High-tech made by MTU
MTU Aero Engines is Germany’s leading engine manufacturer and a firmly established player in the international aviation industry. The company, whose roots reach back to the dawn of powered aviation, designs, develops, manufactures, markets and supports commercial and military aircraft engines as well as industrial gas turbines. MTU has its headquarters in Munich.

Its predecessor companies provided the engines for the first powered airplanes as early as the beginning of the 20th century. Today, the company has carved out leading positions in essential engine technologies: the high-pressure compressors, low-pressure turbines, turbine center frames, manufacturing and repair technologies made by MTU are among the finest in the global marketplace. In the field of engine maintenance and repair, the MTU Maintenance Network is a leading provider and operates locations across the globe.

MTU collaborates with all the world’s major engine manufacturers and has roles in important national and European technology programs. With its partners from industry and science, for decades MTU has been developing advanced technologies to make engines even cleaner, quieter, and more fuel-efficient.

With its broad and well-balanced portfolio, MTU is represented in all thrust and power categories. Featuring most prominently in the commercial product range is the PurePower® PW1000G Geared Turbofan™ (GTF) engine. This game-changing propulsion system is being developed and built jointly by Pratt & Whitney and MTU. It marks the debut of an entirely new family of engines that stand out for their especially high efficiency and low noise levels. The GTF represents a major leap forward in jet engine technology, and it is catching on with customers: Airbus offers this system for the A320neo and Irkut for the MC-21; Bombardier has selected it as the exclusive engine to power its new C Series; Mitsubishi will equip its MRI with the GTF; and Embraer has picked it for its new E-Jets.

Other showpieces in MTU’s commercial engine portfolio are the V2500 for the Airbus A320 family, the PW2000 for the Boeing 747 and C-17, the CF6-80 for the Boeing 747 and Airbus A310 and A330, the GP7000 for the Airbus A380, the GE90 for the Boeing 777 and 747-8, and the GE9X, the exclusive engine for the Boeing 777X. Designed for business jets, the PW800 is also a member of the PurePower® family and is based on the same innovative core engine.

In the military arena, MTU is Germany’s lead industrial partner for practically all engines flown by the German Armed Forces. The company offers the full range of system integration services, from providing basic technologies, through developing and manufacturing engines and engine components, to delivering maintenance and comprehensive support services. Among the company’s major military engine programs are the TP400-D6 engine for the new A400M military airlifter, the EJ200 for the Eurofighter Typhoon, the RB199 for the Tornado, and the MTR390 for the French-German Tiger attack escort helicopter. The company also has stakes in GE’s F114, F110 and T508 military engines.
The growing mobility needs of billions of people, plus the limited supply of raw materials and worsening ecological problems, leave little doubt that new engine solutions must go beyond existing concepts. Current projections assume that air traffic will keep growing at a rate of around five percent a year. To mitigate the impact on the environment, therefore, tomorrow’s aircraft must be even cleaner, quieter and more fuel-efficient.

The Advisory Council for Aviation Research and Innovation in Europe (ACARE) has defined ambitious targets for air traffic and published them in its Strategic Research and Innovation Agenda (SRIA). This strategic roadmap includes the ACARE 2020 and Flightpath 2050 goals. By the year 2050, the industry aims to reduce fuel consumption and CO₂ emissions by 75 percent, NOₓ emissions by 90 percent and noise levels by 65 percent, using values from the year 2000 as a baseline.

Driving the future: The Geared Turbofan™

Solutions have already been found to address the ambitious challenges of tomorrow. With the Geared Turbofan™ engine, Pratt & Whitney and MTU are building the commercial propulsion system of the future. Based on an entirely new engine architecture, the GTF engine features a reduction gearbox between the fan and the low-pressure shaft together with the low-pressure compressor and actuating low-pressure turbine. The gearbox allows the fan with its large diameter to rotate more slowly, leaving the low-pressure compressor and turbine to rotate much faster. This helps achieve lower fan pressure ratios, and hence higher bypass ratios, and lets all components achieve their optimum speeds. Consequently, the Geared Turbofan™ has very high overall efficiency, reducing fuel consumption and carbon dioxide emissions by 16 percent each and decreasing the noise footprint by 75 percent. A further advantage is that its fewer compressor and turbine stages make for lighter engines and lower maintenance costs.

MTU produces the high-speed low-pressure turbine, a key component of the GTF. As Germany’s leading engine manufacturer, it is the only one to have mastered this technology, for which it won two German innovation awards. MTU also provides the first four stages of a novel eight-stage high-pressure compressor, developed together with Pratt & Whitney. The entire compressor is built on the innovative blisk principle: blisks, or blade integrated disks, are high-tech components where disk and blades are manufactured as a single part. This configuration delivers greater strength and better aerodynamic properties at less weight. MTU’s share in the GTF varies depending on the version of the engine, but can be as much as 18 percent.
The third and final stage of Claire calls for ground-to-achieve these goals in its Leading Technology breaking engine concepts, which may well go these goals have in fact been surpassed: fuel emissions by as much as 15 percent and drastically tion. For instance, it would be possible to achieve percent smaller. Conceptual studies for the next stage show that further improvements are pos-16 percent each, and the noise footprint is 75 percent smaller. Conceptual studies for the next stage show that further improvements are pos-ible on the basis of the GTF engine configur-ation. For instance, it would be possible to achieve still lower fan pressure ratios by 2030, which would further increase the bypass ratio—from currently 12:1 to as much as 20:1. Moreover, the core engine’s thermal efficiency could be further improved by increasing the pressure and tem-perature ratios. The idea is to improve the over-all pressure ratio from today’s value, just about 50:1, while dramatically reducing the amount of cooling air needed. MTU has outlined how it plans to achieve these goals in its Leading Technology Roadmap. The third and final stage of Claire calls for ground-breaking engine concepts, which may well go beyond today’s gas turbine technology. MTU is working with universities and research institu-tions to develop studies for this phase, scheduled to start in 2050. Among the options under review are the use of highly efficient heat engines with extremely high pressures or the integration of recuperative elements to improve the thermody-namic cycle. Other conceivable concepts include shielded propellers or fans distributed around the fuselage, or technological solutions such as alternative fuels or moves towards turboelectric flight. MTU is already working on all these ideas; their implementation will be based on pilot con-cepts.

Technology development
MTU’s innovative strength is impressive: every year, it files more than 400 patent applications in Germany and abroad and makes 200 invention disclosure reports. Through its committed, dedi-cated research and development work, MTU secures its technological edge and commercial success over the long term. It strives to success-fully position new products and services on the market, and to do so with shorter and shorter lead times. The pace is constantly accelerating, not least due to increasing digitalization and connectivity. MTU uses a technology radar to find new technological possibilities early on. At the same time, it analyzes future markets, guide-lines of government aviation strategies and social trends, and uses the results to derive initial drafts for future engine concepts. Then the MTU tech-nology process starts in earnest: various depart-ments draw up specific technological concepts and the best ideas are chosen systematically.

All individual projects form the MTU Leading Tech-nology Roadmap, which runs through the year 2030. Developments that will extend past that point are defined in what the company calls pilot concepts.

At present, MTU’s technology portfolio has 150 individual projects in progress. The high degree of networking with industrial partners and the research community, as well as sustained fund-ing from the public sector at the national and European levels—for example, the German govern-ment’s aeronautics research program (LuFo) or the EU’s Clean Sky program—are key pillars for the successful development of new technologies.

Digitalization, too, is playing a bigger and bigger role. At MTU, digitalization is not a vague future concept; it is already a living, breathing prac-
Core competencies

MTU Aero Engines has established itself at the apex of essential engine technologies: its high-pressure compressors, low-pressure turbines and turbine center frames are among the finest to be found in the global marketplace. The company’s other core competencies include high-tech manufacturing and maintenance techniques. In addition, the German engine manufacturer can boast of unique testing expertise and systems competence.

Efficient compressors

MTU’s high-pressure compressors are among the best to be found in the market. For more than 30 years, the company has been developing, manufacturing, repairing and overhauling this component, which is the centerpiece of an aircraft engine. Today’s compressors are built on the blisk principle, where disk and blades are manufactured as a single part. This design offers clear advantages: greater tensile strength, lower weight, greater geometrical accuracy on the blade to enhance the aerodynamic characteristics, no blade roots or disk slots to suffer wear and tear, and no assembly costs. Current flagship products being developed by MTU’s engineers are the compressors of the EJ200 powering the Eurofighter Typhoon and of the TP400-D6 for the new A400M military airlifter.

The high-pressure compressor developed in partnership with Pratt & Whitney is the core component of the new Geared Turbofan™ (GTF) engine family targeted at regional and business jets and short- to medium-haul airliners. To protect high-value components, such as compressor blisks, against erosion by sand and dirt particles, MTU has developed an advanced multilayer coating, dubbed ERCoat. Brush seals permit technical solutions that would not be possible with conventional labyrinth seals.

Another trend is the growing role that active systems will play in compressors. These are assemblies that respond to variations in operating conditions. And further improvements in aerodynamic design coupled with smaller part sizes help lower fuel consumption. Constructions produced in a single piece and novel materials are key to significant weight reduction.

Award-winning turbines

MTU is the world leader when it comes to low-pressure turbines that operate at maximum efficiency. Its technological breadth is enormous, ranging from conventional models for business jet engines and power turbines for heavy-lift helicopters all the way to large conventional low-pressure turbines for turbofan engines powering medium- to long-haul airliners. MTU’s master-piece is the high-speed low-pressure turbine, a key component of the GTF, and a one-of-a-kind technology.

For any new concept, the overall goal is to find a design that strikes the ideal balance of efficiency, weight, noise, costs and service life. To reduce the manufacturing costs, MTU is exploring less complex, novel constructions and looking at new lightweight materials for use at elevated temperatures, as this can reduce the turbine’s weight by as much as 10 percent. A case in point are titanium aluminum rotor blades, which weigh only half as much as blades made of conventional nickel alloys. To keep the noise that the low-pressure turbine contributes to overall engine noise low, MTU is investigating noise abatement measures such as 3D contouring of turbine airfoils.

Turbine center frames

For engines in the upper thrust category, MTU manufactures turbine center frames. It develops and builds this highly engineered component for long-haul aircraft engines: the GP7000 for the Airbus A380, GEnx for the Boeing 787 Dreamliner and Boeing 747-8, and GE9X, the exclusive engine for the Boeing 777X. A central engine module, the TCF fulfills an important function: it routes the flow of hot gases exiting the high-pressure turbine toward the low-pressure turbine. In operation, it is exposed to extreme stresses—high mechanical loads, plus high temperatures. The material and design must satisfy the highest of standards; this in turn requires manufacturing technology at its best. MTU’s production shops in Munich fully meet these demands.
Manufacturing

Engines are high-tech products that call for innovative manufacturing techniques. MTU pursues the full spectrum of activities, ranging from process development, new test and measuring methods to automation and factory planning. Among the most important high-tech processes that MTU uses are laser caving to produce cooling air holes in high-pressure turbine airfoils, as well as adaptive milling, friction welding and precise electrochemical machining (PECM) to manufacture blisks. MTU is one of the world’s leading manufacturers of these components, in Munich, it operates one of the most advanced, pioneering production facilities for building compressor rotors this way.

Additive manufacturing processes are gaining in importance. One of these is selective laser melting, which helps produce complex components almost without the need for conventional tooling. Further advantages afforded by additive processes are markedly greater freedom of design, shorter production times, faster innovation cycles, lighter components with added functionality and lower development costs. MTU is already using such processes in the manufacture of production parts for the GTF engine to power the A320neo.

Solutions

MTU is one of the world’s leading blisk manufacturers. Titanium blisks are made in the blisk center of excellence in Munich, the world’s most modern production facility of its kind. It features a high degree of automation as well as an intelligent control and logistics system.

MTU developed not only the PECM process for the manufacture of nickel blisks, but the machines as well—currently in operation in Munich.

Maintenance

In the field of commercial engine and industrial gas turbine maintenance, MTU has established itself as one of the world’s largest service providers. All activities have been pooled under the roof of MTU Maintenance. MTU is renowned across the globe for its high-tech repairs. Of the more than 15,000 different techniques, most are patented and marketed under the trade name MTUPlus repairs. When developing new repair techniques, MTU can draw on the unique expertise it has gained from development and production in numerous engine programs.

MTU Maintenance uses the “Engine Trend Monitoring System,” designed to capture essential operating data, such as pressure, temperature and vibrations, through the onboard computer. The system then radios or emails it to a ground-based network for continuous comparison with ideal engine data. When deviations are noted, appropriate corrective action can be taken in time to prevent major consequential damage and costly repairs.

Testing and instrumentation

MTU covers all aspects of validation and certification services for engine testing, whether military or commercial, checking materials, parts, components and fully assembled engines. The company possesses unique, world-class expertise that it applies in designing and setting up the tests, carrying them out, and then evaluating the data. When performing the various tests, MTU has its own high-tech test cells, or it can also use test facilities at partner institutions.

The company employs the latest in measuring technology. It develops and runs its own tough test programs, and also creates the innovative instrumentation these require. In addition, MTU supports engine integration and flight testing of prototypes in close cooperation with partners and airframe manufacturers.

The rise in digitalization is a key trend in testing. Optimized computer models mean that more and more procedures can be simulated, which cuts down on expensive and time-consuming tests.

Systems expertise

Engine control and monitoring systems are playing an increasingly important role in modern engines in a bid to operate aircraft in a safer, more efficient way. MTU has more than 30 years’ experience with these systems thanks to its work developing military engines. The company’s product portfolio includes the complete control and monitoring system, electronic and hydraulic subsystems and equipment, plus the associated software. Its expertise runs the gamut from equipment, software and system development to system validation, production support and maintenance.

Advantages can be gained on commercial engines, too, by replacing mechanical and hydraulic components with electric ones, as these are efficient, flexible to install, and smarter. The More Electric Engine of the future will come with a wide variety of sensors, electric motors and control elements, posing new challenges for power management, control engineering and engine monitoring.

To retain control systems expertise over the long term, MTU and Safran Electronics & Defense established the AES (Aerospace Embedded Solutions GmbH) joint venture, which pools the competence of both companies. AES offers the full range of services, from design and testing to certification of safety-critical software and electronics. MTU will continue to draw up the specifications for the control and monitoring systems and to produce and repair the electronic equipment.
MTU Aero Engines has been working on new technologies for decades, thus actively helping shape the future of aviation. It has always set the pace of technological progress. The company’s research and development work is carried out in cooperation with key players in the sector—industry and research partners—and as part of technology funding programs. These activities are based on the MTU Technology Roadmap, which plots the course ahead.

**Leading Technology Roadmap**

Progress in engine construction essentially depends on whether manufacturers succeed in improving the key physical parameters of propulsion efficiency and thermal efficiency, as well as weight and reliability. MTU’s development efforts are targeted at optimizing all these parameters. Every innovation optimizes fuel consumption, pollution and noise emissions, as well as production and maintenance costs. The MTU Leading Technology Roadmap charts the company’s planned course through 2030 and clearly defines its goals: MTU will refine and optimize its high-pressure compressor, high-speed low-pressure turbine, and turbine center frame. Key technologies required by these plans are new, lightweight high-temperature materials, additive manufacturing techniques, and virtual design and production. The Roadmap contains some 150 defined technology projects.

**High-temperature materials**

Any new materials for the next generation of engines have to be lightweight and heat-resistant. Specifically, they are expected to enable weight reduction of up to 10 percent and to withstand higher temperatures than their predecessors—several hundred degrees. MTU seeks out only the best metals plus entirely new classes of material. It focuses on intermetallics and ceramic composites for manufacturing turbine blades, disks and housings. And the company’s experience from the industrialization of titanium aluminate has provided a solid basis for successful development of a new material, right up through large-scale production. One tool is becoming more and more important in this context: simulation.

**Additive manufacturing**

MTU is already using selective laser melting in industrial-scale manufacture of borescope bosses for the PW1100G-JM, the Geared Turbofan™ engine for the Airbus A320neo. It plans to gradually expand the range of components it produces using these methods: first on the agenda are seal carriers, which are installed in high-pressure compressors, to be followed by, for example, bearing housings, brackets and struts. MTU also intends to enhance its processes by broadening online checks and improving surface quality.

**Virtual design and manufacturing**

MTU is going 4.0. The company plans to expand digitalization in the areas of development, materials engineering, manufacturing and maintenance. Its long-term goal is to connect the various steps of the entire value chain, from product development to manufacturing to maintenance, and map them virtually as well. This makes the development and manufacture of increasingly complex products faster and more efficient. ICM2E (Integrated Computational Materials & Manufacturing Engineering) is the use of simulation techniques in materials development and production, thereby eliminating the need for time- and cost-intensive testing. “Lifecycle engineering” describes the push to spread digitalization throughout the engineering processes (keywords: Virtual Engine/4.0 product development). This produces a digital twin of each physical component, into which flows all the data from along the entire value chain: from development to maintenance and repair. Technologies for intelligently connecting production processes and for engineering come under the heading of the digital factory. Here the focus is on simulating production processes and tool developments, as well as all value streams.
Technology funding programs

At both the national and European levels, MTU actively participates in all major research projects. It plays a crucial role in the German aviation research program, as well as the EU’s Clean Sky, ENOVAL, LEMCOTEC and E-BREAK research programs.

**German aviation research program**

MTU is one of the leading industrial partners on the German aviation research program (LuFo) launched by the German federal government. The company cooperates with universities and research institutes, focusing on the development of new high-pressure compressor and low-pressure turbine technologies to further improve efficiencies. LuFo funds have already played a major role in the development of MTU’s successful GTF technologies and also the optimization of blisk manufacturing techniques.

**Clean Sky**

With more than 600 partners, Clean Sky 1 was the largest aviation technology research program ever undertaken by the European Union. It encompassed six Integrated Technology Demonstrators (ITDs) and one Technology Evaluator. Within the SAGE (Sustainable and Green Engine) ITD of Clean Sky, five engine demonstrators in different thrust classes and for different market segments were built and tested. One of the sub-demonstrators, SAGE 4, was led by MTU. In cooperation with partners, the company further developed Geared Turbofan™ technology, particularly the pioneering compressor and turbine technologies. The project was launched in 2008 and will run through 2017. The follow-on research program is Clean Sky 2, which started in 2014, and will be a key technology funding program for MTU until 2020. MTU has expanded its role and is involved as one of 16 lead companies (OEMs). All participants are working on two demonstrators as they develop and test technologies for the next generation of Geared Turbofan™ engines; as before, MTU is concentrating on the compressor and turbine components.

**ENOVAL**

The MTU-led ENOVAL (ENgine mOdule VALida-tors) program was launched in 2013 and will run for four years. A total of 35 European partners from industry, research and academia are developing new technologies for low-pressure components for medium-sized, large and very large turbofans, with the aim of reducing CO₂ emissions by up to five percent and cutting noise levels by up to 1.3 dB. These improvements will be achieved by increasing bypass ratios to between 12:1 and 20:1 and overall pressure ratios to between 50:1 and 70:1. MTU is focusing on the integration and optimization of the expansion system, which consists of the turbine center frame, low-pressure turbine and turbine exit case.

**LEMCOTEC**

Under the LEMCOTEC project, 35 European partners have been exploring options to increase the overall pressure ratio to further enhance the thermal efficiency of future engines. MTU’s workshare involved the design, construction and testing of a new high-pressure compressor with an unprecedented pressure ratio that features lighter high-temperature materials and an advanced secondary air system.

**E-BREAK**

The EU’s E-BREAK technology program is aimed at further reducing the fuel consumption and CO₂ emissions of future propulsion systems and extending their service lives. In a joint effort, 42 partners are working to improve components and engine systems by further developing sealing, material and condition monitoring technologies. The program, which is funded under the EU’s 7th Framework Program, was launched in 2012. MTU is investigating new abradable systems, simulation methods, the lightweight material titanium aluminide as well as engine monitoring systems.
MTU Aero Engines is closely cooperating with research institutes and universities, an approach that benefits both sides: on the one hand, it gives the institutes’ primary focus on fundamental research a more practically oriented tilt; on the other, MTU can draw on the scientists’ excellent expertise. MTU’s network strategy relies on three pillars: trend analysis and development of visionary engine concepts at Bauhaus Luftfahrt; concentration of basic research at just a few top-notch institutes and universities; and regular exchange of experience with experts within and outside the aviation industry.

Bauhaus Luftfahrt
An internationally oriented think tank, Bauhaus Luftfahrt aims to develop innovative approaches for future air transport systems. Among other things, the Bauhaus researchers devise visionary aircraft concepts, investigate ecological aspects of air traffic such as alternative fuels, study revolutionary technologies, and explore the socio-political aspects of aviation. Factors key to its success are the interaction among its in-house disciplines as well as its cooperation with industry and research in a global network. Bauhaus Luftfahrt was founded in 2005 by EADS, Liebherr-Aerospace, MTU Aero Engines and the state of Bavaria. IABG joined later.

Centers of competence (CoCs)
MTU has established strategic alliances with research partners, the aim being to safeguard MTU’s innovative capabilities over the long term and strengthen ties between universities and industry. By getting students in touch with industrial reality early in their academic careers, MTU hopes to produce a continuous pool of young talent. Jointly with leading German universities and research institutes, MTU has launched six different centers of competence (CoCs) to perform specific research tasks. Criteria for the selection of partners were outstanding technical qualification and many years of experience. RWTH Aachen focuses on compressors and production, the German Aerospace Center (DLR) in Cologne on propulsion systems, Technical University of Munich on design, Universität der Bundeswehr München on military engines, and University of Stuttgart on turbine testing and thermodynamics. Leibniz Universität Hannover and the Laser Zentrum Hannover concentrate on turbines and maintenance repair.

DLR-Institute of Test and Simulation for Gas Turbines
The German Aerospace Center (DLR) plans to build a Institute of Test and Simulation for Gas Turbines in Augsburg, which MTU will make intensive use of. The idea behind the new center is to validate numerical simulation processes (virtual engine) with experimental procedures on test cells in such a way that it is possible to draw up new designs in the future with considerably less testing. In addition, the center will host supercomputers for high-resolution and coupled simulations in aerodynamics, structural mechanics and materials mechanics. Two modern test cells will also be set up. The institute is a key element in strengthening the Virtual Engine research landscape. This project receives substantial funding from the German federal government and the state of Bavaria.

Fraunhofer Institutes
Collaboration with various Fraunhofer Institutes throughout Germany is a main focal point of MTU’s cooperative ventures—particularly when it comes to production and materials technologies. With its broad spectrum of expertise, the Fraunhofer-Gesellschaft is ideally positioned to work on industry-related research contracts on behalf of MTU.

Research institutions lay the groundwork, and MTU adds the practical dimension: many students conduct their research here.
Engines of the future

Since the 1960s, the fuel consumption of aircraft engines has been reduced by more than 45 percent. MTU has played a major role in this positive development and plans to continue doing so in the future. With the Geared Turbofan™ engine, Pratt & Whitney and MTU are building the commercial propulsion system of the future.

One future trend is the increasing size of fans with low pressure ratios for new commercial engines, which improves their propulsion efficiency. This calls for an increased use of lightweight materials and an airframe design capable of accommodating the larger-sized propulsion systems. In the engine interior, pressures and temperatures will increase for even higher efficiencies. This requires, for instance, new materials and coatings. Other plans are to further optimize reliability plus manufacturing and maintenance costs. More extensive long-term improvements are promised by distributed and integrated engines as well as highly efficient heat exchangers; these will feature, for example, variable cycle technology, waste-heat recuperation, combined processes and hybrid elements.

MTU pursues all available avenues to further improve aircraft engines and verifies the technical feasibility of the various concepts, for example electric propulsion systems. In addition, the company is committed to promoting the use of sustainable fuels. For the foreseeable future, there is no alternative to the gas turbine engine—in its further optimized version—as the propulsion system for large airliners.

One vision of the aircraft of the future: a study by Airbus.

The airport of tomorrow

Scientists at Bauhaus Luftfahrt have developed a new, comprehensive airport and aircraft concept: the goal of “CentrAlStation” and “CityBird” is to achieve the targets stipulated by the European Commission for the year 2050. By then, 90 percent of all journeys in Europe should take no longer than four hours door to door.

A legacy to live up to

The name MTU stands for leading-edge engine technologies. With its unique expertise and innovative capabilities, the company has established itself as a technology leader in many fields and comes recommended as a reliable partner in the industry. To keep it that way, MTU is investing heavily in a variety of technological activities, new products and services, thus setting the course for the future. For the German company, helping push forward advances in aviation is and will remain a tradition to which it is firmly committed.