue pursuing development work in this area, ideally in a follow-up project of a similar kind so that they can continue to reap the benefits of the excellent collaboration with their partners—one of the key factors that has made their work so successful.



MTU's compressor test facility is extremely powerful.

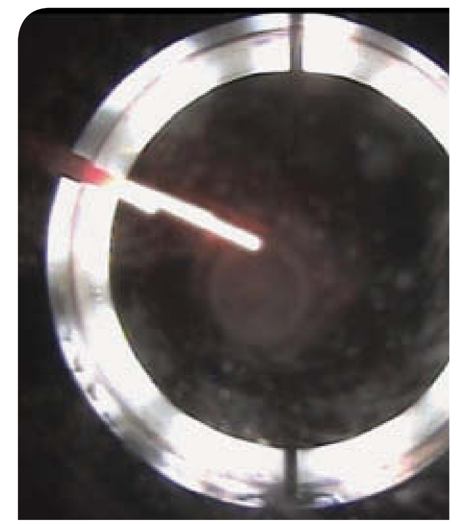
Hanna Reiss of French engine manufacturer Snecma, who heads up research into the Flow Controlled Core (FCC) concept, too, has nothing but praise for the positive working atmosphere in NEWAC. Her project team has developed and tested four different approaches to improve the efficiency of the high-pressure compressor. According to Reiss, the new engines can achieve their full potential only if the compressor design is optimized for high pressure ratios. The FCC approach involves local control of the airflow in the high-pressure compressor. This required multistage 3D CFD (Computational Fluid Dynamics) optimization combined with advanced flow control technologies.

The team focused in particular on the extraction of air from the high-pressure compressor and on reducing performance losses caused by flow separation. Reiss explains that aspiration is being investigated both on casing walls and directly on the blade profiles through tiny ducts in the blades. The first method has already been successfully tested in NEWAC in a new, fully-assembled high-pressure compressor, while preliminary testing of the second method has shown the concept to be very promising, according to Reiss. Testing has also been carried out on optimized, more durable abradable linings in the high-pressure compressor casing.

Overall, Reiss and her team have managed to boost the efficiency of the high-pressure compressor by 1.9 percent and increase the surge margin by 7.5 percent. "We are delighted with the results, but we still need to find a way of making the systems simpler and lighter," says the Snecma manager—hence the decision to keep working on this project even after NEWAC comes to an end.

Much of the responsibility for NEWAC meeting the stipulated target of a 16 percent reduction in oxides of nitrogen emissions lies with Salvatore Colantuoni of Italian engine manufacturer Avio, who heads up research work in the field of combustors. The new combustor technologies developed under his leadership focus on lean combustion. In contrast to conventional combustion, the new technologies feature an excess of air in the combustor rather than fuel. "That is how we reduce the flame temperature and prevent the increased formation of oxides of nitrogen," Colantuoni explains.

Full-annular combustor rig setup for low-pressure test at Avio.



View of the combustor flame at ignition.

However, the extent to which lean combustion technology can be applied to different engine sizes and overall pressure ratios is very limited, which is why Colantuoni's team decided to work on three different concepts in parallel: Lean Direct Injection (LDI), Lean Premixed Prevaporized (LPP) and Partially Evaporated and Rapid Mixing (PERM). "LPP is well suited for the comparatively low overall pressure ratios of intercooled recuperated engines," says the combustion expert. PERM is suitable for average pressure ratios, while LDI development is primarily aimed at the intercooled core engine, which has the highest pressures. All three lean combustion concepts were tested on demonstrators and produced very good results in terms of reducing $NO_X$ emissions, according to Colantuoni.

The next steps are to optimize the weight and reduce the complexity of the system, a process that will require the team to take an even closer look at the interaction between the new combustors and the components closest to them—the high-pressure compressor and the high-pressure turbine, says Colantuoni, adding: "The NEWAC developments have brought us a lot closer to reaching the ambitious ACARE goals."

"One of the best things to come out of NEWAC is the wide selection of innovative technologies that we have developed, something that enables us to make immediate improvements as well as to take some important long-term steps towards eco-efficient flight," says Jörg Sieber, Chief Engineer of the NEWAC technology program.

"We have achieved our goals," enthuses Stephan Servaty, Senior Manager, Technology Programs at MTU and NEWAC coordinator. The money spent by the EU and the program partners is an investment that pays dividends: "It makes a major contribution towards a cleaner environment, and at the same time helps Europe's engine industry to remain competitive in the global marketplace."

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For interesting multimedia services associated with this article, go to www.mtu.de/210NEWAC

# The right technologies at the right time

Intensive research is undertaken in the engine industry to make tomorrow's aircraft fuel-thriftier, cleaner and quieter. The aircraft manufacturers, too, are working ceaselessly to develop new technologies. To learn more about the joint efforts we asked Sébastien Rémy, Vice President, Head of CoC Powerplant Airbus S.A.S. a few questions.

Sébastien Rémy, VP, Head of CoC Powerplant Airbus S.A.S.

*Mr. Rémy, the European Commission has for many years sponsored programs to develop new technologies for engines of the future, a current example being NEWAC. To what extent are airframers involved in such programs?*

Airbus and engine manufacturers have a long experience of collaborative work within E.U. funded frame which has been boosted in the late 90'/early 2000' within the EEFAE & Silencer projects, continued with NEWAC and now developed with the Clean Sky Programs (SAGE, SFWA). The Airbus contribution to E.U. engine led programs always focused on the evaluation of engine technologies potential at aircraft level through the definition of generic aircraft platforms suited to the various engine options investigated. Final objective for both engine manufacturers and Airbus is to get capability to down-select, in a balanced aircraft level way, the most promising engine technologies for further developments.

*All aircraft manufacturers are presently mulling over launching a next-generation passenger aircraft to enter service in 10 to 12 years at the earliest. In what order of magnitude are the expected improvements over today's aircraft in terms of consumption, emissions and life-cycle costs?*

Airbus is always assessing all options from continuous improvement of the current product, with technologies insertion at airframe & engine level, up to the development of new airframe combined with new propulsion system. What drives at the end the selection of the preferred option is the critical mass of technological improvement with the related economical benefits for both OEM and operators. Expected improvements over the next couple of decades can easily range from 10 to 35 percent in term of fuel consumption depending of actual product entry into service horizon.

*Which technical measures will be taken to make sure these targets are met?*

A systematic approach (Technology Readiness Level) is in place at Airbus to develop and down-select the most promising technology options with the ambition to consolidate the performance potential while reducing the development risk. This step by step approach in maturing technologies is well illustrated by a number of collaborative E.U. funded projects covering the full spectrum from academic work, through scale model tests (typically Wind Tunnel Tests) up to full scale demonstration (engine ground test or engine Flying Test Bed). This systematic down-selection approach is largely shared between Airbus and engine manufacturers and has allowed the introduction of the right technologies at the right time over the past decades; best technologies are the ones which find their route to the market.

*Does the industry think about using entirely new materials that are presently in the development stage or not even that?*

Airbus keeps on developing materials, such as CFRP, and investigating new materials which will contribute to aircraft weight reduction, hence reduced aircraft emissions. Our vision (and therefore criteria for success) is however broader, encompassing simplicity in operation, respecting landscape and biodiversity, and ecoefficiency (including green manufacturing and recycling). Some of our objectives for 2020 are, relative to 2006, to reduce energy consumption by 30 percent, $CO_2$ emissions by 50 percent, water consumption by 50 percent, water discharge by 80 percent, and waste production by 50 percent. For instance, significant investment has been made to eliminate chromates in the painting process. And water used for surface treatment can be limited by recycling it, by reducing evaporation thanks to lower bath temperatures and by minimising rinse levels as far as possible. In addition, current practices do not allow recovering more than, at best, 60 percent (in weight) of aircraft materials. This situation is no longer acceptable. Not only it is potentially environmentally damaging through the release of hazardous materials and soil pollution, but it also presents safety risks through the uncontrolled reuse of second hand spare parts. Last but not least, it is uneconomical as only a small part of the materials is recycled. The PAMELA LIFE project, which supplied its final reports in January 2008, demonstrated that up to 85 percent of an aircraft's components can be easily recycled, reused or recovered, with 70 percent reuse and recovery. The experience gained in dismantling and recycling can then be fed back into the Airbus life cycle (reverse engineering, manufacturing, supply chain, raw material etc.), helping to make future aircraft even easier to recycle.

Airbus Concept Plane.

*Which role do the engines play in the achievement of the ambitious targets?*

Future engine technologies are among the most promising lever arms to improve aviation efficiency and environmental friendliness. However, those technologies will only deliver their full promise in case of a smart integration to the airframe. This deserves the cooperation of both actors from the very early stage of R&T, paving the way to the optimum airframe/engine technology package and application. This combined engine/airframe technologies effort is expected to deliver as much as 40 percent of fuel consumption which together with the 10 to 15 percent further reduction expected from ATM improvements will lead to the 50 percent fuel reduction ACARE target vs to current product in operation.

*Today's engines power the aircraft while at the same time ensuring the energy supply to the aircraft. Do you think this will also hold true for future engines or will there be separate systems?*

Engines are to date and will remain within the next decade the most efficient and reliable energy source on board the aircraft. The objective of the airframer is to optimize the level of power-off take which is required from the engine for non thrust related needs. Some evolution can be foreseen first in the ground phase where alternative systems will complement or take-over from engine, to supply energy to the aircraft for various functions (air conditioning...) including taxi phase that could be assisted with independent electrical engine fitted on landing gear.

*What do you think about the use of the much discussed fuel cell on aircraft?*

Fuel cells can produce electricity in a more efficient way than combustion engines. They also offer the perspective to further reduce aviation emissions footprint. Airbus, DLR and Michelin have been first, in February 2008, to fly a commercial airplane with a fuel cell powering the electric motor pump for the aircraft's back-up hydraulic circuit, controlling the spoilers, ailerons and elevator actuator. Research activities related to fuel cells are however at an early stage. Dramatic progress in fuel cell system power density (ratio of power produced per unit weight) is still needed to allow fuel cells to progressively find their way into commercial aircraft.

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For further information on this article, go to
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# The Chancellor's new jetliner

By Patrick Hoeveler

You have probably seen them often on TV, albeit only in the background: The aircraft operated by the Special Air Mission Wing of the German Federal Ministry of Defense frequently form part of the decor when the German Chancellor, the German President or other high-ranking government officials go on official travel. Two new A319s, procured as part of the first stage of an extensive fleet modernization program, will significantly improve the air force unit's mission capabilities. They are each powered by two IAE International Aero Engines V2500 engines, in which MTU has a stake.

The famous "red phone" featured in numerous fictional movies does actually exist on board the two brand-new Airbus A319s—only it is black, not red. But otherwise the interior of the jets, with their discrete ivory and beige paneling and furnishings, is anything but spectacular, and fully in keeping with the missions for which they were designed: transporting VIP passengers on official government business. This is one of the main duties of the Special Air Mission Wing, an air force unit stationed at Wahn air-base near Cologne, which is also responsible for military transportation and logistics support when German troops are posted abroad.

The A319 is the first in a new generation of German-government VIP aircraft that will be gradually introduced as part of a modernization program to replace the present aging fleet of Airbus A310s and Canadair CL-601 Challengers, which have been in service for over 20 years. The first of the two A319 Airbus Corporate Jetliners (ACJ), intended for medium-haul flights, was fitted out by Lufthansa Technik and handed over to the Ministry of Defense at the end of March. The A319 ACJ's special VIP cabin was the result of nine months' work at the company's Hamburg site. The new aircraft will be joined towards the end of this year by two Airbus A340-300s for long-haul flights. The Special Air Mission Wing's remaining Challengers will be replaced in 2011 by four Bombardier Global 5000 jets.

The first of the three new aircraft types to join the fleet has delighted crew and passengers alike. "The A319 has significantly improved the Special Air Mission Wing's capabilities," says Lieutenant Colonel Sascha Kählert, Captain of the 2nd Squadron. "Most importantly, it enables us to transport up to 44 people—delegations and crew—, whereas with the Challenger we were limited to 16." With auxiliary tanks in the cargo bay, the aircraft's range between fueling stops has also been considerably increased. As Kählert says, "We can easily fly non-stop from Berlin-Tegel to Washington D.C. or even Beijing."


The new A319 has been flying in a livery that represents the national colors of Germany since late March.

First Sergeant Maik Kolditz explains the differences between the VIP version of the Airbus A319 and the regular versions flown by commercial airlines such as Lufthansa: "The main modifications relate to the cabin layout and the on board security systems," says the trained A319 technician. The air force models have a personal office in the forward section, equipped with two executive seats and a convertible sofa bed. The unit has its own private shower and bathroom. Immediately adjoining these VIP quarters is a conference area with eight seats, equipped with a full range of multimedia systems including TV and Internet access. State-of-the-art, secure communications equipment is used throughout. The next compartment comprises 32 seats in a conventional layout. Behind this section, on the right-hand side of the aircraft, there is a resting area for the crew. This is necessary because the cockpit team on long-haul flights consists of three instead of two persons, and they are required to remain on duty for up to 18 hours, rather than 14 on shorter flights. Other members of crew on normal flights include between two and four flight attendants, a baggage-handling manager, and two technicians to deal with any problems that might occur when the aircraft has to land on remote airstrips. This is also the reason why the aircraft is equipped with its own deployable air stair.

The Airbus is also intended for use on medical evacuation (MedEvac) missions to transport patients requiring intensive care, in which case it carries additional crew members on board: two physicians, one medical technician, and usually an anesthetist. "Like all other aircraft flown by the Special Air Mission Wing, the A319 can be reconfigured for MedEvac missions. We always have one A310 and either a Challenger or an A319 on standby. This level of mission readiness is unequalled anywhere in the world," says Master Sergeant Guido Rademacher, who serves as a medical flight assistant on the A319. It only takes a few hours to remove the seats from a portion of the passenger cabin and install intensive care units for two patients. In this configuration, the aircraft is mostly used for repatriating injured or critically ill German soldiers and civilians, but also in the context of international humanitarian aid missions in the event of natural disasters.

The Airbus plant at Finkenwerder near Hamburg is responsible for the final assembly of the A319s. Altogether, the German workshare is considerably higher than in previous governmental aircraft. The same holds true for the engine, the International Aero Engines (IAE) V2500. "We are obviously very pleased that the German government has placed its trust in an engine that is built with significant MTU input," says Dr. Anton Binder, Senior Vice President, Commercial Programs at MTU Aero Engines in Munich. As a member of the IAE consortium, the company supplies the low-pressure turbine and holds an 11-percent share in the program, the other shareholders being Pratt & Whitney, Rolls-Royce and Japanese Aero Engine Corporation. Half of all V2500 engines are assembled at the German Rolls-Royce plant in Dahlewitz near Berlin.

"It was no doubt important for reasons of prestige to have a "German" engine on the wing of the German governmental aircraft," says Leo Müllenholz, Director, IAE Programs at MTU. "But the IAE engine was nevertheless selected through a normal competitive bidding process, in which the other candidate was the CFM56. One of the factors that tipped the scales in favor of the V2500 was its lower fuel consumption." The V2500 is a perennial bestseller, with over 4,000 engines delivered worldwide and more than 2,000 on order.

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For further information on
this article, go to
www.mtu.de/210V2500

The German Chancellor's new Airbus is powered by V2500 engines.

## Air Force One—the XXL presidential aircraft

Almost everybody knows "Air Force One" as the name of the U.S. President's personal aircraft. In fact, it is the air traffic control call sign used for any U.S. Air Force aircraft carrying the President of the United States aboard. At present, Barack Obama travels on one of two Boeing VC-25As; the aircraft is a highly customized military version of the 747-200B, which entered into service in 1990. The aircraft is capable of being refueled in flight, and is equipped with state-of-the-art, secure communication systems that allow the jumbo jet to function as an airborne command and control center in the event of a national emergency.


Two Boeing 747s are on standby around the clock for the U.S. president.

The spacious cabin has an interior floor space of over 370 square meters. Four General Electric CF6-80C2B1 engines provide the power for the VC-25A, each with a thrust of 252.4 kilonewtons. Here too, MTU contributes some of the components. "We manufacture the rotor blades and stator vanes for stages 1 and 2 and the disk for the second stage of the high-pressure turbine," says Josef Moosheimer, GEnx Program Team Leader at MTU.

The German engine manufacturer stands a good chance of contributing its expertise to the next generation of Air Force One. Among the possible candidates to replace the VC-25A is the Boeing 747-8, which is powered exclusively by GE Aviation's GEnx engine. Says Moosheimer: "In this case, MTU would be responsible for supplying the turbine center frame."

# A cargo workhorse in the skies

By Andreas vom Bruch

In the wake of the earthquake in Haiti, the U.S. Air Force flew non-stop humanitarian relief missions to provide the affected population with food and medical supplies. Initially, its C-17 Globemaster aircraft could only airdrop their life-saving cargo by parachute. In all, the airlifters completed more than 1,800 flights to the devastated island, carrying a total of 10,000 metric tons of aid and almost 14,000 passengers.

The C-17 Globemaster III transport aircraft is a real allrounder and has been a major player in every recent humanitarian relief mission. Aircraft of this type flew into Pakistan's earthquake region, provided assistance in the wake of the Asian tsunami, and are currently in active service in Afghanistan. They are operated by a number of different nations. The C-17 was originally designed for demanding military missions; its huge cargo bay can accommodate almost any item of combat equipment, including tanks, helicopters and command vehicles. 26 meters in length, 5.5 meters wide and four meters high, it can hold 78 metric tons of freight and is accessed via a loading ramp and door at the rear of the aircraft.

This giant of the skies, which is 53 meters long and has a wingspan of 50 meters, is powered by F117 engines. "Thanks to its four powerful engines, each of which produces 185.5 kilonewtons of thrust, the C-17 is capable of operating to and from temporary airfields with extremely short and unprepared runways. It can also taxi backwards and turn on a dime," says Manfred Vögele, Director, Pratt & Whitney programs at MTU Aero Engines. According to Vögele, the engine, which has been produced jointly by Pratt & Whitney and MTU since 1993, has built a reputation as a "solid performer". It also burns significantly less fuel than comparable engines, not least because it is relatively lightweight. Vögele continues: "The F117 engine builds on the reliability and experience of the commercial version, the PW2040, which powers the Boeing 757. But it is considerably more robust, featuring more durable accessories, for example. One major difference lies in its powerful thrust reversers, which can back a fully-loaded aircraft up a two-degree slope."

Toussaint L'Ouverture International Airport in Port-au-Prince: After the devastating earthquake in Haiti in January 2010 the C-17 Globemaster evacuated victims from the disaster zone.

For Germany's leading engine manufacturer, the PW2000 is of huge strategic importance. Vögele explains: "This engine incorporates the first commercial low-pressure turbine developed by MTU. Today, the company is a world leader in this field." The Munich-based company has been developing and producing components for the PW2000 as a partner of Pratt & Whitney since 1979. Initially, MTU held an 11-percent share in the program and developed and produced the low-pressure turbine and turbine exhaust casing. In 1992, the company's share was upped to 21 percent to include parts of the high-pressure turbine as well. At the time, no one could have foreseen that the program would prove so enduringly successful and ultimately become one of MTU's key drivers of revenue and earnings.

The C-17 Globemaster, too, proved a bestseller and has become a huge export success. The U.S. Air Force currently operates a fleet of 200 of these airlifters, the largest in the world. It took delivery of its first aircraft in 1993 from McDonnell Douglas, which was taken over by Boeing in 1997. Demand continued to rise and the USAF plans to increase its C-17 fleet to 223 units have been built. The United Kingdom's Royal Air Force also highly values the C-17 for its range and versatility. It can fly in and out of combat zones very quickly and, fully-loaded, can travel a distance of 4,450 kilometers without refueling. If refueled in mid-air, it can fly non-stop to any crisis spot in the world. The aircraft is renowned for its superb reliability, low maintenance requirements and fuel efficiency. In light of its impressive capability profile, the U.S. Air Force still considers it the newest and most flexible cargo aircraft in the world.

Currently, the United Kingdom operates six of these aircraft, but this figure will rise to seven by the end of the year. Boeing also delivered four copies each to the Royal Australian Air Force and the Canadian Forces Air Command. In 2006, a number of NATO member states announced their intention to procure three C-17s within the Strategic Airlift Capability initiative. These aircraft are now flying with mixed crews from the Netherlands, Norway, Sweden, the U.S. and Lithuania. Qatar and the United Arab Emirates also rate the C-17's capabilities highly: Qatar has painted the military transport in commercial livery and makes it available to members of the country's royal family and government officials. Now India is also showing strong interest and plans to procure ten aircraft.

Boeing has delivered a total of 219 Globemasters to customers all over the world. This April, the American aircraft manufacturer took delivery of the 1000th F117 engine; it was ceremonially handed over to the U.S. Air Force in May. From 2011, Boeing intends to downscale C-17 production to around ten aircraft a year. Production will continue at the company's Long Beach facility in California until 2012 at least. And perhaps even longer, since the C-17 Globemaster is still second to none.

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# PW2000 maintenance in Langenhagen

MTU generates a significant amount of additional revenue through the maintenance of the commercial PW2000 engine, from which the F117 powering the C-17 has been derived. This work is carried out at MTU Maintenance Hannover in Langenhagen. According to Customer Program Manager Thomas von Kaweczynski, more than 400 maintenance orders for complete engines have been handled since 1989, and some 200 orders for engine modules. This year alone, Kaweczynski is expecting as many as 40 engine shop visits.

A Pratt & Whitney PW2000 in the development test cell of MTU.

Customers of the Langenhagen-based facility are airlines which operate Boeing 757s with PW2000 engines on the wings, among them Shanghai Airlines, VIM Airlines, Finnair and also UPS, the parcel delivery service. "In the early years, the engines had to be overhauled after 10,000 flying hours at the latest. But today's reduced temperature configuration (RTC) engines can easily fly more than 15,000 hours between overhauls," says Kaweczynski. This improvement is owed to technical modifications to the low-pressure compressor and low-pressure turbine incorporated to increase the air mass flow in the high-pressure compressor and high-pressure turbine, which allows the combustion chamber and the high-pressure turbine to operate at a significantly lower temperature. As a result, wear is reduced and less maintenance is needed.

Assembly of a PW2000.

# Power from algae

By Achim Figgen

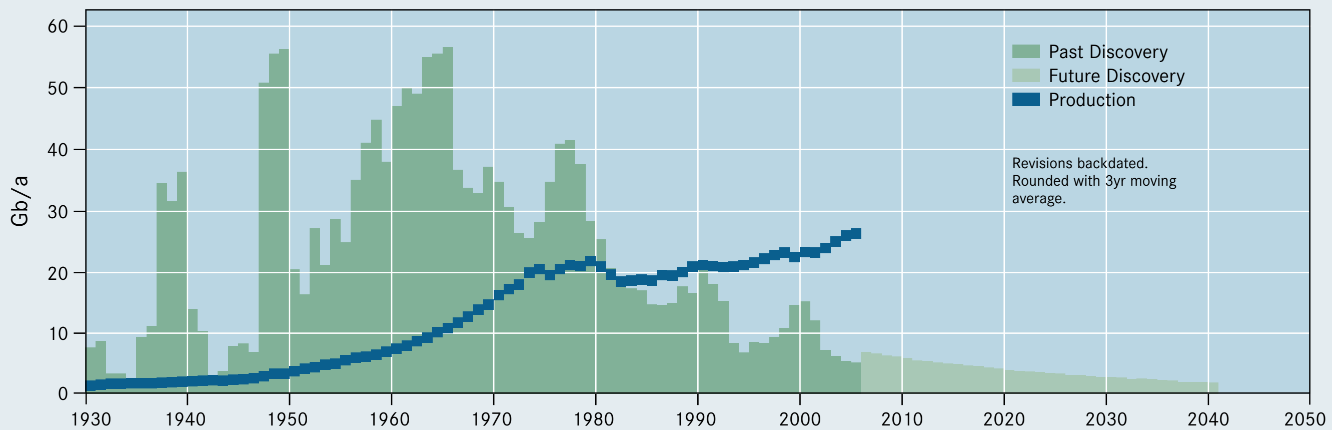
If we are to believe many of the major airlines, it is only a matter of time before biofuels are widely used in air transport. Test flights have already proved that there is a number of viable alternatives to kerosene, among them ethanol, synthetic kerosene from plants, and hydrogen. But it remains to be seen which particular raw material—and indeed which process—will ultimately prevail and be used to manufacture non-fossil fuels.

The activities pursued in this field are multifaceted and span the globe. In early May this year, airlines, industry associations and a number of organizations in Brazil joined to form the "Aliança Brasileira para Biocombustíveis de Aviaçaõ" (ABRABA). Not long after, Boeing launched an initiative to cooperate with Chinese companies to establish an aviation biofuels industry in China. And at roughly the same time, Lufthansa announced its plans to start using biofuels for scheduled commercial flights in the near future. This project will be pursued under the Future Aircraft Research (FAIR) program, in which MTU Aero Engines will be responsible for analyzing data and assessing the engines on completion of the tests. Lufthansa is hoping that testing of alternatives to kerosene over a longer period of time will provide reliable data regarding the feasibility of using such fuels on scheduled services.

Other airlines, such as Continental and KLM, and even the U.S. Air Force, are likewise exploring various options and have already carried out test flights using a blend of conventional kerosene and fuels derived either from biological feedstock or natural gas. All these efforts go to show that biofuels are a hot topic, not only because crude oil resources are limited; demands for lower $CO_2$ emissions and greater sustainability overall are forcing the aviation industry to act.

The fact that it is technically possible to run aircraft on synthetic fuels, that is fuels not obtained by refining crude oil, has been successfully demonstrated in numerous experiments, among them the demonstration flights made by EADS and Diamond Aircraft at this year's ILA Berlin Air Show using a DA42 aircraft. For these flights, one of the small jet's two AE300 diesel engines was powered exclusively by an algae-based biofuel.

**The growing gap regular conventional oil**
ASPO The Association for the Study of Peak Oil and Gas




The most important prerequisite for the widespread use of synthetic fuels in aviation is that they should be as similar to kerosene as possible in terms of physical properties, such as freezing and boiling points, viscosity and energy density. In other words, they should behave just like kerosene. It must also be possible to mix them with standard jet fuel in any ratio, to obviate the need for separate fuel depots at airports, for instance. Provided these essentials are met, Dr. Jörg Sieber from MTU's innovation management department believes that, from the engine manufacturers' perspective, nothing stands in the way of using biofuels. "Official approval has already been granted for scheduled flights with fuel mixtures containing up to 50 percent synthetic kerosene alongside kerosene derived from crude oil. Basically, aero engines may well be able to run on a wide range of alternative fuels." What is more critical than the engine is the substantial airport infrastructure and aircraft design issues these fuels present.


A major attraction at ILA 2010 Berlin Air Show: the daily demonstration flights of a Diamond Aircraft DA42 New Generation powered solely by a biofuel obtained from algae.

The idea of substituting fuels derived from crude oil with fuels obtained from alternative source materials is by no means a 21st century invention. During World War II, Germany manufactured liquid fuel from the country's abundant reserves of coal. And 40 or so years ago, when oil was scarce in South Africa owing to the international embargo imposed because of its policy of apartheid, the country turned to large-scale coal liquefaction to produce petrochemical fuels. This process was (and indeed still is) used to produce not only gasoline and diesel, but kerosene, too.

Coal-to-liquid (CTL) or gas-to-liquid (GTL) fuels could undoubtedly help alleviate dependence on crude oil and make sure that a certain security of supply is maintained for future generations. However, from the point of view of sustainability, these solutions are anything but optimal, not least because the Fischer-Tropsch (FT) synthesis used for the

## Kerosene, the fuel of today

Kerosene, chemically speaking a mixture of several combustible liquid hydrocarbon compounds, is a middle distillate fuel derived from petroleum. Depending on the specific type, it freezes at temperatures between -60°C and -40°C and boils above 175°C. The two main types currently used in commercial aviation are Jet A1 (U.S.) and Jet A (rest of the world); the military generally use the variant JP8. There are additional specifications for flights in particularly cold regions of the world (Jet B and JP4, respectively).

Arizona State University scientists are exploring algae and other feedstocks as potential renewable sources for the production of biofuels.

An integrated algal biorefinery is being set up in New Mexico, which will produce algae-based fuel for commercial purposes.


By 2020, it should be possible to mix kerosene with up to ten percent biofuels. Lufthansa plans to start long-term testing of such fuels in scheduled revenue services within the next two years.

# Alternative fuels for the future

For some time now, airlines, airframers and engine manufacturers, and research institutes have all been looking for alternative fuels that might be suitable for use in aviation. In Brazil, Embraer's Ipanema aircraft, which is employed in agricultural pest control, boasts a piston engine that does not run on aviation gasoline, but on ethanol. However, the energy density of this alcohol is significantly lower than that of kerosene or gasoline, so the aircraft's range is rather limited. Biodiesel suffers from the same problem and is, furthermore, unsuitable for use in commercial airliners because of its relatively high freezing point.

Hydrogen is not really a viable alternative either, at least not in the medium term, despite the fact that a number of test flights have already taken place, including some by a modified Tupolev Tu-154. Firstly, because it takes a relatively large amount of energy to produce hydrogen, and secondly, because any aircraft using it would have to undergo major modifications. Because of its low energy density hydrogen would have to be liquefied, and large-volume and well-insulated tanks would be needed. That said, it seems a good idea to begin using hydrogen in fuel cells which could replace the auxiliary power units (APU) that are currently used to supply energy to on board systems while the aircraft is still on the ground.

The oily seeds of the Jatropha shrub, too, are a suitable feedstock for high-quality biofuel.

One thing that is completely unrealistic to imagine is that a commercial airliner could be powered by solar energy collected during flight. The sun's rays are capable of supplying no more than the energy needed to power an extremely light aircraft, such as the Swiss-produced "Solar Impulse", which was developed specifically to make a record round-the-world flight.

purpose, which was developed in Germany as early as in 1925, is relatively energy intensive. By contrast, the situation looks a lot more promising if a renewable resource is used instead of coal or gas (biomass to liquids, or BTL). Why? Because the carbon dioxide that is produced in an engine during combustion has previously been taken out of the atmosphere by the plants used to make the fuel. Suitable materials include wood or wood wastes, corn, straw or algae, to name but a few.

Alternatively, it is possible to produce oil from certain types of algae that can be converted by a catalytic reaction with hydrogen into a hydrocarbon compound that is similar to kerosene: hydrogenated vegetable oil (HVO). This process uses less energy than the FT synthesis. HVOs can also be produced from plants such as oil palms, jatropha or camelina. However, not all the resulting oils exhibit the carbon chain length range that is typical of kerosene; palm oil, for example, would be more appropriate as a substitute for diesel.

The various approaches show that there is more than one way to produce a synthetic fuel from renewable resources. Which of the options considered will ultimately be adopted depends to a large extent on which raw material can be made available in sufficient quantities. Careful consideration must also be given to the selection of crops and cultivation areas to make sure biofuel production does not divert food away from the human or animal food chain. The ideal solution would be a non-edible plant that would thrive in just about any soil conditions and climate.

Bauhaus Luftfahrt, a Munich-based think tank that was established in 2005 by EADS, Liebherr-Aerospace and MTU Aero Engines in conjunction with the Bavarian Ministry of Economic Affairs, is currently looking into the crucial question of exactly how much biomass can theoretically be produced if strict sustainability criteria are applied, and is attempting to carry out a comparative assessment of the available options. Chief Technical Officer Prof. Mirko Hornung does not think there will be one single solution: "At the end of the day," he says, "a number of options will most probably be pursued in parallel."

It is conceivable that in the not-so-distant future, kerosene may be derived not only from hydrogenated vegetable oils, but also from biowaste generated by agriculture and forestry, using the Fischer-Tropsch process despite the amount of energy it needs. Prof. Hornung believes we are currently on the threshold of commercialization. The various processes have already been shown to be basically suitable, at least in the prototype stages; the next step is to find optimum solutions for large-scale production. It is unlikely that the industry will be able to do entirely without government funding, since synthetic fuels will only establish themselves if they can be brought onto the market at competitive prices.

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# K3–cool coating

By Denis Dilba

When Dr. Bertram Kopperger and Dr. Manuel Hertter start talking about their latest project, people might be tempted to think that they have been watching too many episodes of Star Wars. They talk about a particle gun that fires rounds at supersonic speed. And even the name of the new process–kinetic cold gas spraying, or “K3” for short–has a futuristic ring to it. The two MTU engineers are using the gun to spray fine powder material instead of firing laser beams. Their mission is to repair engine components or protect them against high stresses.

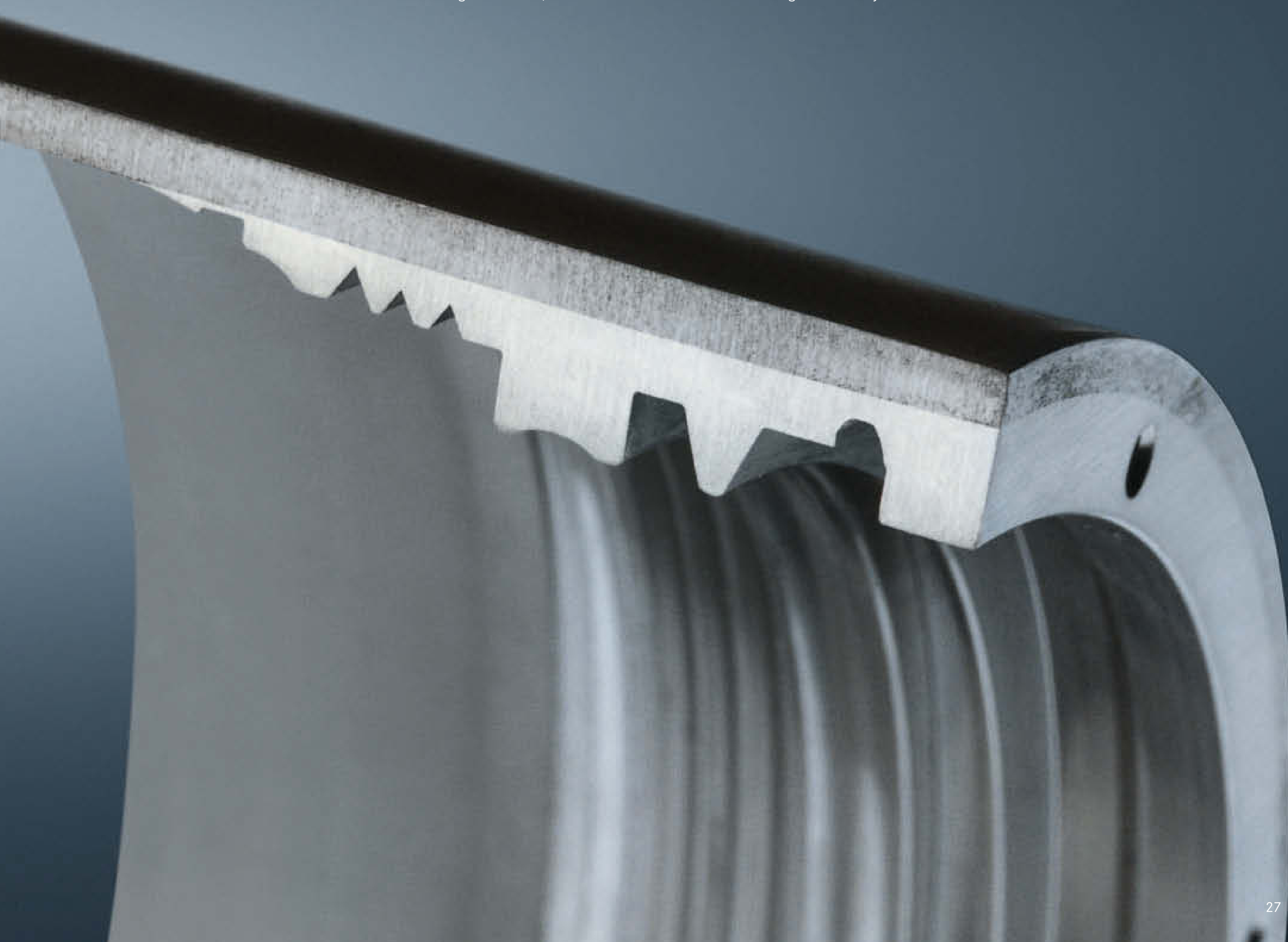
“K3 counts among the thermal spray processes that include plasma spraying, flame spraying, high velocity flame spraying, and wire arc spraying,” explains Kopperger, Senior Manager, Manufacturing and MRO Technologies at MTU Aero Engines in Munich. But in reality this classification is somewhat arbitrary, says the MTU expert, because the new high-performance technology differs in several major respects from the other processes in its class. It is these distinguishing features that promise to open up numerous interesting applications for the new process in the world of industrial coating.

The traditional way to protect turbine blades or engine casing components against corrosion or wear, and to repair them when they are damaged, is to deposit a functional coating on the component using a thermal spray process. But the turbulent flow generated when the powder material comes into contact with the ambient air often results in a porous coating structure that is not sufficiently durable for certain applications. The kinetic cold gas spraying process introduced by MTU is the first to offer a solution to this problem–quite apart from its potential applications in other domains.

The basic working principles of the K3 process can be described in simple terms. Firstly, a gas–typically helium or nitrogen–is compressed and heated to a temperature of around 800 degrees Celsius, and then expelled at supersonic speed through a convergent-divergent de Laval nozzle. The powdered coating material is introduced into this high-speed working gas jet with the aid of a carrier gas. When the microscopic particles in the flow of hot working gas collide with the surface of the component–at a temperature well below their normal melting point but at a very high velocity–they bond firmly with the substrate to form a very dense layer that adheres exceptionally well on the component surface.

“Since the comparatively low thermal energy of the particles is here compensated for by a much higher kinetic energy, the coating particles in the gas jet need not be molten as with conventional thermal spray processes,” explains Dr. Manuel Hertter. Far from being a drawback, this essential difference has some major advantages. According to MTU’s thermal spraying expert, it prevents oxidization and vaporization processes that otherwise occur within the flow of gas and have led to problems in the past. As an added benefit, the high particle velocity results in a particularly dense coating.

It was precisely these oxidation and vaporization phenomena that Kopperger and Hertter had set out to avoid, considering the reduction in adhesive strength and durability of the deposit they cause. “Layers applied using the K3 process are of such low porosity that we are now aiming to produce the first coatings that actually increase the component’s structural durability,” says Kopperger. In other words, the applied coating adheres so well to the substrate and is so strong that it is virtually impossible to discern the coating/substrate interface, at least in the case of low-melting materials. Another advantage of the new process is that it is suitable for a wide variety of coating materials. The low temperature of the particles permits the K3 process to be used not only for nickel and titanium alloys but also magnesium. “In all other thermal spray methods, this highly reactive material is completely oxidized before it even impinges on the surface of the component,” says Hertter.



Tube segment with machined K3 spray coating on the inner diameter.

The K3 process also scores high when it comes to coating thickness. There is virtually no limit, and even several centimeters are achievable, enthuse the MTU engineers. Another advantage of the new process relates to the diameter of the spray jet, which can be focused down to about five millimeters, enabling it to precisely follow surface contours and selectively apply coatings, sometimes even without the need for masking. For comparison, Hertter points out that with flame spraying processes the diameter of the spraying cone is much larger. In other words, the coating efficiency of the new K3 process is much higher, and according to the MTU expert can reach 90 percent, whereas the best result with flame spraying is 40 percent.

Despite its many advantages, kinetic cold gas spraying is not a universal solution. "Each thermal spray process has applications for which it is particularly suited, and K3 cannot be a substitute for all of them," according to Kopperger. One of the requirements of the new process is that the coating material must be ductile, which rules out its use as a means of depositing ceramic coatings. And if certain areas of the component have to be protected from the particle spray, sophisticated steel maskings have to be used, whereas simple adhesive tape is sufficient for other thermal spray processes. Kopperger therefore sees K3 mainly as a solution for applications "that wouldn't have been possible before," such as depositing functional structures on precisely defined areas of a component.

Hertter reports that the team is currently testing the process as a means of restoring damaged areas of steel, nickel, titanium, and magnesium engine casing components. The new process even permits repairs that used to make no sense from an economic point of view. Worn-down flanges of engine casing components, for example, would be carefully cut out, repaired and then welded back in place. But in most cases the high heat input during welding would cause the casing to distort to such an extent that the repaired component would have to be scrapped anyway. "We are working on a solution that involves spraying material onto the casing using the new process and then reworking the new flange," says Hertter. If this is successful, the developers intend to use the same approach to restore sealing fins or to eliminate machining defects by applying a new layer of material.

According to Hertter MTU has been working intensively on the K3 project since 2008. In the first phase, the process was used exclusively on non-safety-critical components. Now the aim is to perfect the coating technique to the point where it can be safely used to repair or coat rotating parts. "We plan to introduce K3 as a standard process for repairs to blades of the Tornado's RB199 engine by around 2012," reports Kopperger. It will not be introduced in commercial maintenance until some time later, the expert goes on to say, because in this area the company needs to obtain the approval of its consortium partners, whereas in the military sector it can undertake work under its sole responsibility. Naturally, the competitors are not sitting idle and are pursuing similar developments, says Kopperger, who has been keeping a close eye on the market. "But whatever happens, we can rightly claim to have pioneered the use of the K3 process in the engine industry."

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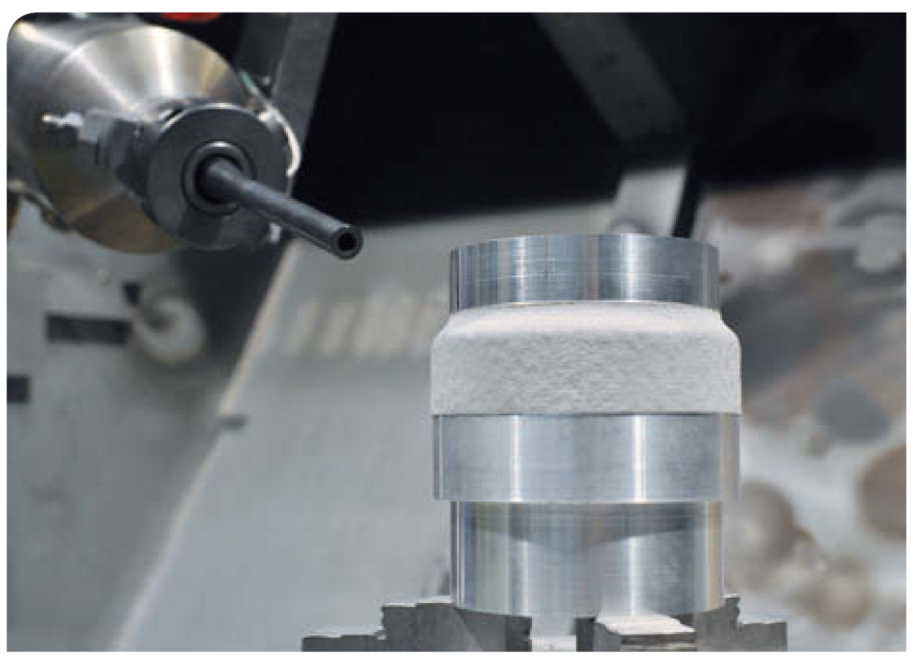

Aluminum tube with K3 spray coating and spray gun.

Aluminum tube with K3 coating in the finish-machined condition.

# Adaptive laser welding

By Daniel Hautmann

Solid and square-shaped, the "box" resembles an enormous wardrobe. Its doors slide open at the push of a button, revealing a room flooded with light. This is the setting for precision work at its best: a high-tech machine that is capable of repairing a wide range of engine components, fully automatically and more efficiently than any other known system. Located at MTU Aero Engines in Munich, it has been in production operation since September.

Compressor and turbine components of aircraft engines have complex geometries—the kind that can cause something of a headache for specialists in the parts repair business. Previously, the only way to get to grips with these parts was to perform measurements manually before carrying out the actual repair. However, MTU has now come up with a design for a new machine that takes accurate measurements of the parts and uses laser powder cladding to repair the damaged areas and restore the components to an airworthy condition.

"We refer to it as the adaptive laser powder cladding machine, which is a bit of a mouthful!" says Wolfgang Werner, Senior Manager, Engineering, Parts Repair at MTU Aero Engines in Munich. The machine's complicated technical name gives some idea of just how much high-tech wizardry has been packed into this 1.4-million-euro system. Its most impressive feature is its ability to cater to any part, whatever its shape, a feature that experts refer to as adaption.

Precision at its best: the two-kilowatt disk laser.

Adaption is important because there is so much variation among the engine parts that typically need repairing; given their different applications, they are subjected to different forms of stress and wear. Rather than just handling one type of component, such as blades, the machine has to cope with a wide range of parts with dimensions from fingernail-sized to hand-sized. Werner explains that there is a broad spectrum of very delicate contours, with some blade tips just 0.2 millimeters thick and others measuring several millimeters. What all the variants have in common is that, sooner or later, they need to be repaired. Airborne particles and the tremendous heat inside the engine wear away material and damage the blades—so much that their actual dimensions can end up deviating significantly from the original size. Experts refer to this phenomenon as "twisting".

Adaptive laser powder cladding machine, a complex high-tech facility.

"Each individual blade has a unique damage pattern," Werner says. That means that each part has to be considered in isolation in the parts repair unit. This task was previously carried out by experienced employees who examined the parts and repaired them on a conventional laser cladding machine, which probed the contours and welded new material in place where needed. However, setting up the machine for each part was a time-consuming business. Dirk Eckart, Senior Manager, Engineering, Parts Repair, Special Processes at MTU, was frustrated with the lack of any commercially available machines that could support this process. He therefore decided to take matters into his own hands and promptly came up with a plan for a suitable machine. Mulling over his concept, he began making phone calls and coordinating the next steps and eventually pulled together a team of experts from research institutes and from a number of national and international companies. This ultimately gave rise to the idea of optically measuring the actual contour of each individual blade and comparing it to the blade's nominal contour (adaption), followed by the application of material in a custom-tailored deposition process.

Responsibility for measuring the part geometries and for the welding process fell to Siegfried Scharek from the IWS Fraunhofer Institute for Material and Beam Technology in Dresden, who notes that "laser deposition welding is our core competence." Specifically, the Fraunhofer specialists developed the camera-based contour tracking system and the coaxial nozzle that distributes the powder—which could be titanium-, nickel-, cobalt- or steel-based—in the form of a ring around the laser beam with a precision of just tenths of a millimeter, a solution that impressed Scharek no end: "The system's level of complexity is truly remarkable."

But the machine also owes its existence to yet another technical innovation: the ability to precisely adjust the power of the two-kilowatt disk laser. "We can power the laser down to 50 watts and then adjust it in increments of 100 watts, something we never thought possible before," Werner enthuses. "That enables us to deposit material with a tremendous degree of accuracy, which significantly reduces the need for rework." The machine's seven axes allow it to cater to any blade type in virtually any position, without having to constantly reposition and re-clamp the part in the machine. With the system having gone into production operation in September, everyone involved agrees that it was worth the effort; in fact the project team succeeded in reducing the time taken to perform a typical turbine blade repair by some 30 percent.

But the value the "futuristic box" represents to MTU comes not just from the efficiency of the blade repair process, but also from the potential it offers for both current and future development work: The new machine enables a range of welding tests to be performed in an inert-gas atmosphere, including tests involving new, highly heat-resistant materials such as titanium aluminide. These kinds of proofs-of-concept including all the required parameters previously had to be purchased from external companies, many of whom now regard what the Munich team has achieved with a certain degree of envy, since, as Werner says, "this is the only machine of its kind anywhere in the world."

## The adaptive element

The adaptive element has so far only penetrated niche areas of the repair business, but the aim is that it should gradually be incorporated in other fields, too. Already well-established in milling and finishing, welding has now become the latest production process to adopt this new approach. "It offers a de facto leap in efficiency, which translates into a faster repair process," confirms Dr. Christoph Ader, responsible for Engineering, Commercial MRO at MTU.

An adaptive element has been integrated in repair processes for commercial and military propulsion systems carried out by Germany's leading engine manufacturer, for example in the repair of blade tips for compressor and turbine blades and blisk blades and the restoration of turbine vane contours.

Adaptive milling of a low-pressure compressor stator.

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For interesting multimedia services associated with this article, go to www.mtu.de/210Adaption

# The final touches

By Bernd Bundschu

The desire to set new standards is what drives all engineers, whether they work to develop innovative products or devise new processes. In the field of engine maintenance, MTU Aero Engines engineers have once again accomplished a remarkable achievement in this respect: A project team drawn from various locations has now successfully developed an automated process for the difficult and time-consuming final contour machining of IAE V2500 high-pressure turbine vanes. And what is so special about it: Every single vane can now be given a new, optimum shape.

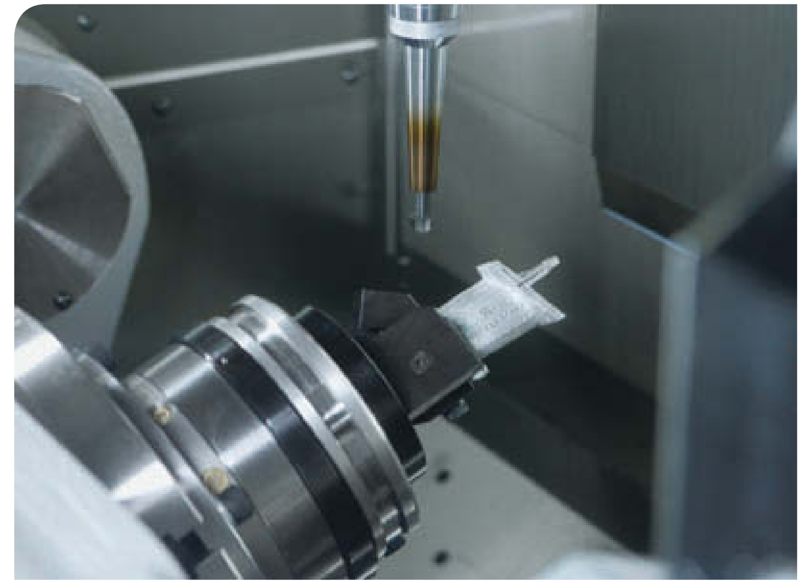
The V2500 high-pressure turbine has two stages, each of which consists of rotor blades and stator vanes—an arrangement that permits a high level of efficiency. To make sure the parts are able to withstand the searing temperatures that occur in the engine, the stage 1 vanes are made of MAR-M 509, a cobalt-based alloy, and the stage 2 vanes of the nickel-based MAR-M 247 alloy. "We then use a plasma spraying process to coat these high-temperature castings with a 0.2 millimeter thick protective ceramic coating, before finally drilling numerous cooling air holes into them," explains Project Manager Marcus Klemm, a specialist in joining technology who develops manufacturing and repair techniques at MTU in Munich.

To repair worn vanes, it is first necessary to remove their protective coating using a combination of chemical and mechanical processes. The cooling air holes and any cracks present are then filled with brazing paste, which is allowed to dry before the component undergoes vacuum brazing. The next step is to restore the vane to its proper shape. Until now, this final contouring process could only be done by hand, and MTU specialists would carefully machine the vanes to reproduce their original geometry using grinding sticks and small belt grinders. Dieter Scheibe, component specialist at MTU Maintenance Hannover, explains: "The job requires a lot of experience, a good eye for detail and a very light touch, so you don't take off more material than necessary." The repaired vanes are subsequently given another ceramic coating before new cooling air holes are produced by laser drilling.

Already in productive use: fully automated final contour machining system for blades and vanes.

"Essentially, the new procedure follows the same principles and sequences. Only now, the final contour of the vanes is restored using a fully automated adaptive milling process performed on a special facility comprising a measuring system, a handling system and a milling machine," reports Klemm. Each vane prepared by brazing is first scanned all over using a 3D laser scanner. The computer then compares the virtual image of the vane in question with the stored contour of a new part. Klemm continues: "These two data sets can differ quite considerably because engines are subjected to different stresses depending on the type and duration of flight operations, which result in the vanes becoming more or less severely distorted."

A high-pressure turbine vane before and after machining to produce the optimum contour.



Clamped component and tool ready for the final touches.

The most notable aspect of the new process is that a repaired vane is not simply given the contour of a new part. Instead, the software analyzes the two data sets and determines a new, optimum shape for each individual vane. For the process to work, brazing alloy is not applied all over but only where needed—the more of the original metal surface the scanner is able to identify, the more successful the restoration of the vane contour will be. The newly calculated data is then transmitted as a CNC file to the milling machine, which produces the final contour of the vane.

The innovative technique has a whole host of advantages. "Because the vanes are processed by machines, the repair quality is higher, and the rejection rate lower," says Bernd Kriegl, Director, Engineering Commercial MRO. At the same time, losses in vane wall thickness are minimized. Adaptive milling allows the original vane material to be preserved to the greatest possible extent; it is practically only the brazing alloy that is removed, which means that vanes can be repaired more often than in the past. For customers, this is significantly more cost-effective than vane replacement. Finally, the new technique improves reproducibility and cuts the processing time. Kriegl is very pleased with the results: "Overall, automation of the final contour machining process makes sure that the vanes can be optimally repaired. That improves engine efficiency and also saves the customer money." And, of course, the new capability gives MTU a competitive edge.

The new system was jointly planned and implemented by the project management team in Munich, MTU Maintenance Hannover and British prime contractor TTL. MTU contributed its expertise in adaptive milling acquired from the manufacture of blisks, while TTL programmed the software and acted as system integrator. Carsten Behrens, who supervises the vane repair lines at MTU Maintenance Hannover, is fully satisfied with the job done by TTL: "Thanks to their commitment, we were able to cut the processing time from initially 25 to 17 minutes and minimize wear of the milling tools. We've already introduced the process in production, and the results achieved so far fully meet specification requirements in terms of quality and processing time."

In future, the automated final contour machining process will be used for all repairs to V2500 high-pressure turbine vanes at MTU Maintenance Hannover—that is over 12,000 a year. In the long term, the MTU engineers intend to use the new technique on other blades and vanes as well, gathering experience along the way that they hope will be useful for processing even more complex component structures in the near future.

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## Repair beats replacement

MTU Maintenance has been offering maintenance services for IAE's best-selling V2500 engine since 1989. The work is undertaken at the company's facilities in Hannover, Germany, and in Zhuhai, China. With a 34-percent share in V2500 maintenance operations overall, MTU is now one of the world's leading maintenance providers for this engine type, and in China it is the undisputed market leader. In early May 2010, it celebrated the 2,500th shop visit of a V2500, which had been sent in for overhaul by Turkish airline Onur Air.

Assembly of a V2500 engine at MTU Maintenance Zhuhai.

An MTU customer of many years: Turkish airline Onur Air.

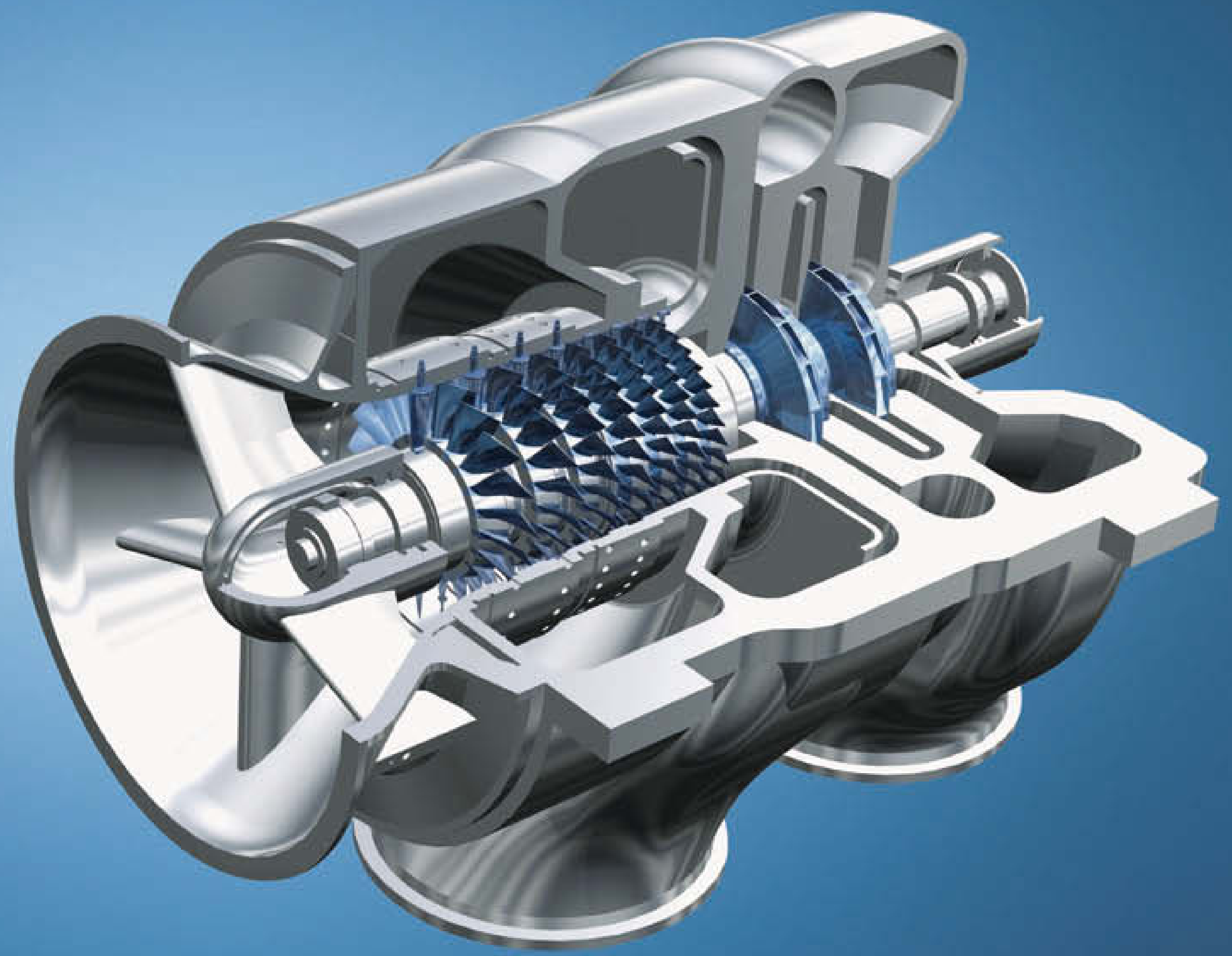
Boasting innovative techniques and decades of experience, MTU Maintenance is able to carry out cost-effective repairs even of severely worn assemblies, components and accessories. Where others would simply replace a part, MTU will repair it.

MTU's high-tech repair capabilities are unique in the world; most of the processes are patented, and known by the brand name MTU$^{Plus}$ Repairs. Examples include Autoclave Airfoil Cleaning, which was developed specifically to clean sand-clogged cooling holes, ERCoat, an erosion-inhibiting coating, and CBN Tip Protection, a wear-resistant hardfacing for the tips of high-pressure turbine blades.

# MAX1— A great leap forward

By Martina Vollmuth

One of the two companies builds the world's biggest industrial compressors and the other the finest compressors for aero-engine applications. Three years ago, MAN Diesel & Turbo and MTU Aero Engines joined forces in a project to develop a new MAN hybrid axial compressor. It is the first of its kind and the forerunner of an entirely new generation of compressors. As a reduced-scale rig known as MAX1 it has now entered the test phase at MTU in Munich.



In late July, members of the executive management and the development teams from both companies came together at MTU in Munich for the traditional last-bolt ceremony. This symbolic act was performed jointly by Klaus Stahlmann, CEO of MAN Diesel & Turbo, and the host of the event, Egon Behle, CEO of MTU Aero Engines. It marked the official go-ahead for the test program, which will be conducted on the MAX1 rig, a reduced one-third scale model of the new compressor, which initially consists of seven stages. The first series of tests will focus exclusively on the new axial blading for the future axial-radial compressor. The seven-stage version of the compressor is expected to be brought to the market before the year is out. It will be followed in the spring of 2012 by other versions featuring a greater number of stages, after testing has been completed on a second, ten-stage MAX1 rig.


Last bolt ceremony: MTU CEO Egon Behle and MAN Diesel & Turbo CEO Klaus Stahlmann (from left) are tightening the last bolt.

Axial compressors are one of the core competencies of MAN Diesel & Turbo. The largest industrial compressors ever built were produced at the German company's Oberhausen plant. The giant machines have been installed in Ras Laffan, Qatar, and Escravos, Nigeria, where they are used in air separation units in plants for the production of fuels from natural gas, coal and biomass, and for other applications. The new series represents a great leap forward in compressor technology. Dr. Hans-O. Jeske, Chief Technology Officer and Head of the Turbomachinery Strategic Business Unit at MAN Diesel & Turbo, says: "As the world market leader in axial compressors, we have closely followed the trend towards ever bigger plant complexes and have therefore constantly developed our relevant products to ensure 'mega capability'. However, to economically meet the performance requirements of future plant sizes, we needed a technological quantum leap. We have now managed this—after three years of development work—with the engine compressor technology know-how of MTU."

The result of the joint development effort is a compressor design that, thanks to a novel blading concept, combines the advantages of industrial compressors—high efficiency, robust design and wide operating range—with the significantly higher power density of gas-turbine compressors. MAN Diesel & Turbo CEO Stahlmann attributes this success to an approach that "combines the best technologies of both worlds". And MTU CEO Behle adds: "MTU has contributed its compressor know-how to optimize the blading design."

With MAX1 both companies are treading new trails. For MAN it is the biggest compressor development project the company has ever tackled, also in terms of the financial investment. For MTU, it is above all the size of the new compressor that made it a challenging project, the company usually handling compressors of much smaller dimensions. The latest MTU compressor for the geared turbofan engine, which was tested on the same test facility, weighs in at 300 kilograms and has a diameter of approximately 50 centimeters. Compare this with the impressive seven metric tons of the one-third scale model of the new MAN compressor's seven-stage version. When scaled up to its full real size, its weight will be somewhere in the region of 340 metric tons, and its diameter will be as large as 600 centimeters. MTU had to modify the test cell to be able to accommodate MAX1. New pipes were laid to modify the exhaust system, adding three metric tons to the weight of the test facility. And 26 metric tons of steel were used to reinforce the foundations.


The new MAN hybrid axial compressor with the instrumentation being fitted.

MAX1 is visible proof of the fruitful cooperation between two companies from different industries. According to Dr. Kai Ziegler, Vice President, Engineering, Compressors at MAN Diesel & Turbo, "MTU was our partner of choice for this joint development project. Collaboration has been excellent and MAX1 is a showcase project in this respect." He attributes the project's successful outcome to "MTU's outstanding engineering expertise" and also to the close ties between the two companies. "MTU and MAN have a shared history, and we were lucky to have some former MTU employees on our team. So our cooperation went exceptionally smoothly." There is consensus among all involved that it is certainly worthwhile to continue the exemplary partnership between the two companies.

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For interesting multimedia services associated with this article, go to www.mtu.de/210MAX1

# Make it clean and keep it clean

By Silke Hansen

The de-icing vehicle's cabin is rising over the wings of a Lufthansa Airbus A340-600 parked on the tarmac, as high as 15 meters above the ground. It is a cold, damp February day at Munich Airport and there is a lot to do for the "polar bears". That is what the de-icing crews affectionately call the highly-efficient and environmentally-friendly purpose-built vehicles used to de-ice aircraft prior to take-off while these sit in dedicated zones close to the runway heads, the so-called "remote areas". During the de-icing season, which in this part of the country runs from October to April, the "polar bears" go to work on as many as 13,000 aircraft.

The airliner, which is bound for San Francisco International Airport, is due to take off in a few minutes. But before it does, it will be given a warm shower. "We're the largest airport to carry out this kind of de-icing routine right next to the runway. The aircraft can take off without undue delay and without having to be retreated," says Hans-Joachim Püschner, Managing Director of EFM (Gesellschaft für Enteisen und Flugzeugschleppen am Flughafen München mbH), a provider of de-icing and towing services.

Up to four of the vehicles work on an aircraft simultaneously. They use remote-controlled nozzles maneuvered by the operators in the cabin to within a meter of the surface to be treated to spray de-icing fluid over the wings and the horizontal and vertical stabilizers on the tail. They have to be both quick and accurate—the next aircraft is already waiting in line. Clouds of billowing steam appear as soon as the de-icers set to work. The de-icing agent—a thin, orange-colored mixture of water and glycol—is heated as high as 85 degrees Celsius before it is applied, and thaws ice or snow as fast as lightning.


The “polar bears” of Munich airport.

De-icing is very important because all the aerodynamically critical parts of an aircraft must be kept free of ice and snow in the winter. Even a thin film of ice can be enough to cause problems during take-off. The buildup of ice adds to the aircraft’s overall weight and, more importantly, it impairs its aerodynamic efficiency; it disturbs the airflow and can even cause a stall when worst comes to worst. That is why pilots adhere to the rule: Make it clean and keep it clean. It is the pilot, after all, who decides whether the aircraft needs to be de-iced or not, and for how long it should be protected against new ice. If anti-icing protection is required, the de-icer operators finish their job by applying a green-colored liquid which is undiluted and more viscous than the de-icing agent so that it adheres to the aircraft for longer and safely prevents new ice from forming prior to take-off.

The amount of de-icing fluid used depends on the thickness of the ice and the size of the aircraft. Up to 2,000 liters may be needed to de-ice a Boeing 747. At Munich Airport, the glycol mixture is collected in drain channels. If the waste water contains more than five percent glycol, it is fed to special basins and then treated in the airport’s own recycling facility to produce new de-icing fluid. If the glycol content is lower, it is disposed of via the wastewater treatment plant. In this case, recycling does make sense neither from an economic point of view nor from an ecological perspective since the process uses much energy. Püschner is proud of the recycling rates achieved in Munich: “We recycle 53 percent of the glycol we use. That’s more than any other airport does,” he says. And it is not only the airlines that save money as a result, the airport, too, benefits from this “green” de-icing service. Püschner explains: “We supply waste heat from the recycling plant to the energy cycle and use it for airport heating purposes.” “Ecology meets economy”, is how Püschner characterizes the exemplary recycling system in place at Munich airport. Here, recycling is an issue of growing significance because the quantities of de-icing agent used are increasing. Munich is becoming an increasingly important air travel hub, and the aircraft landing there are bigger than they used to be.

The Lufthansa aircraft bound for San Francisco is now ice-free and ready for take-off. The de-icing agent drains off the aircraft as it takes off from the runway, as it would otherwise reduce lift. Once the aircraft is airborne, on board systems and hot bleed air from the engine compressor ensure it remains ice-free until is has safely landed. Meanwhile, on the ground, the de-icing vehicles are already clustered round their next customer. On their busiest days, they de-ice almost 500 aircraft. “With 520 scheduled take-offs a day and just a few weather-related cancellations, we’re de-icing practically every single aircraft,” says Püschner. His men are also on standby at night, as every now and then air ambulances are called out to emergencies. During the 2009/2010 winter season, they administered glycol showers to almost 12,000 aircraft, from small Learjets to Airbus A340s.

Sometimes, de-icing may even be necessary in mid-summer. Munich’s de-icing specialist explains: “If an aircraft has cold fuel in its tanks and the weather’s damp, clear ice can form on the wings despite the warm ambient temperature.” That kind of ice is particularly treacherous because it is almost invisible to the naked eye. When it does occur, the de-icing vehicles are hauled out of their parking area to make short work of preparing the aircraft for take-off.


The glycol mixture is collected via drain channels in the tarmac.


Glycol recycling facility at Munich airport.

## Ice-free engines

For an aircraft to fly without a hiccup, its engines must be in perfect operating condition. So when ice and snow occur in the winter, the engines are always the first parts of an aircraft to be de-iced. Hans-Joachim Püschner, Managing Director of EFM (Gesellschaft für Enteisen und Flugzeugschleppen am Flughafen München mbH), says: “We do that at the parking position, while the aircraft is being fueled and loaded. Engines aren’t covered at night—that would simply take too much time and effort.” They are cleaned using nothing but hot air, because de-icing agent could get into the cabin ventilation system and cause a rather pungent smell on board.

“On an engine, ice will form mainly in the inlet casing and on the nose cone,” says Kurt Scheidt, head of Civil Engine Testing at MTU. “But when an engine is started, the fan must be able to rotate freely. Ice can also affect the aerodynamics and thus the engine’s operation. And at higher speeds, the ice would break up and chip off.” If that happens, it can get ingested into the engine and cause damage.

After it has been de-iced and started, the engine protects itself against frost. “Once it’s running, there’s no need for further de-icing prior to take-off. An engine produces hot air, which is used to keep the critical areas free of ice. For the purpose, the air is bled off the high pressure compressor and fed via the shaft to the nose cone and from there through other pipelines to the inlet casing.”

Aircraft also have their own heating systems, whether electric or working on hot bleed air from the engine. The leading edges of the wings and the stabilizers are the critical areas. For smaller aircraft, a simple pneumatic pump system generally suffices; rubber boots on the surfaces inflate regularly, causing any ice to break up and drop off. Scheidt explains that ice is most likely to form during take-off and landing, as well as during climbs and descents. “At cruising altitude, it’s cold but dry. The weather’s always good up there,” he says.


Ice in the engine intake is removed using hot air.

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For further information on this article, go to www.mtu.de/210Deicing

# CityFlyer relies on MTU Maintenance

British regional airline BA CityFlyer will send the 22 CF34-8E and CF34-10E engines powering its fleet of Embraer 170 and 190 jets to MTU Maintenance Berlin-Brandenburg for maintenance and repair.

The wholly-owned subsidiary of British Airways has signed a seven-year agreement with the Ludwigsfelde maintenance specialists, which is valued at some 20 million euros. It includes options to add more engines powering Embraer 170s or 190s and provisions for an extension of the term of the contract.


The CF34 engines powering CityFlyer's Embraer jets are now maintained by MTU's Ludwigsfelde shop.

# MTU Maintenance adds GE90-110B and -115B engines to its portfolio

MTU Maintenance Hannover has expanded its repair capabilities by including GE Aviation's GE90-110B and -115B engines in its portfolio. The addition of these propulsion systems for wide-body aircraft, which are sold successfully worldwide, broadens the facility's range of products and services. The necessary certificates have already been obtained from the European Air Safety Agency (EASA) and its U.S. counterpart, the Federal Aviation Administration (FAA).

The GE90-110B and -115B are the exclusive powerplants for Boeing's 777-200LR and 777-300ER. To date, some 300 of the world's largest twinjets are in revenue service around the globe, and about another 300 units are on order.


GE90 engines help extend the range of Boeing 777 airliners. They are supported by MTU Maintenance Hannover.

# Positive first-half-year business results

MTU Aero Engines has posted successful results for the first six months of this year. Revenues amounted to around 1.3 billion euros. The operating profit, or EBIT, improved by five percent to 144.1 million euros and net income increased by nine percent to 60.6 million euros.

"MTU has achieved good results in the past six months," said a pleased Egon Behle when he presented the half-year report in Munich. The MTU CEO is also confident about the future: "The market is picking up as expected and we are additionally benefiting from the tailwind of the euro's falling exchange rate against the U.S. dollar. These circumstances have permitted us to lift our full-year forecast. We are now aiming for revenues of around 2.75 billion euros by the end of the year and earnings (EBIT adjusted) in the region of 310 million euros." Behle expects the free cash flow to reach 120 million euros, even while maintaining the present high level of investments into the company's future.

**MTU Aero Engines – Key financial data for January through June 2010**

(Figures quoted in € million, calculated on a comparable basis, statements prepared in accordance with IFRS. Figures calculated on a comparative basis apply adjustments to the IFRS consolidated results to exclude restructuring and transaction costs, capitalized development costs, and the effects of IFRS purchase accounting.)

| **MTU Aero Engines** | **H1 2009** | **H1 2010** | **Change** |
|---|---|---|---|
| Revenues | 1,376.0 | 1,348.8 | - 2.0 % |
| of which OEM business | 802.1 | 819.0 | + 2.1 % |
| of which commercial engine business | 570.2 | 569.7 | - 0.1 % |
| of which military engine business | 231.9 | 249.3 | + 7.5 % |
| of which commercial MRO business | 589.0 | 544.0 | - 7.6 % |
| EBIT (calculated on a comparable basis) | 137.1 | 144.1 | + 5.1 % |
| of which OEM business | 98.4 | 103.0 | + 4.7 % |
| of which commercial MRO business | 39.9 | 39.2 | - 1.8 % |
| EBIT margin (calculated on a comparable basis) | 10.0 % | 10.7 % | |
| in the OEM business | 12.3 % | 12.6 % | |
| in the commercial MRO business | 6.8 % | 7.2 % | |
| Net income (IFRS) | 55.7 | 60.6 | + 8.8 % |
| Earnings per share (undiluted) | € 1.14 | € 1.24 | + 8.8 % |
| Free cash flow | 66.7 | 125.1 | + 87.6 % |
| Research and development expenses | 93.9 | 107.8 | + 14.8 % |
| of which company-funded R&D | 53.1 | 70.1 | + 32.0 % |
| of which outside-funded R&D | 40.8 | 37.7 | - 7.6 % |
| Capital expenditure | 59.6 | 44.4 | - 25.5 % |
| | **Dec. 31, 09** | **June 30, 10** | **Change** |
| | | | |
| Order backlog | 4,150.9 | 4,717.2 | + 13.6 % |
| of which OEM business | 3,965.1 | 4,524.6 | + 14.1 % |
| of which commercial MRO business | 185.8 | 198.0 | + 6.6 % |
| Employees | 7,665 | 7,739 | + 1.0 % |

## New man at the helm of MTU Maintenance Berlin-Brandenburg

MTU Maintenance Berlin-Brandenburg in Ludwigsfelde has a new President and CEO: André Sinanian has taken over the reigns from Dr. Wolfgang Konrad effective October 1, 2010.

Dr. Stefan Weingartner, MTU Aero Engines' President and CEO, Commercial Maintenance: "André Sinanian is a capable manager and has substantial experience working at our company. With him at the helm, the impressive success story of the Berlin-Brandenburg location is sure to continue."

Sinanian, who holds a degree in aerospace engineering, has been with the company since 1999. He served diverse management and project functions at MTU Aero Engines' various locations before he was appointed Vice President & COO CF34 program two years ago. In this function he was responsible for all activities relating to the maintenance of that highly successful engine family.

André Sinanian

# Success story in the Middle Kingdom

MTU Maintenance Zhuhai is set to grow: To boost its market clout, the Chinese location, which occupies a 156,000-square-meter plot of land in the Zhuhai Special Economic Zone, plans to increase its shop and office floor space by 10,000 square meters to almost 33,000 square meters. The expansion is expected to be completed in the spring of 2012.

The company is the largest maintenance provider for aircraft engines in China and specializes in V2500, CFM56-3, -5B and -7 engines. In the regional market, the shop has become the market leader in V2500 repairs.

MTU Maintenance Zhuhai's targets are ambitious: In a few years' time, the shop expects to provide service support for markedly more V2500 and CFM56 engines than today by increasing its capacity from presently 200 to 300 shop visits a year. It also plans to add other engine types to its portfolio.


The new building of MTU Maintenance Zhuhai was officially opened in a ceremony attended by representatives of the German and Chinese partners.

Performed to bring good luck and fortune: the lion dance.

The first extension, a shop with a floor space area of around 3,700 square meters, has been up and running since the summer.

# Debut in Europe

The renowned U.S. trade journal Aviation Week & Space Technology has chosen Munich, the place of business of Germany's leading engine manufacturer MTU Aero Engines, as the venue for the first Engine MRO Forum held in Europe. The forum, which deals with intelligent innovations for engine maintenance, brings together experts from MRO facilities, engine manufacturers and airlines. It will be held at the Westin Grand Munich hotel from November 30 to December 1, 2010. MTU, a main sponsor of the event, will attend the forum and also host a tour of its Munich facility.

Dr. Stefan Weingartner, President and CEO, Commercial Maintenance, will deliver the opening keynote address, entitled "Innovative Strategies to Meet Future Challenges".

The first day of the event is dedicated to technical lectures and the exchange of knowledge and experience. The highlight of the second day is a shop tour at MTU, during which attendees will see first-hand how MTU's facility operates. The company will present its highly advanced production and maintenance shops, a full-scale geared turbofan model, a V2500 on the test bed, assembly of the GP7000 low-pressure turbine and final assembly of the Eurofighter's EJ200 engine.

For further information go to:
www.aviationweek.com/events/current/mroeng/index.htm


# New faculty in Munich

The research community in Bavaria has a new member, the Munich Aerospace faculty. It was founded in July this year by the Technical University of Munich, the university of the German Federal Armed Forces in Munich, the German Aerospace Center (DLR) and Bauhaus Luftfahrt. The new faculty is intended to provide a research, development and educational platform for Munich's aerospace industry.

With this new and promising model, the partners from industry, research and development are hoping to pool academic and non-academic talent in a constructive manner—for the benefit of everybody involved and to help make air traffic cleaner and safer. The new faculty will have 55 professorships.


The founders of the new faculty (from left): President of the Technical University of Munich Prof. Dr. Wolfgang Herrmann, DLR Board Chairman Prof. Dr. Johann-Dietrich Wörner, Bavarian Minister of Economic Affairs Martin Zeil, President of the university of the German armed forces in Munich Prof. Dr. Merith Niehuss, and Bauhaus Luftfahrt CEO Prof. Dr. Mirko Hornung.

# Multimedia on the Internet

MTU technology on board—as from now on this not only applies to a wide variety of commercial and military aircraft but also to mobile phones, PDAs and computer screens.


MTU is offering wallpapers and screensavers that are easy to download on almost all types of end devices. Images of the Eurofighter and the Airbus A380 as well as of engine components manufactured by MTU, embedded in nature photographs, are available for downloading.

And aviation enthusiasts who want to have a real great ringtone for their mobile phone can download the powerful sound of the Eurofighter's EJ200 engine at take-off. Wallpapers, screensavers and ringtones can be downloaded from the company's website at www.mtu.de.

Two of six great motives: MTU wallpapers and screensavers can be downloaded on almost all types of end devices.


**Masthead**

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