AEROREPORT 01|18

The aviation magazine of MTU Aero Engines I www.aeroreport.de

Ideas for the future

Innovations in engine technology

TECHNOLOGY
ENOVAL: High-bypass engines of the future

MARKET
Building a global MRO network for PW1000G engines

PARTNERS
Development of blisk prototypes for the second generation of GTF engines


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Dear readers,

What does giant reed have to do with aviation? This plant, which can grow to heights of up to six meters, is extremely flexible yet sturdy—properties that compressor blades need to have too. Vibration damping is one of the most important tasks in developing rotating engine components, which is why an MTU engineer studied this plant and its design extensively to derive ideas for improving compressor blades. His work won him one of the first-place prizes in a competition we held for MTU employees worldwide in 2017 to develop ideas in relation to bionics.

The competition was aimed at further strengthening the innovation culture that we have always cultivated at MTU Aero Engines. After all, the expertise of our employees is one of our greatest assets. Innovation is a vital element in our partnerships with engine OEMs. Every year, MTU employees file, on average, 400 patent applications and around 200 invention disclosure reports, to say nothing of the numerous smaller ideas for improving company processes or manufacturing and repair techniques. I experienced this time and time again in my last three years as Executive Vice President, OEM Operations at MTU Aero Engines. Now I look forward to helping MTU gear up for and shape the next innovation cycle in aviation as Chief Operating Officer.

While production is just ramping up for new programs that we're involved in, such as the PurePower® family and the T408 helicopter engine, MTU developers have long since begun working on technologies for the next generation of engines and the generation after that—for instance in connection with the EU's ENOVAL technology program, in which participants are studying how to improve bypass ratios. You can read more about this in one of our stories.

This new edition of **AERO**REPORT also provides a general overview of MTU's technology roadmap. We accompany research aircraft and address alternative fuels, new airship concepts and environmentally friendly production for more sustainable aviation. We take a look at Germany's neighbor, Poland, where MTU already operates a successful facility and is now setting up a joint venture with Lufthansa Technik. And we delve into the leasing market, where innovative ideas are helping customers.

Happy reading!

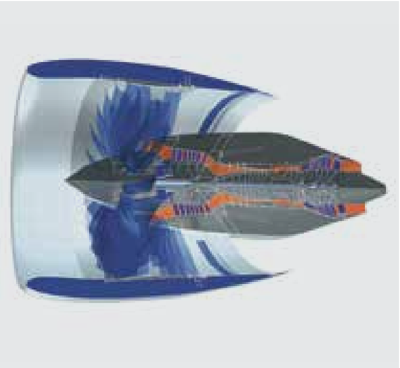
Lars Wagner
Chief Operating Officer

COVER STORY

Ideas with a future

Aviation is synonymous with high technology and aircraft engines are built on a wealth of combined engineering skills. MTU Aero Engines is following a Leading Technology Roadmap to develop innovations for next-generation engines – taking them from evolutionary to revolutionary.

page 8



TECHNOLOGY

More is less

In the EU technology program ENOVAL, MTU Aero Engines is developing innovative low-pressure turbine technology for the engines of tomorrow. Very high bypass ratios of up to 16:1 will make engines quieter and more efficient, with lower emissions.

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TECHNOLOGY

Cruising with the climate sniffers

NASA's DC-8 and the German Aerospace Center's A320 ATRA are together testing the behavior of alternative fuels. **AERO**REPORT author Andreas Spaeth reports about the research campaign directly from the aircraft.

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Caymankind

From an unexpected in-flight shutdown to a flexible MRO and lease solution: How MTU Maintenance's creative response helped Cayman Airways return to the blue Caribbean skies – quickly and safely.

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MARKET

In the hands of the experts

To offer customers high quality, efficient and innovative repairs on their PW1000G engines, Pratt & Whitney, MTU Aero Engines and other partners are setting up a global network for aftermarket services.

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Developers of tomorrow's technology

MTU Aero Engines has been working with the Fraunhofer Institute for Production Technology IPT on compressor and manufacturing technologies for ten years. Now, at a dedicated blisk prototyping facility, MTU is taking their collaboration to the next level.

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FACTS

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All articles from the print edition are also available online at www.aeroreport.de, optimized for smartphone and tablet. There you find informative videos, photo galleries, zoomable images and other interactive specials too.

The GE9X begins flight testing

The **maiden flight of the GE9X** in the skies above Victorville, California on **March 13**, 2018 lasted over four hours. Mounted on the wing of a Boeing 747, GE Aviation‘s giant new engine was able to demonstrate its capabilities for the first time. The flight was the prelude to a flight test campaign that will last several months and will put the engine‘s performance through its paces at different altitudes and flight phases. „Our teams have spent months preparing for the flight. Today, their efforts have paid off with a picture-perfect first flight,“ says general manager of the GE9X program Ted Ingling. Certification testing for the engine began in the test cell in March 2016. The engine certification is expected in 2019. MTU Aero Engines delivers the turbine center frame through which gases at temperatures of up to 1,000 degrees flow from the high-pressure turbine into the low-pressure turbine, with as little aerodynamic loss as possible.

ICD rig for lighter aircraft engines

MTU Aero Engines, German Aerospace Center (DLR) and **GKN Aerospace Engine Systems** join forces to optimize compressor systems. The **Inter Compressor Duct,** or **ICD** for short, is the ideal solution for those looking to further reduce the weight of future engines through extremely compact designs. „This transition duct between low and high-pressure compressors has the potential for a much more compact design,“ says Dr. Gerhard Kahl, Chief Engineer, Technology Demonstrators and Rigs at MTU Aero Engines. „However, in order to achieve that, we have to better understand the flow within this duct,“ he continues. To this end, test operations were started on a joint ICD rig set up in Cologne by the German Aerospace Center (DLR), MTU, and GKN as part of the European research program Clean Sky 2.

The rig measures the duct flow in the ICD in unprecedented detail: 500 pressure measurement points, probe measurements at three traversal levels, laser techniques and turbulence probes allow an accurate insight into the flow. According to Kahl, the goal is to fine-tune the interaction of the low-pressure compressor, ICD and high-pressure compressor. The new finding could then be used to design the next generation of Geared Turbofan™.

E190-E2 begins scheduled services

All set _____ *The Embraer E190-E2 in special livery for the 2018 Singapore Airshow.*

56 months after the program was first launched, the Embraer **E190-E2** has finally received approval to fly from the U.S. aviation authority (FAA). The latest addition to the successful E-jet family sets itself apart with its new quiet and fuel-efficient engines: Each of the Brazilian mid-range jets are powered by two **PW1900G engines,** which are virtually identical to the PW1500G engine for the C Series. The launch customer is the Norwegian regional airline Widerøe. In April, the airline begins scheduled services with the E190-E2 following a comprehensive test program, in which four prototype aircraft successfully completed a total of over 2,000 flight hours and 45,000 hours of ground tests. MTU holds a **17 percent** share in the engine. Embraer has received firm orders for **74 E190-E2 aircraft.**

MTU closes 2017 on a record high

MTU Aero Engines once again looks back on a successful fiscal year. **Revenues** in 2017 rose by 6 percent to a new all-time high of **5 billion euros. Operating profit** grew by 21 percent, reaching a record high of **607 million euros.** Adjusted net income stood at a record 429 million euros, 24 percent above the previous record in fiscal 2016. Both results helped MTU exceed its twice-revised fiscal targets for the year. And the prospects look good for MTU to continue its growth trajectory in 2018. The workforce grew by almost 500 employees in 2017. And there are plans to recruit more staff in the new fiscal year too: MTU is looking for over 500 new employees to join its ranks in 2018.

The T408 engine goes into production

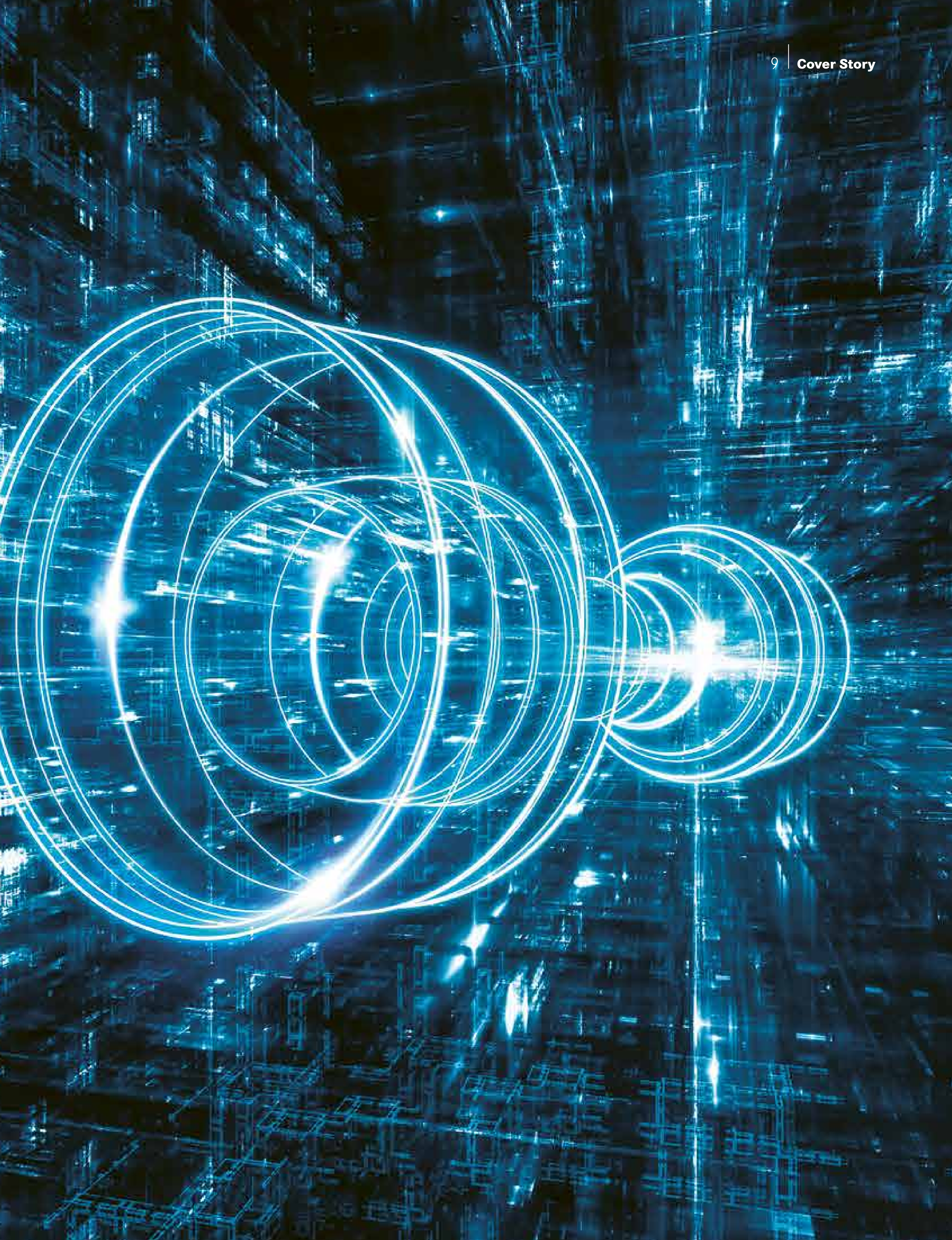
T408-GE-400

The U.S. Armed Forces and GE Aviation have reached a delivery agreement for 22 **T408-GE-400** engines that also includes technical and logistical support. This agreement paves the way for the start of production of the T408 engine that will power the **CH-53K heavy lift helicopter** for the U.S. Marine Corps. MTU Aero Engines holds an **18 percent stake** in the engine program and is responsible for developing and manufacturing the power turbine as well as carrying out its maintenance, final assembly and testing. Thanks to the T408, the CH-53K can transport an additional load of 12,000 kilograms over an operating radius of more than 110 nautical miles and triple its load capacity compared to its predecessor, the CH-53E. In addition, the T408 delivers 57 percent more power and is more resistant to environmental factors such as sand and water, thus making it the ideal mission helicopter for the U.S. Marine Corps.

Ideas with a future

In a continuous drive to enhance engine design, MTU Aero Engines is pursuing a Leading Technology Roadmap for innovations in its strongest areas of expertise.

Text: *Silke Hansen*



The figures are impressive to say the least: MTU Aero Engines submits some 400 patent applications and registers around 200 inventions on average every year. You could liken the company to a fountain of ideas. And that's the way it should be. After all, a strong innovation culture and finely tuned technology processes secure its crucial technological leadership. Aviation is a research-intensive industry characterized by high-technology products. For this reason, innovation is a key aspect of MTU's partnerships with engine OEMs and central pillar of long-term success.

"Driven by our innovative strength, MTU plays an active role in shaping aviation, both today and in the future," explains Dr. Stefan Weber, Senior Vice President, Technology & Engineering Advanced Programs at MTU. "After all, the only way to ensure our continued success in the long term is to guard and extend our technological lead. "And innovation and creativity are the key," adds Weber.

"Driven by our innovative strength, MTU plays an active role in shaping aviation, both today and in the future."

Dr. Stefan Weber,
Senior Vice President, Technology & Engineering Advanced Programs at MTU Aero Engines

To harness the incoming waves of new developments, MTU is pursuing a Leading Technology Roadmap that serves to chart the course of its flagship modules: compressors, turbines and turbine center frames. The roadmap is comprised of 150 individual projects from all technical departments, development, production, assembly and maintenance, which pave the way for the launch of a new engine generation by 2030+ an enhanced and above all even cleaner and quieter Geared Turbofan™ (GTF). After all, the number of passengers choosing to travel by air is increasing every year.

MTU's research and development activities focus on five key areas in which the company is driving promising solutions towards production readiness. Because new technologies have to prove what they can do before they make it onto the wing of an aircraft.

Enhancing the compressor

MTU developers are exploring ways to increase overall pressure ratios to over 50:1. High pressures allow the compressor components to be scaled down in size. Overall, this advances the compressor's efficiency and stability. To achieve these results, MTU's engineers are taking the fundamentally new approach by optimizing the high- and low-pressure compressor designs together to create an integrated compression system. To this end, the engineers are using a unique two-shaft compressor rig at the German Aerospace Center (DLR) in Cologne.

Making what's good even better

The high-speed low-pressure turbine—one of the core components in the Geared Turbofan™ engine—is set to get a full upgrade in terms of its efficiency, weight, noise emissions, robustness and cost-effectiveness. Quite a feat given that MTU's turbines are already relatively light and yet very efficient.

Using new materials for the turbine

The roadmap focuses on high-temperature, lightweight materials as the key to achieving further weight reductions—of up to ten percent—and a more efficient use of cooling air. Decreasing the weight of components results in lower fuel consumption and fewer CO_2 emissions. This calls for nothing but the most superior metals such as advanced nickel-based materials or brand-new materials—known as "beyond nickel-based superalloys", such as intermetallic and ceramic composites.

Turning visions into reality

Tomorrow's engines are increasingly designed on computers. MTU is building up its expertise in another key technology, virtual design, and expanding its use of new simulation techniques to develop materials and optimize production processes, for example. Digital transformation is well underway at the company and numerous digitalization projects have been launched across all areas. The end goal is to introduce the use of simulations and digital processes across the board and connect the various steps of the entire value creation process, from product development to finished engine, and map them virtually as well.

In parallel to the physical engine component, a digital twin collects and stores all the data generated from development and operations all the way to maintenance and repair. This data can then be used to leverage all potential for product improvements. At MTU, Industry 4.0 is accelerating the development and production of products with ever-increasing degrees of complexity, while concomitantly improving efficiency and quality—for example by eliminating the need for time and cost-intensive tests on new materials.

Taking production to the next level

MTU is continuing to develop additive manufacturing techniques, such as selective laser melting, with the aim of stepping up their use. In line with the roadmap, the company will gradually expand the range of components it produces using additive methods. In the future, new processes of this kind will enable complex components to be manufactured more quickly, cost effectively and with higher degrees of flexibility, without the need for conventional tools. They also give engineers unprecedented levels of freedom in component design, and at the same time offer potential for optimization.

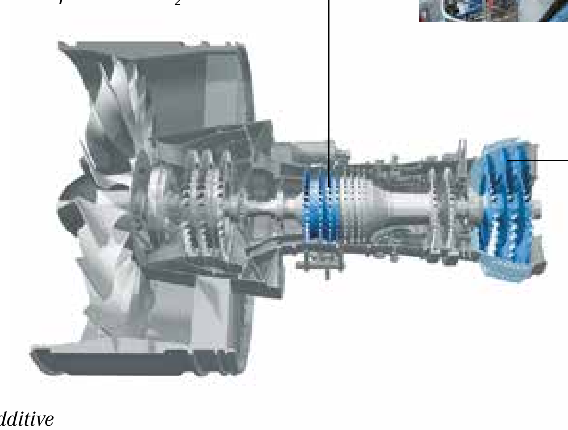
GREENER, QUIETER, MORE EFFICIENT: THE GEARED TURBOFAN™ 2030+

Materials

Able to take the heat: New lightweight materials for the turbine can withstand extreme temperatures and reduce the weight and amount of cooling air required. In turn, this cuts fuel consumption and CO_2 emissions.

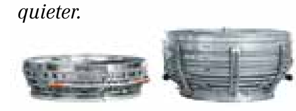
High-pressure compressor

Small but powerful: Despite its compact design, the compressor system of the future achieves even higher compression ratios.

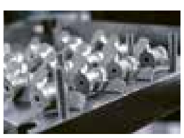


Low-pressure turbine

Geared up for the future: With only three stages, the high-speed low-pressure turbine is one of the core components in the Geared Turbofan™ engine (compare conventional turbine on the right). A comprehensive upgrade is set to make it even lighter and quieter.



Additive manufacturing



Production in the digital age: Additive manufacturing is set to play a greater role in the inner workings of next-generation engines. MTU's selective laser melting process makes this possible.

> *"The GTF concept still has enormous potential for improvement and with the developments and enhancements outlined in our roadmap, we'll be able to meet the targets for stage 2 by 2030+."*

Dr. Stefan Weber,
Senior Vice President,
Technology & Engineering Advanced Programs at MTU Aero Engines

Staged goals until 2050

MTU's Leading Technology Roadmap forms part of a larger agenda at MTU: the Clean Air Engine (Claire) technology program. Claire sets out staged goals for achieving reductions in fuel consumption, CO_2 emissions and noise by 2030 and 2050. "The GTF concept still has enormous potential for improvement and with the developments and enhancements outlined in our roadmap, we'll be able to meet the targets for stage 2 by 2030+," Weber explains.

And initial pilot concepts already look very promising for achieving the highly ambitious targets for stage 3 by 2050. "At this stage we'll need disruptive approaches to the engine, and above all to the design of the aircraft itself," says Weber.

Do you have any questions, requests or suggestions?
Contact the editors here: **aeroreport@mtu.de**

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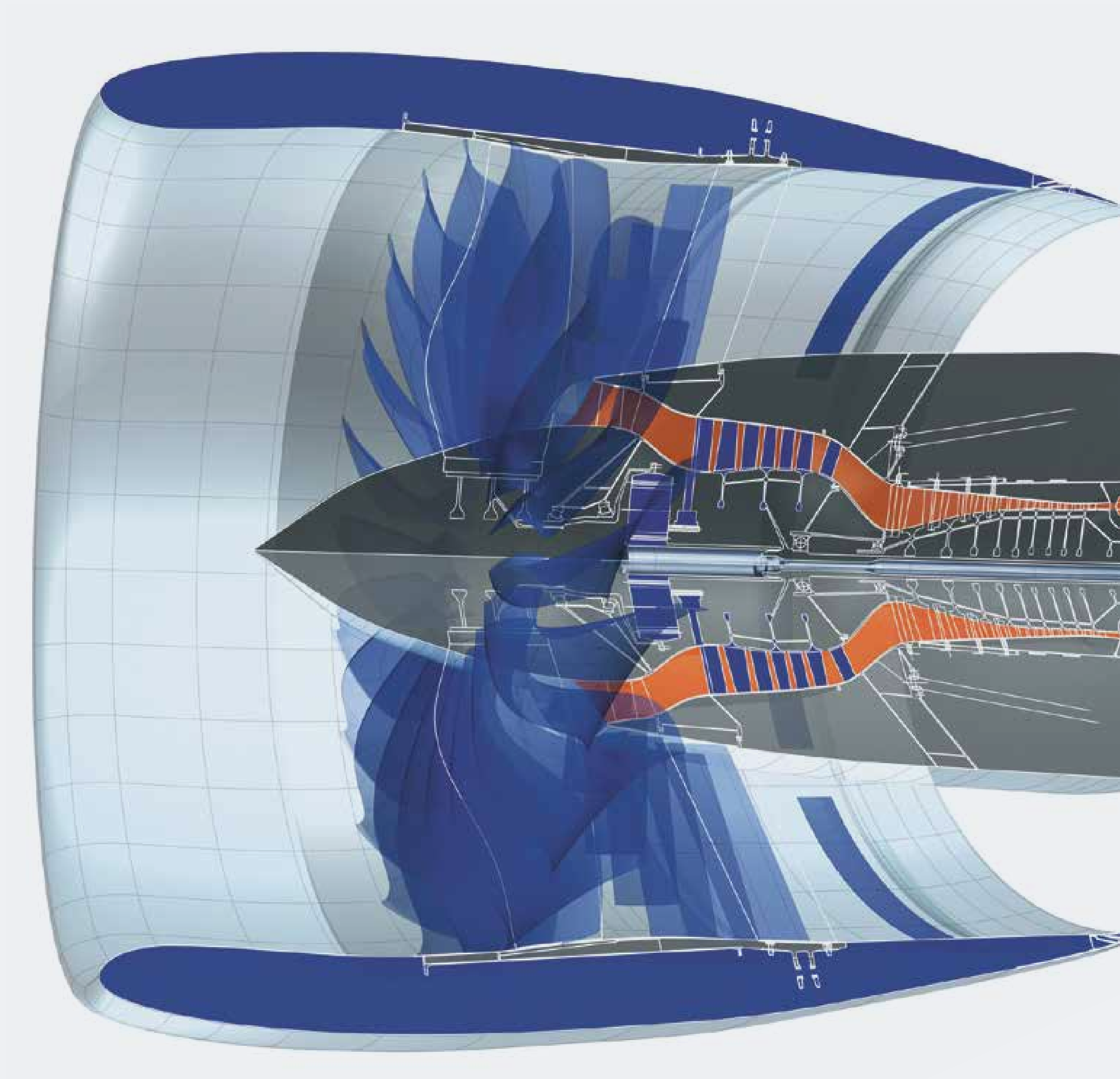
Text:
Silke Hansen writes for **AERO**REPORT as a freelance journalist. For over ten years, she has covered the world of aviation, focusing on technology, innovation and the market. Corporate responsibility reporting is another of her areas of specialization.

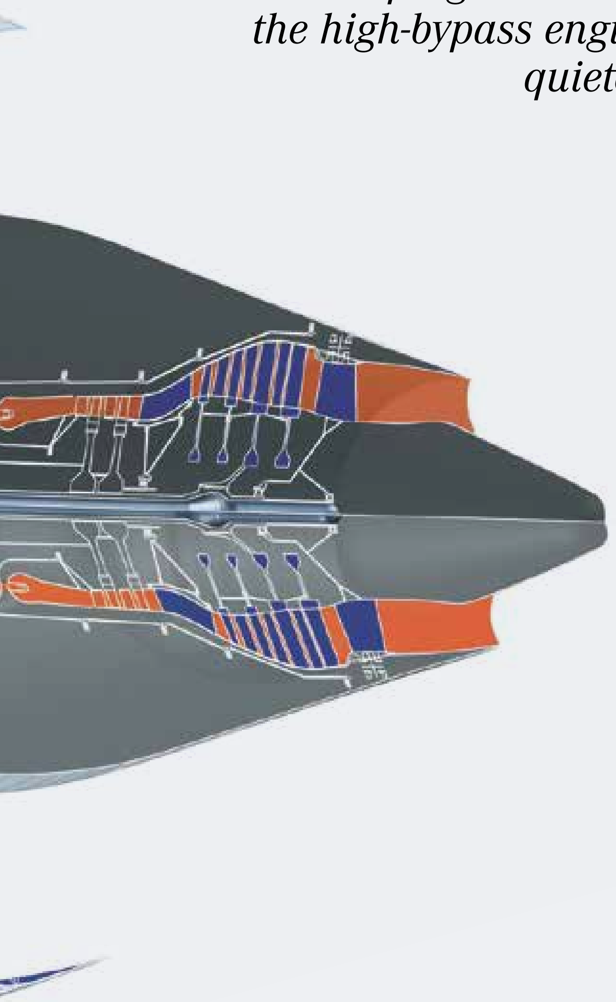


Increasing the bypass ratio ____ *Higher bypass ratios improve engine efficiency, which in turn reduces fuel consumption. Partners in the EU's ENOVAL project are investigating the technical requirements and limits of ultra-high bypass ratios.*

More is less

In the EU's ENOVAL program, MTU Aero Engines is developing innovative low-pressure turbine technology for the high-bypass engines of the future, which will be cleaner, quieter and more economical.

Text: *Denis Dilba*



Worldwide growth in air traffic has been on a continuous upward curve for decades. And it will continue to climb, with experts estimating an annual growth rate of between four and six percent. Another curve has a similar shape, the one showing how the bypass ratio (BPR) of engines has developed over time. The bypass ratio indicates how much air inside the nacelle flows past the combustor and how much passes through it. As a rule: the higher the ratio, the more efficient the engine. And more efficient engines mean lower fuel consumption and emissions.

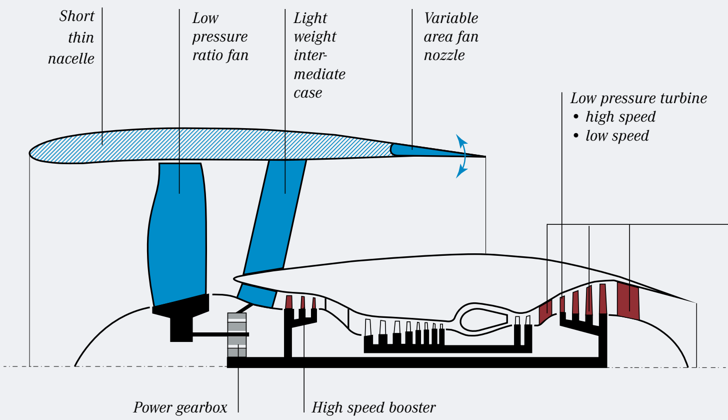
Higher BPRs are therefore one of the most effective tools for engineers striving to make aviation more environmentally friendly. The BPR curve is an impressive record of the industry's success. Since the 1960s, the ratios have climbed from an initial value of 2:1, reaching 6:1 for the classic V2500 engine in the 1980s, before the Geared Turbofan™ (GTF) achieved the current record of 12:1. Dr. Edgar Merkl from MTU Aero Engines in Munich is now ensuring that the BPR curve continues to rise for the engines of tomorrow in his capacity as coordinator of the EU's ENOVAL project, which started four years ago.

Greater efficiency, less noise

In the ENgine mOdule VALidators (ENOVAL) project, 35 partners from ten different countries—including aviation companies, research institutes and universities—are developing engine technology for bypass ratios higher than 12:1. Experts refer to an ultra-high bypass ratio (UHBR). "In ENOVAL, we're working with a range between 14:1 and 16:1," says Merkl. By virtue of the higher BPR, there will not only be an increase in thrust efficiency, with corresponding reductions in fuel consumption and emissions, explains the ENOVAL Coordinator, "but the new engines that result will be even quieter than the Geared Turbofan™ is already."

This is achieved by slower flow speeds in the exhaust jet and lower rotational speeds in the fan. As a result, the blade tips no longer enter the supersonic range, which is one of the main sources of noise for engines that—unlike the GTF and engines with ENOVAL technologies—do not use a gear system to allow the fan and the turbine to rotate separately in their own optimum speed range. Overall, the new UHBR engines will be 1.3 decibels quieter and will emit up to five percent less CO_2. For medium-haul jets such as the Airbus A320, this saves 1,200 tons of CO_2 per year, which is equivalent to the carbon emissions produced in serving the annual electricity needs of 325 average households.

ENOVAL LOW PRESSURE SYSTEM MODULES



Focusing on the low-pressure system ___ *The main focus of ENOVAL is to research technologies for reducing noise, fuel consumption and emissions in the low-pressure system. This differs from the LEMCOTEC and E-BREAK projects, which concentrated on the overall pressure ratio and materials to withstand higher pressures in future engines, respectively. The low-pressure system is comprised of the fan, gearbox, low-pressure compressor and the low-pressure turbine. MTU's role in the project focuses on the low-pressure turbine.*

Source: Enoval

Focus on the low-pressure system

"If we also factor in technologies from predecessor projects such as LEMCOTEC and E-BREAK, then we're actually nine decibels quieter than an engine from the year 2000—and we've reduced CO_2 emissions by around 28 percent," says ENOVAL Chief Engineer Dr. Jörg Sieber. Overall, this already comfortably fulfills the ACARE goals for 2020. Whereas LEMCOTEC and E-BREAK were about developing technologies that increase the overall pressure ratio and therefore thermal efficiency, while also adapting materials and subsystems to the rising pressures and temperatures in the future, ENOVAL focuses on development of the low-pressure system for UHBR engines.

MTU's role in the project is predominantly concerned with the high-speed low-pressure turbine, with other ENOVAL partners responsible for the fan, gear and low-pressure compressor systems. Always keeping the improvement of the overall system in sight is a major challenge. "Just optimizing each component in the engine separately and then fitting them all together—that alone won't give you an optimum UHBR engine," says Sieber.

Another challenge is that UHBR engines will be larger and heavier in the first instance. "To be able to move more air mass, the fan needs to be larger," says Sieber, and this increases air resistance in turn. These negative factors will have to be counterbalanced by lighter and more efficient low-pressure modules, explains the MTU engineer. However, the new UHBR engines will definitely need more space beneath the wing: they will be between 20 and 35 percent larger than a year-2000 engine, depending on whether they are optimized for short- or long-haul aircraft.

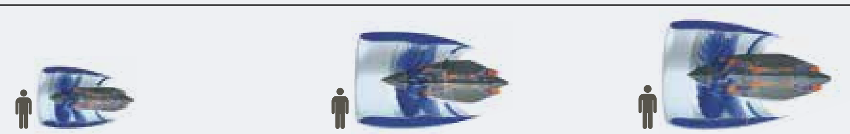
Larger engine diameters to influence aircraft design

Rolls-Royce's UltraFan will be just as large, if not larger. For the engine, which is set to have a BPR of over 15:1 and is slated for release in 2025, the British company is inserting a gearbox between the fan and turbine for the first time. "Because of the advantages that a gear configuration yields in terms of overall efficiency, there is a clear trend among all competitors in favor of this design," says Merkl. With the UltraFan, Rolls-Royce is targeting the successors of the large passenger jets, such as the Boeing 747 and the Airbus A380. Engines with ENOVAL technology also still fit beneath the wings of aircraft with classic design configurations.

However, when engine diameters get even larger, you quickly reach the point at which you have to consider other aircraft configurations, says Dr. Jochen Kaiser, Head of Visionary Aircraft Concepts at the Bauhaus Luftfahrt research institution in Munich. "For instance, you could place the wings higher up on the fuselage, or build larger high-wing aircraft," says Kaiser. This is the name given to aircraft such as the Airbus A400M, whose wings are mounted flush with the upper edge of the fuselage.

Such a configuration may even make open-rotor concepts a viable possibility. These engines, in which one or two rotors are spun by a core engine, have BPRs in excess of 30, but their open designs without casing create noise problems. "For large aircraft, we think there's no real question of using them," says Merkl. "But for smaller aircraft, the open rotor might become attractive at some point." Possibly, these engines could be placed on the

THREE ENGINE DEMONSTRATORS COVER A WIDE RANGE OF POTENTIAL APPLICATIONS



	Small to Medium Turbofan	*Large Turbofan*	*Very Large Turbofan*
Thrust Take-Off	*85.8 kN / 19.3 klbf*	*252 kN / 56.7 klbf*	*340 kN / 76.5 klbf*
Configuration	*1-Gear-3-8-2-3*	*1-Gear-4-11-2-4*	*1-Gear-3-9-2-4*
Fan diameter	*2.03 m / 79.8 in*	*3.17 m / 124.6 in*	*3.84 m / 151.1 in*
Fan pressure ratio (Top of Climb)	*1.36*	*1.51*	*1.41*
Bypass ratio (Mid Cruise)	*16.2*	*16.2*	*16.0*
Overall pressure ratio (Top of Climb)	*54.7*	*73*	*59*
Specific fuel consumption (Mid Cruise)	*13.98 g/kN/s / 0.494 lb/h/lbf*	*13.73 g/kN/s / 0.485 lb/h/lbf*	*13.47 g/kN/s / 0.476 lb/h/lbf*
Engine weight	*4,000 kg*	*10,136 kg*	*11,625 kg*

Source: Enoval

wings, which would shield the noise. However, this would require new aircraft designs.

"For the classic aircraft configuration, it will be possible to increase the BPR further up to 20:1—but then we have reached the maximum," says Merkl. Achieving this, however, will require new materials and improved sealing systems, which allow the pressure ratio in the core engine to be increased further. No progress can be expected on this front before 2035. The ENOVAL generation of UHBR engines will be ready long before then: "We expect entry into service to begin from 2025," says the ENOVAL Coordinator.

By then, work will probably be underway on the following generation of UHBR engines. "After all, we want to maintain our edge," says Merkl.

FACTS ENOVAL – ENGINE MODULES VALIDATORS

ENOVAL
is an initiative of the Engine Industrial Management Group (EIMG). ENOVAL completes the roadmap of the Level 2 (component validation) engine programs within the 7th Framework Program of the EU. ENOVAL complements the Level 2 projects LEMCOTEC and E-BREAK.

Budget:	*45.1 Mio. € (EU Commission funding 26.5 Mio. €)*
Duration:	*58 month Oct. 2013 – July 2018*
Partners:	*35 partners from 10 countries*
Coordinator:	*MTU Aero Engines AG, Munich/Germany*

Do you have any questions, requests or suggestions?
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Denis Dilba holds a degree in mechatronics, is a graduate of the German School of Journalism, and founded the "Substanz" digital science magazine. He writes articles about a wide variety of technical and business themes.

It pays to go green

Green production goes hand in hand with clean aircraft, which is why environmentally friendly manufacturing processes are becoming increasingly important.

Text: *Monika Weiner*

The lighter and quieter the better: in the interest of protecting the environment and cutting operating costs, aircraft and engine manufacturers are busy fine-tuning their products to trim every last gram of weight and decibel of noise.

Thanks to new technologies, today's aircraft consume 45 percent less fuel than those in service in the 1960s. Over the next few decades, innovative designs and propulsion concepts are set to halve CO_2 emissions and fuel burn again. This will preserve the earth's oil resources, protect the environment and help airlines cut down their fuel costs. But it's not just a case of protecting the environment when aircraft take to the skies. "Clean production and efficient manufacturing and maintenance processes all contribute to making an aircraft 'clean'," says Stefan Lange who heads up building and plant modernization at MTU Aero Engines.

Reducing emissions and consumption despite increasing production volumes

With the objective of improving energy efficiency and conserving resources, airframers and engine manufacturers are methodically analyzing and optimizing their production processes. At its European sites, Airbus, for instance, has reduced its energy consumption by three percent, CO_2 emissions by 14 percent and volatile organic compound emissions by 21 percent within ten years. At the same time, the airframer succeeded in cutting water usage by 19 percent, despite increasing the number of aircraft produced in the same period by one third. In 2006, Airbus introduced a treatment system for river water at its Hamburg site in Germany, which cut annual drinking water consumption by 82,000 cubic meters. A special sensor system for the early detection of leaks resulted in further savings of 10,200 cubic meters.

MTU, meanwhile, launched a program to reduce its environmental footprint in production and maintenance back in 2010. Thanks to CLAIR-IS, an acronym for Clean Air Industrial Site, Germany's leading engine manufacturer has achieved savings in CO_2 emissions to the tune of 20,000 metric tons at its Munich site alone since it began upping the use of well water for cooling machinery. In November 2017, MTU introduced a new cogeneration plant that runs on bio-methane, reducing CO_2 emissions by a further 6,800 metric tons a year. To make additional energy savings, the company insulates its buildings, repairs leaks in compressed air systems and switches off machines and equipment at night and on public holidays. And production isn't the only area in which MTU is going green. MTU Maintenance Canada based in Richmond, British Columbia, has joined an initiative led by nearby Vancouver International Airport to measure and analyze its carbon footprint. MTU's Canadian subsidiary is now using this information to systematically reduce its emissions. The facility now runs exclusively on hydropower, a renewable source of energy. "In the last 25 years, we've halved our overall CO_2 emissions here at MTU," says Lange to sum up.

"Clean production and efficient manufacturing and maintenance processes all contribute to making an aircraft 'clean'."

Stefan Lange,
MTU Aero Engines, Munich

Processes that conserve resources

Today, MTU's engineers employ innovative technologies such as additive manufacturing to produce components for tomorrow's clean engines with maximum efficiency and using as little energy as possible. "This way, we can generate parts straight from CAD data. A laser melts the metal powder particle by particle and builds it up layer by layer precisely as specified," says Dr. Karl-Heinz Dusel, who heads additive manufacturing technology at MTU. He goes on to explain that this production method has several benefits: "No material goes to waste. At the end of the process, any loose metal power is shaken off, filtered and recycled. Plus, you need less material allowance compared with traditional methods, such casting or machining forged components, because the blank requires only minimal rework." Another advantage is that this technique allows new functions to be integrated directly into the component—cooling holes, for example. Optimized design also reduces weight. The design engineers plan to ramp up use of the technology in the future. MTU already uses additive manufacturing for the large-scale production of borescope bosses for PW1100G-JM engines. The next step is to apply for approval to manufacture lightweight brackets that support oil lines in the same way.

"New, resource-conserving processes like additive manufacturing are extremely important for reducing the aviation industry's environmental impact," says Dr. Sascha Gierlings, Head of Prototype Manufacture at the Fraunhofer Institute for Production Technology IPT in Aachen (see also "Developers of tomorrow's technology" on page 48 of this issue). He's working in close collaboration with the MTU engineers to analyze and compare different process chains. "Depending on the thermo-mechanical load on a component in operation, we have to use different production techniques and processes. But we can make significant savings with them all, because making engine components is such a costly and time-consuming process by nature."

Through its participation in the Clean Sky 2 European research program, MTU is working with 200 research centers and companies to explore and develop innovative solutions aimed at reducing harmful gases and noise levels produced by aircraft. One aspect of Clean Sky 2 is dedicated to eco-design and how to reduce the consumption of materials, energy and resources across the entire lifespan of an aircraft—taking a "cradle to cradle" approach from production all the way through to recycling.

Text:
Monika Weiner has been working as a science journalist since 1985. A geology graduate, she is especially interested in new developments in research and technology, and in their impact on society.

Biofuel in the tank

To achieve the climate protection goals for aviation, sustainably produced fuels are essential. The first production processes for biokerosene have reached maturity.

Text: *Nicole Geffert*

Plants, wood, straw and algae-most of us would not immediately associate this list with aviation fuels. Yet these raw materials can be used to make alternative fuels to make more climate-friendly aviation possible. The International Civil Aviation Organization has set ambitious goals for the sector: aviation growth is to be carbon-neutral from 2020, and CO_2 emissions from aviation are to be halved by 2050 compared to 2005 levels.

Although the manufacturers of aircraft and engines continuously optimize their products, that alone is not enough to achieve the climate protection goals. “Alternative fuels with a much smaller carbon footprint are essential for sustainable aviation,” says Dr. Jörg Sieber, who is responsible for innovation management at MTU Aero Engines. “In addition, we have to reduce pollutant emissions to alleviate damage to the environment.”

MTU is strongly advocating the introduction of sustainable kerosene,for example, through its work in the Bauhaus Luftfahrt think tank and in the Aviation Initiative for Renewable Energy in Germany (aireg) association, which brings together airlines, manufacturers and research institutes-with the goal that 10 percent of the kerosene used in Germany by 2025 will come from alternative raw materials. This corresponds to 1.1 million tons of fuel required every year.

"New fuels have to go through a lengthy, complicated certification process. The model allows you to estimate the potential of a new fuel before embarking on costly laboratory testing."

Manfred Aigner, *Head of the Institute of Combustion Technology at the German Aerospace Center*

Several alternative fuels already approved for aviation

Several alternative fuels have already been approved for flight operations. These drop-in fuels can be mixed with conventional Jet A-1 kerosene and meet the high quality and safety requirements for aviation fuels. Because of the ranges involved, aviation fuels must have a very high energy density as well as a high flash point and a low freezing point. After all, temperatures at cruising altitudes are minus 50 degrees Celsius.

Scientists are not lacking in ideas for methods of converting biomass-from energy crops, for example-into fuel. The experts at aireg currently see the greatest potential in a conversion process which uses the hydration of vegetable oils, specifically hydroprocessed esters and fatty acids (HEFA). HEFA biokerosene meets the specifications for fossil kerosene and has been successfully tested, and now the process has reached maturity. The biofuel has been ASTM-approved since 2011 and is already being used in large volumes in passenger air transport for testing purposes.

Reducing greenhouse gases by at least 60 percent

In addition, analyses are available on greenhouse gas emissions and other environmental impacts. The results show that HEFA is able to comply with the requirements of the European Union's Renewable Energy Directive under certain boundary conditions. To ensure that biofuels actually offer advantages with regard to climate, this directive stipulates that as of 2018 they must demonstrate greenhouse gas reductions of at least 60 percent compared to fossil fuels.

Another approved production method is biomass to liquid (BtL), which chiefly uses wood as the biomass. Experts view the technology as extremely challenging on the whole, which makes cost-effective production difficult at present-although BtL-produced biokerosene has been ASTM (American Society for Testing and Materials)-certified since 2009.

Evaluation model for alternative fuels

How can the potential of a new fuel be evaluated in advance? As part of the "InnoTreib" project, researchers from the German Aerospace Center (DLR), Hamburg University of Technology (TUHH) and the University of Stuttgart developed a model that can be used to design sustainable fuels on a computer. "New fuels have to go through a lengthy, complicated certification process. The model allows you to estimate the potential of a new fuel before embarking on costly laboratory testing," says Professor Manfred Aigner, Head of the Institute of Combustion Technology at the German Aerospace Center. Another expert to give a positive verdict is Professor Martin Kaltschmitt, Head of the Institute of Environmental Technology and Energy Economics at TUHH: "The methods developed in the project allow us to identify promising combinations, showing how sustainably produced biofuels can be used as efficiently as possible in aircraft engines."

Inside MTU ___ *Highly efficient heat engines*

To reduce CO_2 emissions in aviation, efficiency improvements in aircraft, engines and air traffic management must play a role, as must low-carbon fuels. All-electric engines will only be able to achieve marginal reductions by 2050, because batteries with sufficient storage capacity do not exist for large airliners, which make up by far the greatest part of air traffic. Therefore, experts at MTU Aero Engines favor the development of new high thermal efficiency engines, which form the basis not only for advanced high bypass engines (see "More is less" article on page 12), but also for turboelectric drive systems with distributed propulsion. As part of the company's Claire (Clean Air Engine) technology agenda, MTU has set itself ambitious goals for the engine, such as a reduction of fuel consumption by 40 percent by 2050 compared to year-2000 levels. Together with low-carbon drop-in fuels, this makes it possible to achieve the necessary reduction in CO_2 emissions despite increasing air traffic.

Fuel generation with wind power and solar energy

Non-biogenic processes could also offer long-term alternatives. Working together in the SOLAR-JET project, an international group of researchers has managed to produce aviation fuel out of sunlight, water and carbon dioxide for the first time. This alternative fuel has the considerable advantage of being based on almost unlimited resources. Another pioneering technology is the power-to-liquid method, which uses wind power and solar energy to generate hydrogen, which is then synthesized into hydrocarbons by adding carbon dioxide and processed into a liquid fuel.

These examples show that there is a lot happening in the sector. And yet the biggest challenge consists in making the processes more cost effective. Biofuels still cost twice as much or more than conventional kerosene. Consequently, engineers worldwide are working on solutions to reduce costs.

For the present, sustainably produced kerosene is the only game in town. The ability to power large aircraft by purely electrical means still lies far off in the future. Sustainable drop-in fuels, by contrast, can be used in today's aircraft, which-given their long service lives-will be carrying goods and people to their destinations for many years to come.

Do you have any questions, requests or suggestions?
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More on this topic: **www.aeroreport.de**

Text:
Nicole Geffert has been working as a freelance journalist covering topics such as research and science, money and taxes, and education and careers since 1999.

Cruising with the climate sniffers

How do exhaust gases from alternative aircraft fuels behave in the atmosphere? An unusual flight log.

Text: *Andreas Spaeth*

Tracking down contrails
The German Aerospace Center's A320 ATRA flying ahead. The German Aerospace Center (DLR) and NASA take to the skies above northern Germany on a joint mission to collect exhaust gas data from biofuel.

01

On a joint mission ______ *This is not the first collaboration between the aerospace research organizations NASA and DLR, which are two of the most important in the world. They conducted their first joint mission in Palmdale, Florida, in 2014 to demonstrate that admixing biofuels reduces smut in the exhaust gases.*

Mission statement ______ *The joint research flight campaign bears the name ND-MAX/ECLIF 2, which stands for NASA/DLR Multidisciplinary Airborne eXperiments/Emission and CLimate Impact of alternative Fuel.*

It's a rainy January morning at Ramstein in south-western Germany. The ramp of the biggest American air base outside the U.S. is packed with grey C17 transport aircraft parked side by side. Somewhere in between hides an odd couple of civilian aircraft, smaller than the rest and easily overlooked. One of them is a real rare species: the world's last flying DC-8 passenger jet now serving as NASA's flying laboratory, stationed in Palmdale, California. It is accompanied by German Aerospace Center's ATRA (Advanced Technology Research Aircraft), an A320 based in Braunschweig. The German research aircraft, which used to fly passengers for holiday airline Niki and is now used for scientific missions, is having 18 tons of fuel pumped into its wings. Half of it consists of the biofuel HEFA (hydro-processed esters and fatty acids), which is obtained from camelina oil seeds. The aim of this research mission is to prove with physical measurements that mixing kerosene with biofuels reduces the impact of flying on the climate. Today's schedule: in-flight probing of emissions caused by jet fuel mixed 1:1 with HEFA. This high ratio of HEFA is being tested for the first time; in day-to-day flight operations a much lower concentration is more realistic.

Fly straight ahead for six minutes, turn to the left, straight ahead for another six minutes, turn to the right

After take-off from Ramstein the flight turns towards Northern Germany into temporarily restricted air space. It is here that

01 ___ *Ramstein Air Base, 8 a.m.: Ground testing before the two research aircraft take off.*

02 ___ *Now flying lab equipment instead of vacationers: Measuring instrumentation on board the DLR's A320 ATRA, which was previously operated by holiday airline Niki.*

03 ___ *The DLR's A320 flying ahead looks tiny against NASA's DC-8.*

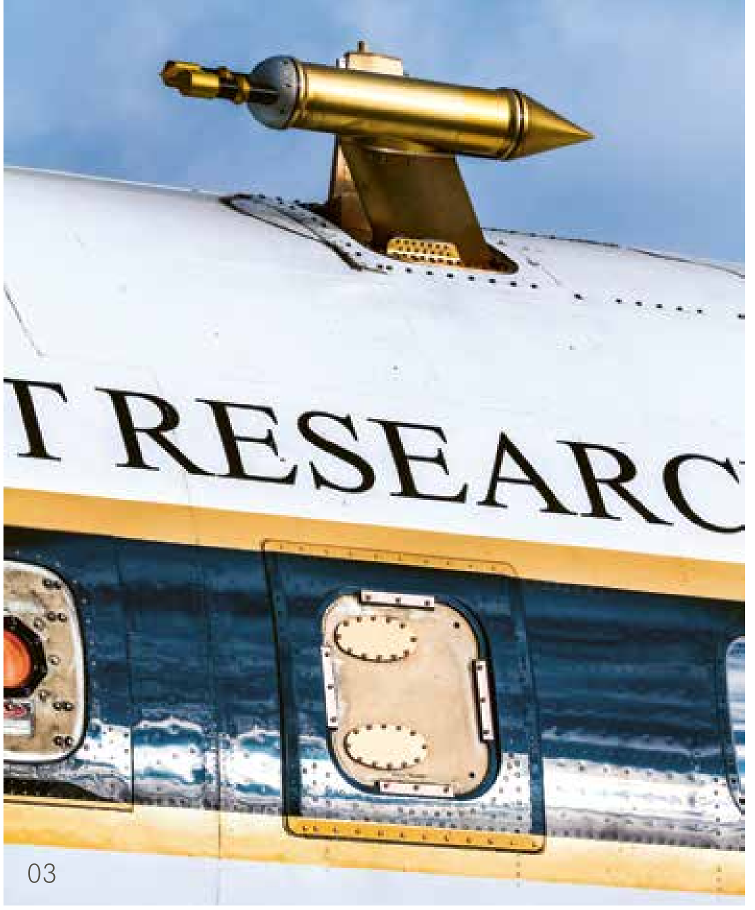
the Airbus flies around hour after hour, six minutes straight ahead, a turn to the left, straight ahead for another six minutes, then a turn to the right. But the A320 is not flying alone. Shortly after the ATRA, an aircraft that is probably the most unusual flying lab in the world has taken off and is following the Airbus. This is a four-engine passenger jet from the early days of the long-haul aircraft age, a McDonnell Douglas DC-8-72. Many European airlines such as KLM, SAS or Swissair operated DC-8s from the 1960s to the 1980s. This aircraft, the last remaining one of its kind, was originally delivered to Alitalia in 1969. Since 1986, it has been serving as NASA's biggest research aircraft. At the time it was retrofitted with CFM56 engines that are still surprisingly quiet by today's standards. "With its infrastructure and expert crew, the DC-8 is the best research platform in the world," says Dr. Hans Schlager from the German Aerospace Center's Institute of Atmospheric Physics. Before the aircraft crossed the Atlantic, the German Aerospace Center and NASA installed instruments for taking 20 different kinds of measurements in the 42-meter long cabin, which used to accommodate over 250 passengers. Some tubes are also installed outside on the fuselage. On the right wing tip there is a golden cloud spectrometer, which combines five complex instruments in one. There is also a laser pointing through the window at the wing tip to measure water vapor in the vicinity of contrails and ice clouds.

Reducing climate effects despite growing air traffic

The aviation industry is often blamed for exacerbating global warming, so far mostly focusing on emissions of the greenhouse gas CO_2. Here aviation has set itself ambitious goals: Through improvements in aircraft and engine technology as well as use of fuels and measurements to compensate climate effects, any growth must be CO_2-neutral. Guidelines issued by the UN aviation organization ICAO call for halving CO_2 emissions versus the 2005 amount by 2050. "Aviation is responsible for about five percent of human-induced climate effects, of which CO_2 emissions account for two fifths. The rest are nitrogen oxides and long-lasting contrails, which are now in focus," says Schlager. This is where we can

01

02



03

01 ___ *Ready for boarding in ideal cold and damp weather conditions: The DLR's A320 ATRA.*
02 ___ *Instrumentation for conducting 20 different types of measurement is installed in the DC-8's cabin, which is some 42 meters long and previously accommodated 250 passengers.*
03 ___ *Collecting data: Cloud spectrometer on NASA's DC-8 aircraft.*

make a difference, according to scientists, to reduce the effects of the ever-growing aviation industry on climate change. Every 15 to 20 years, global air traffic doubles; in 2017 a new record was set with 4.1 billion passengers. By 2036, IATA forecasts 7.8 billion. To meet this demand, aviation must become more sustainable.

Alternative fuels hold great promise for achieving more environmentally friendly flying. Many tests and their daily use in scheduled operations have proven that fuels produced from biomass or seed oil can be easily mixed and burned inflight together with ordinary kerosene. The problem is, however, that this sustainable fuel is currently three times the price of fossil fuel, so the commercial incentive to use it is lacking. "But it is important to develop data and methods for its use now while oil prices are relatively low, so that we have it available once oil becomes expensive again and the focus shifts towards renewable energies," says Dr. Patrick Le Clerq from the German Aerospace Center's Institute of Combustion Technology.

Flying into the secondary zone of contrails

After taking off from Ramstein with 14 scientists and six crew members on board, it is NASA pilot Wayne Ringelberg's job to go on a "sniffing" mission for climate research. "We have to fly very precisely into the secondary zone of contrails, about 15 to 20 miles behind the ATRA while maintaining a distance of at least 2.5 miles from the preceding A320, so sometimes we experience some turbulence on board," says the former combat pilot. The scientists are mostly buckled in during the missions of up to six-hours and communication is only possible via headsets. Damp and cold weather is a decisive prerequisite for the missions, as these conditions are ideal for the formation of contrails. Conditions are good when 45 minutes after take-off they reach the target area above the coast of the Baltic Sea. Briefly, the DC-8 flies alongside the ATRA to calibrate the altimeters. Then she settles behind the Airbus for hours to thoroughly document the emissions of its engines and what kind of contrails they create at altitudes between eight and twelve kilometers. Especially relevant to the climate are the long-lasting ones that remain in the sky for

between two and 20 hours, creating high-altitude ice clouds known as contrail cirrus clouds. While these clouds can have both cooling or warming effects on the ground, their warming effect is more prevalent.

They are created when water droplets condense on soot particles from the engine exhaust, then freeze and form ice particles. “The number of soot particles plays an important role. Burning biofuels results in up to 50 percent less soot, which in turn changes the number and size of ice crystals,” explains Schlager. “This way, the life span of the contrails is shortened and they have a reduced radiation impact on average.” If all flight operators would fly with a fuel mix containing 50 percent HEFA, scientists estimate that the contrail cirrus clouds worldwide could be reduced by 30 percent.

The significant effect of long-lasting contrails is a recent scientific finding. “They probably have more of a warming impact on the earth’s atmosphere than all CO_2 emissions in the atmosphere produced by aviation collectively in the last hundred years,” estimates Schlager. “But then the exact global impact of contrails is very hard to calculate with theoretical models. That’s why the measurements we take in this campaign are so important,” says the expert from the German Aerospace Center. It will take another year, however, to analyze the gigabytes of data they obtain. As both aircraft return to Ramstein, the scientists on board are treated to a glimpse of the evening sky, which is spectacular tonight—mostly thanks to the many contrails crisscrossing it, glowing in deep shades of orange and red.

Do you have any questions, requests or suggestions?
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Text:
Andreas Spaeth has been traveling the world as a freelance aviation journalist for over 25 years, visiting and writing about airlines and airports. He is frequently invited to appear on radio and TV programs.

The power of expertise

Poland is an attractive location for the aviation industry. The MTU site in this country is growing fast. And now a new joint venture has been founded.

Text: *Thorsten Rienth*

MTU AERO ENGINES POLSKA

Poland

The sixth-largest country in the EU, with 38.5 million inhabitants, is nestled between the Baltic Sea and the Carpathian Mountains. In the south of the country just outside of Rzeszów, a special economic zone is home to more than 80 aviation companies with production and research facilities.

> *"Here in Rzeszów we found a high concentration of aviation expertise and an excellent infrastructure."*

Krzysztof Zuzak
Managing Director, MTU Aero Engines Polska

Under normal circumstances, managers are advised to keep a rein on their emotions. But there are also times when a display of emotion is perfectly acceptable. Dr. Uwe Zachau could not hide his enthusiasm a moment longer. He speaks of a milestone for both companies, an ambitious ramp-up plan, an excellent and highly motivated team. Zachau is describing a new maintenance, repair and overhaul (MRO) joint venture between Lufthansa Technik and MTU Aero Engines that bears the name Engine Maintenance Europe or EME Aero for short. Zachau is the COO of the new company; Derrick Siebert the CEO. He says: "We are paving the way for MRO of the new generation of Geared Turbofan™ engines in Europe." Both partners hold a stake of 50 percent in the new company.

The joint venture will be located in Poland, where MTU has already been able to gather many years of experience. In 2007, the company set up MTU Aero Engines Polska in a special economic zone in the southeast corner of the country. "This zone is the economic powerhouse of the region," says the regional administration. Many well-known companies have opened branches with production and research facilities there. The original plan was to stop offering business advantages in the Polish special economic zones in 2020. But the special rights granted to these zones have now been extended up until 2026. Almost every month, new firms are moving in.

Region with a tradition in aviation

Much like MTU did roughly ten years ago. In the space of just nine months it built the 18,000-square-meter MTU Aero Engines Polska facility right opposite the international airport in Jasionka near Rzeszów and equipped it with the first machines. MTU has invested a total of over 50 million euros in this project. The deputy Polish prime minister and finance minister attended the opening ceremony in May 2009.

"Here in Rzeszów we found a high concentration of aviation expertise and an excellent infrastructure", says Krzysztof Zuzak. He has been managing director of the site from the very beginning. Over 14,000 students attend the local polytechnic where the proportion of future aviation engineers is especially high. "Rzeszów has a long tradition in aircraft construction," says Zuzak. "More than 60 percent of our engineers come from the polytechnic here in Rzeszów." There is a faculty of mechanical Engineering and Aeronautics that offers courses and specializations related to the aviation industry. Dr. Joachim Wulf, head of development at the site from 2009 until some years ago, once said that: "Rzeszów is a very charming university town like Tübingen in Germany."

MTU started with the development and manufacture of vanes and blades for low-pressure turbines, the assembly of low-pres-

Repair engineering ______ *As part of their job, development engineers at MTU Aero Engines Polska work on new repair technologies.*

Component production ______ *A V2500 ring is deburred at MTU Aero Engines Polska.*

"We designed the building so that it could be extended for future requirements."

Krzysztof Zuzak
Managing Director, MTU Aero Engines Polska

sure turbines and repair of aircraft parts. The advantages of the location, the town and its surroundings, soon became clear. Especially since all three areas of expertise, namely development, production and repair of engine components were brought together under one roof here: a first for MTU.

Expansion is part of MTU's investment and growth strategy

The initial workforce of 200 grew fast. Four years later, when the decision was made to expand the site, the workforce had grown to 500 – as of 2017, it is more than 750. Moreover, the foresight at the planning stage has now paid off. "We designed the building so that it could be extended for future requirements," says Zuzak. With the addition of the new buildings, the Jasionka site now covers almost three hectares. Just like the blisk production facility in Munich and the logistics center in Hannover, which were completed at about the same time, the expansion is part of MTU's investment and growth strategy.

The extension in Rzeszów houses preparatory work for the new Geared Turbofan™ engines as well as projects, which resulted from the upshare in the A320's V2500 engine program. There, the Polish plant is now responsible for logistics, procurement, design and quality assurance. It also bundles the module assembly activities for various commercial programs. At the moment, the development department is being enlarged. It will offer jobs for 140 engineers in total.

The best of both worlds

At EME Aero, the teams are currently finalizing the details of an ambitious ramp-up plan for the shop. This is a complex matter says Jana Kotlar, the project manager at MTU. "Not only will we have to build a new facility, we also had to implement stable processes in a relatively short timespan."

At some point this year, employee training will go ahead. And a subsequent simulation phase to test every last detail of the MRO

Post-processing ___ *Engine components undergo cleaning at MTU Aero Engines Polska.*

Module assembly ___ *A PW2000 low-pressure turbine is assembled at MTU Aero Engines Polska.*

process from order dispatch to final acceptance will take place. "We use the best of both worlds in designing our processes," says Kotlar. The expansion project comprises more than a dozen subprojects. "In each case, one partner will take the lead, but process interfaces are seamless."

The joint venture benefits from the considerable expertise accumulated by Lufthansa Technik and MTU in their respective fields. Since 2003, they have been operating a similar 50:50 MRO joint venture in Malaysia. It specializes in the repair of airfoils for low-pressure turbines and high-pressure compressors. "We also know each other well from working together in Germany," says Kotlar, "for example through mutual support in test runs or piece parts."

The first PW1000G engine will arrive at the shop for maintenance in 2020. Once the ramp-up has been completed, EME Aero will employ a workforce of 1,000.

Inside MTU ___ EMEAERO

ENGINE MAINTENANCE EUROPE

The new Polish joint venture between Lufthansa Technik und MTU Aero Engines will begin PW1000G engine repairs in 2020. Staff training as well as simulation and preparation of the maintenance processes are set to start in 2018.

Do you have any questions, requests or suggestions?
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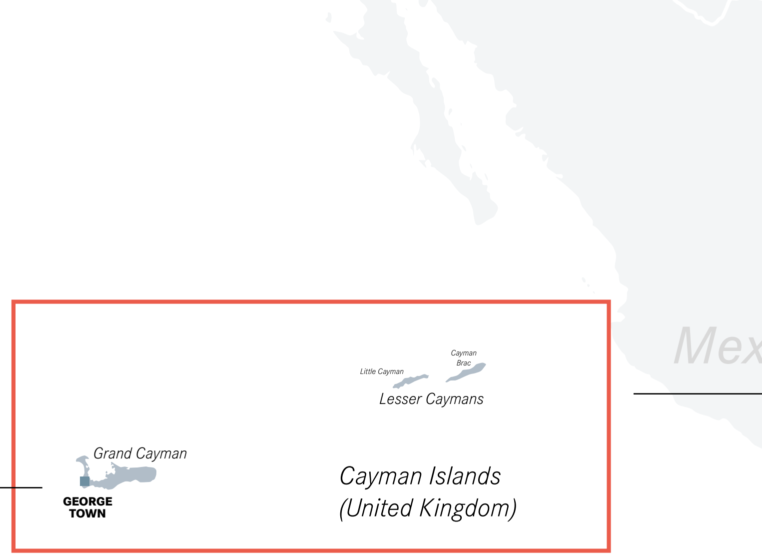
Text:
Thorsten Rienth writes as a freelance journalist for **AERO**REPORT. In addition to the aerospace industry, his technical writing focuses on rail traffic and the transportation industry.

Grand Cayman _____ *At 196 km², the island is almost the size of Hannover – but with its own airline. Grand Cayman is the largest of the three Cayman Islands and home to the Cayman Airways head office.*

Caymankind

From in-flight shutdown to flexible MRO and lease solution: How a creative response helped Cayman Airways get back in the air–fast.

Text: *Victoria Nicholls*



A fresh coat of paint ___ *Since the end of 2017, the entire fleet, including the Boeing 737-300s, have borne the Cayman Islands flag on the side rudder.*

Cayman Airways

Cayman Airways ___ *is the flag carrier of the Cayman Islands. With its head office in George Town, it operates out of Owen Roberts International Airport.*
Established: *1968*
Fleet: *8*
3 Boeing 737-300
1 Boeing 737-800
2 Saab 340B+
2 De Havilland DH-6

In Autumn 2017, Cayman Airways had an in-flight shutdown. "The borescope inspection report showed the number three bearings had caused significant damage to the core of the engine—the high-pressure compressor, high-pressure turbine and low-pressure turbine were all impacted and the scrap rate of the affected parts was likely to be 100 percent," said Wayne Miller, VP Maintenance and Engineering, Cayman Airways. It was the last thing he wanted to be seeing. Miller needed a solution and he needed it fast.

On the advice of his aircraft/engine lessor he called MTU Maintenance and other providers for their best, not-to-exceed proposals. Initially, Miller working with his lessor, received exactly what they had asked for: standard overhaul offers with replacement parts and some used serviceable material. But when MTU Maintenance approached them with an

improved concept, Miller realized he needed something "alternative, unconventional and palatable. I was looking for an immediate, cost-efficient turnkey solution," he says. "MTU had exactly the right resources to both: address my needs as a small operator and keep my lessor happy." In fact, his lessor's recommendations and existing relationship with MTU helped tremendously to make the process that much more comfortable for Cayman Airways.

The "Caymankind" mentality

Cayman Airways was founded in 1968 and operates three Boeing 737-300s with CFM56-3 engines, one Boeing 737-800 with CFM56-7 engines, two Saab 340B+ and two de Havilland DH-6 aircraft. It is a state-owned airline headquartered in Grand Cayman, the largest of the three Cayman Islands, and flies its 737 jets internationally to Cuba, Honduras, Jamaica and the USA, while flying its turbo prop fleet domestically within the Cayman Islands, located in the western Caribbean approximately 150 miles south of Cuba.

Although the airline is small, it has a big, Caribbean personality: "We emulate the 'Caymankind' mentality throughout our organization," Miller explains. "We're full of national pride and are highly service-oriented, but also reserved and laid back." For instance, the airline offers passengers two free checked bags in economy and three for business class passengers. Also in keeping with the nature of the Caymanian community, Cayman Airways passengers (aged 18+) receive a free rum punch inflight, as well as a free full meal on flights longer than 2 hours in duration. And listening to the Caribbean melodies in his voice, it is easy to believe the airline's motto, "Those who fly us, love us."

For an airline like Cayman Airways, the MRO solution needed to be highly creative and fast in equal mix. Engineered and executed by MTU Maintenance's experts, it included an independent inspection to discover what really happened, a cost-efficient overhaul that used a donor module sourced via MTU Maintenance Lease Services, and a lease engine. "It was just the music I wanted to hear," Miller says.

Miller's fleet is operating as usual again and the damaged engine is going through the MTU Maintenance shop. "But based on the enthusiastic, experienced and proud employees we met at the Hannover facility, I'm sure we'll like the taste of the product when we eat it," he says.

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Text:
Victoria Nicholls is a specialist for aftermarket topics such as engine MRO, leasing and asset management, as well as international market trends. The British-born editor lives in Berlin and works for MTU's corporate communications in Hannover and Ludwigsfelde.

In the hands of the experts

A global MRO network for PW1000G engines is in the making. Customers will benefit from high-quality maintenance and repairs and first-class service.

Text: *Nicole Geffert*

High-value asset ____ *A low-pressure turbine disk for the PW1100G-JM undergoes visual inspection. One of these components costs about the same as a limousine from one of Germany's premium car manufacturers. Customers can entrust the repair of this high-value asset to the OEM's international MRO network.*

A PW1100G-JM in the test cell at MTU Maintenance Hannover. These engines power the A320neo aircraft family.

Visual inspection at the PW1100G-JM fan assembly line.

A PW1100G-JM high-pressure compressor blisk is masked prior to plasma spraying.

The Geared Turbofan™ (GTF) is taking the market by storm: airlines around the world have already ordered more than 8,000 of these energy-efficient propulsion systems. MTU Aero Engines works in partnership with Pratt & Whitney (P&W) on the PW1000G engine series, which five major aircraft manufacturers have selected for new aircraft programs. To offer customers the same high standards of quality, efficiency and innovation in the repair and maintenance of the engines, P&W is joining forces with its partners to set up a global network for PW1000G aftermarket services.

"The network offers the full range of maintenance, repair and overhaul (MRO) services for PW1000G engines," says Dr. Christian Winkler, Program Manager PW1100G-JM and PW1400G-JM at MTU. In 2015, P&W, MTU and Japanese Aero Engines Corporation (JAEC) signed a cooperation agreement formalizing their agreement to collaborate on maintenance services for the PW1100G-JM—the engine powering the A320neo—through the International Aero Engines (IAE) LLC joint venture.

Thanks to the MRO network for GTF engines, customers will have access to shops with available capacities that provide expert, high-quality services performed by experienced personnel. Every shop offers the same high level of expertise in disassembly, assembly and testing. "We guarantee consistently high quality standards across all facilities," says Dr. Rainer Fink, Aftermarket Manager PW1100G-JM at MTU. The top priority for each repair shop in the network is ensuring quick turnaround times and punctual delivery of the engines. "Each shop specializes in certain repair techniques, which means that components in need of repair are always in the hands of the experts best qualified for the job."

Bringing out the best of every shop

All partners bring their strengths to the network and MTU—as one of the companies involved in development and production for the PW1000G program—is no exception. Thanks to its manufacturing expertise and high-tech products, such as the high-speed low-pressure turbine, MTU is making a valuable contribution to the GTF engine program. In addition, its subsidiary MTU Maintenance brings to the table over 35 years of success, experience and expertise in the independent MRO business. MTU Maintenance Hannover has been qualified to carry out PW1100G-JM engine maintenance since 2016 and is certified to provide MRO services as part of the new maintenance network.

MTU is even helping to build a new facility specifically for GTF engine repairs. In December 2017, MTU and Lufthansa Technik set up Engine Maintenance Europe—EME Aero for short. This MRO joint venture will be located in Poland (see also article "The power of expertise" in this issue).

As things stand, EME Aero is the youngest member of the network. Other participating MRO shops include P&W Columbus Engine Center (Georgia, USA), Christchurch Engine Center (New Zealand), a joint venture between P&W and Air New Zealand, and P&W Eagle Services Asia (Singapore), a joint venture between P&W and Singapore Airlines Engineering Company, as well as the MRO shop operated by JAEC consortium partner IHI Corporation (Mizuho, Japan). The experts at each facility are constantly in touch and sharing their expertise with one another. As Fink says, "This is an example of a genuine partnership working for the benefit of our customers and allowing us to offer them the best possible service."

A PW1500G powerplant for the Bombardier C Series in the test cell at MTU in Munich.

The PW1100G-JM assembly line at Pratt & Whitney in Middletown, Connecticut.

Predictable repair costs and first-class service every time

Most new generation engines, such as the PW1000G series, are purchased with maintenance contracts directly with the OEM (Original Equipment Manufacturer), which takes overall responsibility for the engine. A large number of customers have signed a Fleet Hour Agreement (FHA) when purchasing GTF engines. "The customer pays a fixed rate for every hour the engine flies, which means they can easily plan their repair costs. Responsibility lies with the OEM to cover any costs that exceed the amount agreed in the contract for the defined scope of maintenance or repair," explains Michael Hauser, Head of Maintenance Cost Management at MTU.

There are several different types of FHA: For example, with the pay-as-you-go agreement, the amount the customer owes is calculated by multiplying the negotiated flight hour rate by the number of hours flown. With the pay-at-shop-visit agreement, the customer only pays the amount owed at the next shop visit. "Airlines that lease rather than buy new-generation engines also benefit from maintenance contracts with the OEM," says Hauser. "Leasing companies expect their engines to be returned in excellent condition at the end of the contract period. So, to make sure that they can comply with these terms, airlines sign MRO agreements directly with the OEM."

Time-and-material contracts are another option, whereby the customer is charged for the costs of labor and materials. If airlines have their own shops, they are guaranteed a maximum sum for repair work (Maintenance Cost Guarantee). "Whichever contract the customer goes for, they can always rely on the first-class service provided by the network partners," says Winkler.

This service guarantee also applies to engine leasing. MTU is a partner in PW1100G-JM Engine Leasing, LLC, which is an IAE company and the IAE consortium partners are also those responsible for producing the PW1100G-JM. Now, PW1100G-JM Engine Leasing is setting up a pool of spare and lease PW1100G-JMs, which customers can turn to, if need be, to ensure the smooth and uninterrupted operation of their fleets.

Do you have any questions, requests or suggestions?
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More on this topic: **www.aeroreport.de**

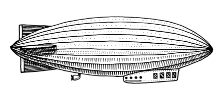
Text:
Nicole Geffert has been working as a freelance journalist covering topics such as research and science, money and taxes, and education and careers since 1999.

The airship of tomorrow _____ *Airships have been around for a long time, but now engineers are going back to the drawing board to design new prototypes. Their uncomplicated take-offs and landings make airships especially attractive for use in remote areas.*

There's something in the air

To date, very few airship plans have managed to mature past the idea stage. Recent projects could change this: they are targeting the right market niches.

Text: *Denis Dilba*



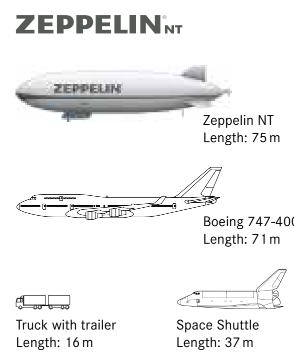
The quiet hum of the engines can't be heard from the ground. For the observer, the "cigar" floats silently and at a majestically leisurely pace some 300 meters above Lake Constance. When the weather is really good, the panoramic windows reveal breathtaking views as the airship moves with the gentle rise and fall of the thermals: the Alpine peaks, the Black Forest and the Swabian Jura are so close you can almost reach out and touch them. "Our passengers often compare the gentle free-floating with a combination of diving and a ship gently rolling with the waves," says Franz Günther, chief pilot of the German Zeppelin Transport Company and flight operations manager for the Zeppelin NT. This airship, stationed in Friedrichshafen, has already delighted more than a quarter of a million passengers worldwide with a new perspective of the world from above since it began commercial flights in 2001. "Our flight operations are economically sustainable and profitable," says Eckhard Breuer, Günther's boss, visibly pleased.

Development costs underestimated

That is precisely what a whole host of other companies that want to conquer new markets and make big bucks with airships dream of doing. They want to shake up the transportation sector with their new designs, guard borders from the air, create flying research platforms and communication networks, or transport wealthy tourists to remote locations. Uwe Apel, a professor of aerospace engineering at Bremen University of Applied Sciences, is familiar with all these concepts. "There have been many interesting ideas in past decades, but despite their great potential, to date, most of them have remained just that: namely ideas," says the expert. Apel considers one main reason for this to be the chronic underestimation of the development costs for these unusual flying machines: "They are comparable to those for an airplane."

What makes it expensive isn't the aluminum or the high-tech envelope, but the process to get the systems certified as safe, Apel explains. In principle, the cost of development can be roughly estimated based on the empty weight of an aircraft: "Rarely will it be possible to develop something for under 40,000 euros per kilogram," says Apel. This, among other things, was also the problem with the most famous of the recent airship projects. In the late 1990s, the CargoLifter was to become the largest airship ever built, with a massive length of 260 meters and a net weight of 260 tons—as much as the Airbus A380. "So they should have been budgeting for several billion euros," says Apel. CargoLifter set development costs at half a billion. "There are no measures that would let them recoup that later," says Apel.

SIZE COMPARISON



The Zeppelin NT is four meters longer than a Boeing 747-400, one of the largest aircraft in the world.

Zeppelin NT ____ *This airship, stationed in Friedrichshafen/Bodensee, has already delighted more than a quarter of a million passengers worldwide.*

LM-H1 ____ *The hybrid airship is capable of taking off and landing on rough terrain and touching down on water.*

MANUFACTURERS OF THE NEW AIRSHIPS

Lockheed Martin ____
The long-standing U.S. aircraft manufacturer has been developing a hybrid airship for more than 20 years on the grounds that "over half of the world's population lives in remote areas without access to proper roads or runways".

Hybrid Air Vehicles ____
The British company is convinced that when it comes to delivering supplies to remote areas and guarding borders, its Airlander 10 is unrivaled. Prototypes already flying.

Flying Whales ____
The French company expects its LCA60T prototype to take to the skies in 2019. The behemoth will be 140 meters long and have a load carrying capacity of up to 60 metric tons.

Economical transportation means for remote areas

But that doesn't have to mean that all future airship projects are doomed to fail, says Apel. "Airships are practically predestined for certain tasks, especially supplying remote areas." These remote areas, such as settlements in Alaska or Canada, can be accessed via ice roads in winter and by transport aircraft in summer. However, climate change is causing the connecting ice roads to melt away ever faster and establishing a road infrastructure isn't worthwhile. Airships require very little infrastructure for taking off and landing—and they are also cheaper to operate than airplanes so it makes good business sense to use them to close this supply gap. The prerequisite for success is always the same, says Apel: "Airships have to perform the task better than the transportation means that currently performs it."

British company Hybrid Air Vehicles is even convinced that its Airlander 10 isn't just better at performing these kinds of supply flights and guarding borders, but that it is virtually unrivaled. This owes to its construction design—it is currently the largest airship in world, with a length of 92 meters. And it is a hybrid airship. In contrast to normal airships, which float because they are charged with gas, the hybrid generates some of its lift in much the same way the wing of an airplane does, by virtue of its shape, despite being heavier than air. As a result, unlike its relatives, this wide, bulbous giant—which looks like multiple airships nested within each other and goes by the nickname "flying bum"—simply descends when it is no longer in motion. This makes takeoffs and landings less complicated. Conventional airships require a mooring mast and an area the size of a circle with a radius equal to the airship's length, and they must be parked with their nose into the wind, which can come from any direction.

U.S. technology giant Lockheed Martin wants to leverage the advantages of these hybrid airships, too. According to the company, their 82-meter-long prototype LM-H1 is in the construction phase and is on track for completion in 2018. Flying Whales, a French company, says its LCA60T prototype will be in the air a year later. CEO Sébastien Bougon says its behemoth will be 140 meters long and have a carrying capacity of up to 60 tons. It is intended primarily for transporting wood away from inaccessible terrain, but Bougon can also imagine it being used to hoist wind turbines or power lines onto mountain peaks, or to transport prefab houses or large aircraft components. "That all sounds very nice, but apart from Hybrid Air Vehicles, no other company has produced a flying prototype," says Apel. And the Brits have yet to demonstrate that their design really lives up to its promise. The company most recently made headlines with two accidents involving its airship.

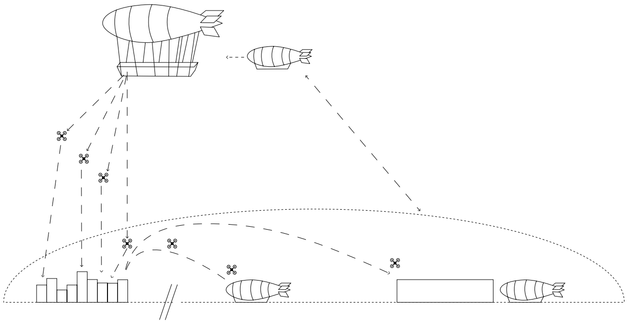
AIRLANDER 10 _____ *Measuring 92 meters, the world's longest airship generates some of its lift itself by virtue of its shape.*

The airship projects of internet billionaires

The idea that Amazon patented in the U.S. in 2016 could therefore, at first glance, be classed as science fiction: the online retailer envisions serving its customers from huge airships that float permanently at an altitude of around 13 kilometers above cities, with drones transporting the goods. While a floating warehouse like this is doubtless an extreme technological challenge, experts don't consider the vision impossible, but it is still entirely unclear whether and when Amazon will launch such a delivery service. Amazon boss and multibillionaire Jeff Bezos certainly would have the resources. According to rumors, though, Bezos' billionaire colleague, Google co-founder Sergey Brin, has a concrete project in the pipeline. U.S. news agency Bloomberg claims to have learned that something resembling a massive Zeppelin is currently being built in one of the world's largest airship facilities in Mountain View, California. It could be an XXL luxury liner. Brin himself is silent on the matter.

As vague as the prospects are at the moment, bets on the future could potentially pay off faster than we think: "If stricter environmental regulations are passed, airships will have a distinct advantage," says Apel, because "they are extremely resource efficient in flight." Perhaps then Zeppelins will go back into series production in Friedrichshafen—where everything began with the first flight of the LZ 1 airship nearly 120 years ago.

SUPPLIES FROM THE AIR



Floating warehouse _____ *Online retailer Amazon envisions serving its customers from huge airships-cum-storage facilities, with drones transporting the goods.*

Text:
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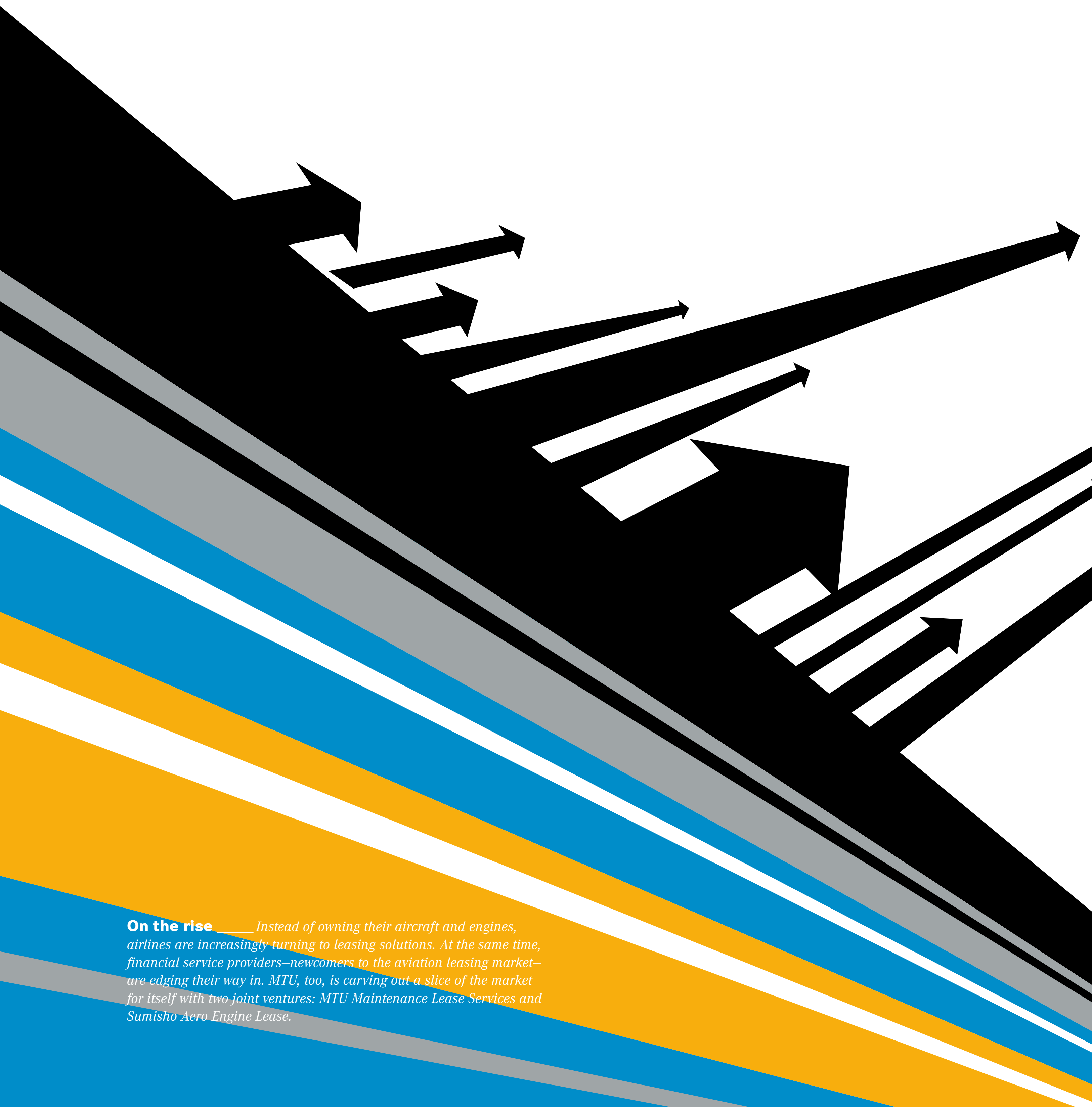


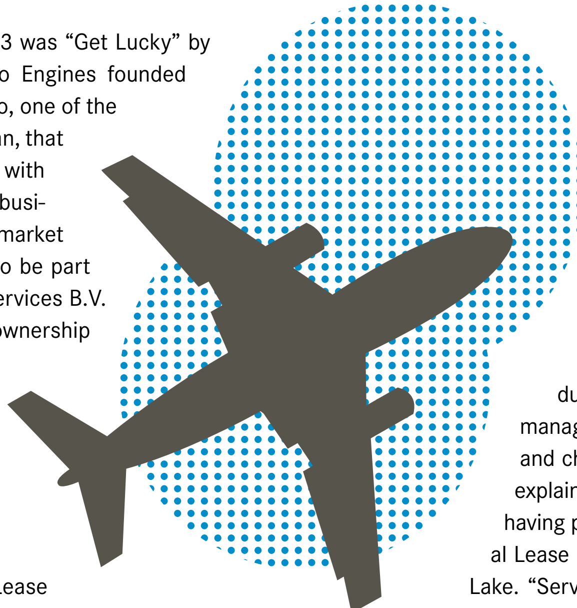
On the rise ____ *Instead of owning their aircraft and engines, airlines are increasingly turning to leasing solutions. At the same time, financial service providers–newcomers to the aviation leasing market–are edging their way in. MTU, too, is carving out a slice of the market for itself with two joint ventures: MTU Maintenance Lease Services and Sumisho Aero Engine Lease.*

You have to be in it to win it

The aero engine leasing market is growing and changing – and MTU Maintenance Lease Services B.V. with it. **AERO**REPORT *catches up with VP and Head of Global Leasing Alistair Dibisceglia to find out what's next for the leasing and asset management specialists.*

Text: *Victoria Nicholls*

Among the biggest tunes in 2013 was "Get Lucky" by Daft Punk. But when MTU Aero Engines founded two joint ventures with Sumitomo, one of the largest trading companies in Japan, that same year, this had nothing to do with chance: it was about an astute business observation. The leasing market was growing, and MTU wanted to be part of it. MTU Maintenance Lease Services B.V. (MLS) with 80 percent MTU ownership and a focus on short-term leasing and Sumisho Aero Engine Lease B.V., 10 percent MTU ownership and a focus on mid and long-term leasing were born.



Since then, MTU Maintenance Lease Services has exceeded all expectations. It has grown to an over 30 man operation out of Amsterdam and has over 100 engines available in its lease pool, including the popular CFM56, V2500 and GE90 engines.

This success is in part due to a growing industry: global consulting company ICF reports that around 12,000 commercial jet aircraft, valued at approximately 240 billion US dollars, are owned by operating lessors and leased on this basis to the global airlines, representing more than 40 percent of the fleet by unit and value today – with the market continually growing in absolute size. ICF also comments that operating leases, although more dominant for narrow body jet at 52 percent leased, have also gained traction in the regional jet (37 percent) and wide body fleets (40 percent).

Reacting to increased competition

But MLS' positive development is not down to sheer market growth. After all, a financially attractive market draws in more players and, as such, competitiveness is increasing. For instance, Boeing Capital Corporation has reported that a new insurance market emerged in 2017, enhancing the diversity of financing available to airlines and lessors to support their fleets.

"With the growing competition in the market, we have to be on the pulse of what our customers need, thinking of solutions and options before they might even have," says Alistair Dibisceglia, VP and Head of Global Leasing at MLS. "It is for this reason we are steadily developing our product portfolio." When it started in 2013, MLS quickly introduced asset management to its services to help owners maximize the utilization of their assets. Now, the company is focusing on lessors.

Lessors want more involvement

Borne from the observation that an increasing number of aircraft and engine lessors looking to take a more active role in managing their most valuable assets – engines – MLS has created a Lease Enhancement Program for lessors and lessees across the lifecycle. "We're seeing lessors want to be more involved in engine maintenance decisions, particularly during the transition between lessees, in managing and optimizing maintenance reserves and choosing the timing of engine shop visits," explains Dibisceglia, who joined MLS mid-2016 having previously held senior roles at International Lease Finance Corporation/AerCap and CastleLake. "Services can start from the moment the engine is purchased, or at any point in the lifecycle. It is a case of opt-in and opt-out at any time. And it's all about risk mitigation and residual value retention," Dibisceglia adds.

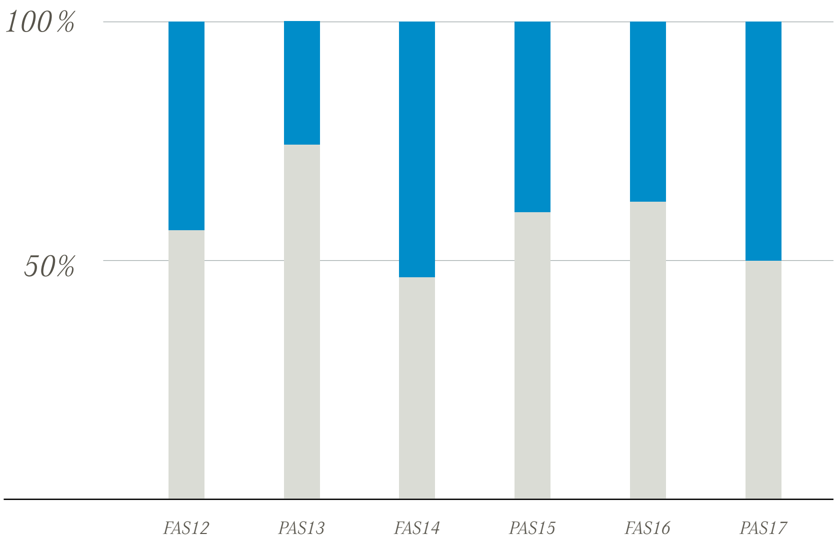
Furthermore, MLS assets lessors and owners with technical consultancy as well as helping lessors and lessees through transitions and across the lifecycle. "This comes from the fact that we have extensive MRO background," says Dibisceglia. "New money, such as from insurance and equity, is entering the market and these investors need technically savvy partners who manage the engines on their behalf, making sure the assets are healthy at all times preserving and maximizing their residual values." Services range from physical inspections and checks to fleet management and, of course, MRO oversight through shop visits. Additionally, MLS performs asset valuations and investment appraisals, training and brokering.

Creative thinking

But MLS is also available and able to create entirely new solutions for operators and owners. Say for instance a lease agreement is coming to an end. The asset owner might want to dispose of the asset from their portfolio through a sale, while the airline might still want to operate the aircraft. But the capital expenditure to acquire it and to maintain the engines through its remaining life might not in their best interest.

This is where MTU Maintenance Lease Services steps in. It acquires the engines from the current owner and leases them to the airline for the remaining green-time. Furthermore, to allow the aircraft to fly for the duration of its economical service life, MTU can replace any unserviceable engines with serviceable engines from its pool.

ORDERS FROM AIRSHOWS (PARIS AND FARNBOROUGH) 2012 TO 2017



According to UK aviation consultancy IBA, 1,070 firm orders and letters of intent/memorandums of understanding were placed and 188 options communicated at the Paris Airshow in 2017. Airlines and lessors together accounted 86 percent of the firm orders and MOUs, of which 53 percent came from lessors and 47 percent from airlines. The graph shows the distribution of orders at the Farnborough and Paris airshows in the last five years.

Outlook

All in all, the leasing world is buoyant and it is likely to stay that way. Boeing Capital Corporation forecasts that operating leasing will account for 50 percent of the in-service fleet by the end of this decade. And as more than 19,000 commercial jet aircraft are expected to be required by 2025, it expects lessors to provide a significant amount of the financing needed to support this growth. These are all trends MTU sees in the engine leasing market also, and something the company is gearing up for. "After all," says Dibisceglia, "you've got to be in it to win it."

Do you have any questions, requests or suggestions?
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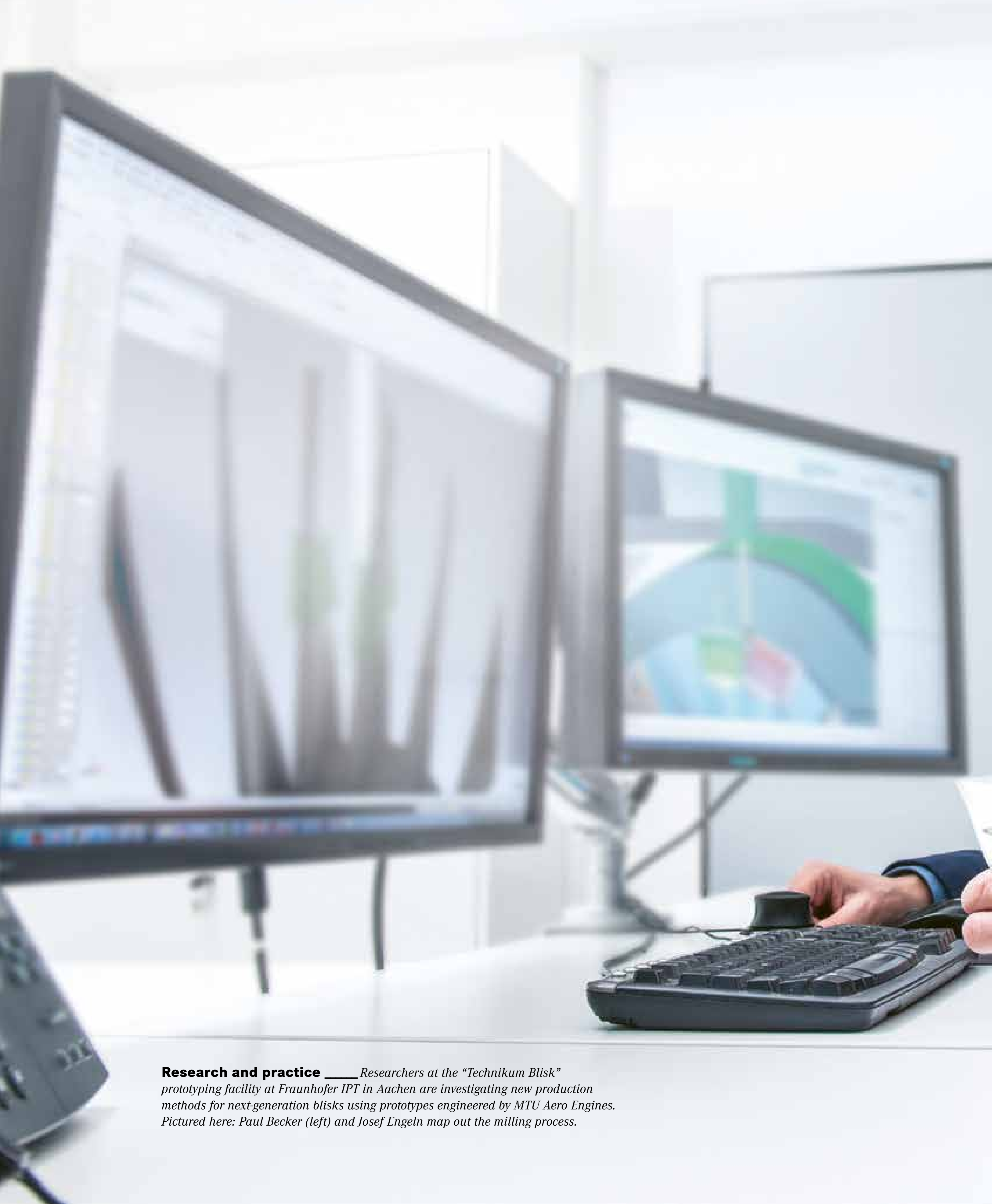


Research and practice _____ *Researchers at the "Technikum Blisk" prototyping facility at Fraunhofer IPT in Aachen are investigating new production methods for next-generation blisks using prototypes engineered by MTU Aero Engines. Pictured here: Paul Becker (left) and Josef Engeln map out the milling process.*

Developers of tomorrow's technology

As the ramp-up of the current PW1000G engine generation continues, MTU has already started developing blisk prototypes for the next GTF generation at a dedicated blisk prototyping facility.

Text: *Thorsten Rienth*

Kilian Fricke (left) and Willi Tontsch from Fraunhofer IPT program the five-axis milling machine used to process the blisks. **01**

At Fraunhofer IPT in Aachen the blisk prototypes are produced using the same five-axis milling machine model as production parts at MTU in Munich. **02**

A production blisk for the PW1100G-JM, which entered regular service in 2017. The blisk prototypes to be produced in Aachen from now on could become production parts for next-generation aircraft engines. **03**

The probe is capable of checking the blisk's surface with a much higher degree of precision than the human eye. **04**

Dr. Sascha Gierlings lifts a blisk out of the machine, but it looks different to what you might expect. The prototype still has a silvery shine to it, just like a piece of jewelry, but its blades look slimmer than conventional blisks. It's supposed to look this way. "This is precisely where the trend for blisks in the next generation of GTF engines is heading."

By about 2030, these blisks could help power the aircraft that will eventually succeed the Airbus A320neo and the C Series. As before, this new blisk design is the brainchild of MTU engineers. At the Fraunhofer Institute for Production Technology IPT in Aachen, Gierlings has been busy addressing the question of how best to produce the new blisks.

"Advanced compressor architecture calls for new blade designs, something we have already been able to depict using computer models," explains developer Dr. Bertram Kopperger. Kopperger, who heads up the production technology program at MTU Aero Engines in Munich, was the one who commissioned „Technikum Blisk", the dedicated blisk prototyping facility at Fraunhofer IPT. "To demonstrate the potential of design optimizations in practice, we have to set up a rig and then run a great number of tests on the prototypes."

Producing the prototypes is a long and costly process. "Their design is entirely customized, each blisk is a separate entity," Kopperger explains. "We have, in fact, vastly expanded our blisk production capacity in Munich." But the whole shop is geared towards automated processes and disruptions have to be avoided wherever possible. Adding new prototypes to the workload would cause complications in blisk production for the current PW1000G engine family. For this reason, MTU plans to shift more of the blisk prototype production to Fraunhofer IPT in Aachen in the future, which is precisely the thinking behind the prototyping facility collaboration. This move will help ease workloads at the production line in Munich.

Applied research in the truest sense

Higher levels of engine sophistication require increasingly complex production processes. "For us, the prototypes represent applied research in its truest sense," says Dr. Thomas Bergs, Managing Director of Fraunhofer IPT, outlining the institute's motivation. "It's vital for us to verify our theoretical models in a real-life environment."

Slimmer blades are less stiff, which means they vibrate more. However, the tools used in production can inadvertently cause vibrations that can potentially have a negative impact on quality. What poses a real challenge is finding a solution to control these vibrations. In simple terms, the approach that Gierlings and his team are currently investigating is as follows: Using the tool and position data in conjunction with an analysis of the vibrations, the researches can predict the impact of the tools on the entire component surface. Then, they use the control software to adjust the process parameters, reducing the vibrations or even stopping them completely. "We do this by precisely controlling the speed of the milling tool in critical areas," says Gierlings.

One year, four blisk prototypes

MTU has been working in close collaboration with Fraunhofer IPT at the center of competence for compressor and manufacturing technology for ten years now. Needless to say that Bergs, Gierlings and Kopperger have come to know each other pretty well. Their activities focus on the material, processes and machines used to produce highly engineered components for aircraft engines. "Back at the start, our first strategic step was to acquire identical machines to the ones at MTU in Munich," explains Managing Director Bergs. This foresight is paying off.

These very machines have now produced the first blisk prototype—the one held by Gierlings. The blisk is now on its way to Technische Universität Darmstadt, where it will be set up in a test rig. "But this is only the beginning," says Bergs. On average, the prototyping facility plans to deliver about four blisk prototypes a year to MTU.

Text:
Thorsten Rienth writes as a freelance journalist for **AER**OREPORT.
In addition to the aerospace industry, his technical writing focuses on rail traffic and the transportation industry.

Faster arrivals

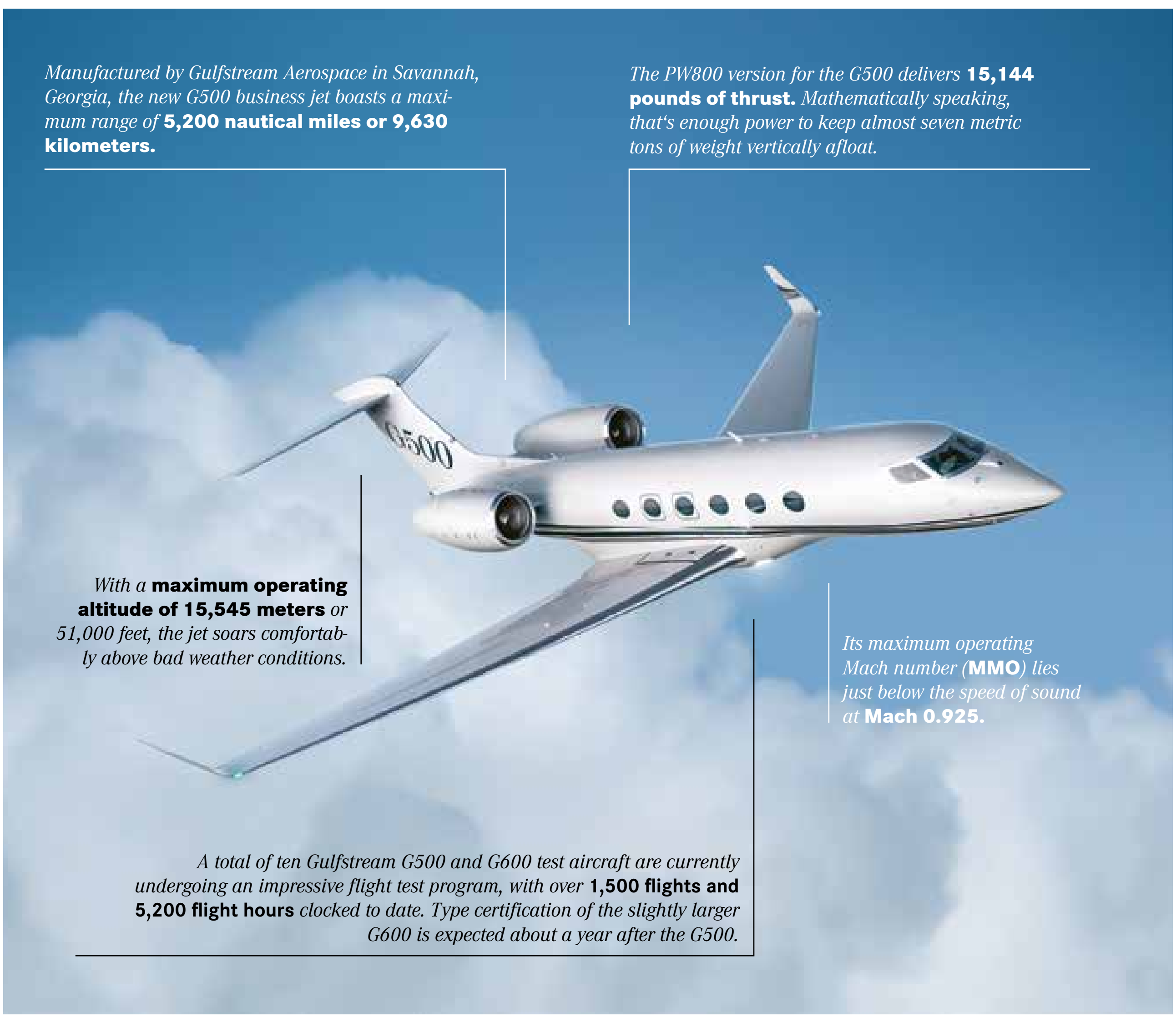
The Gulfstream G500 powered by the PW800 engine is fast approaching type certification.

PW800

The two Pratt & Whitney Canada **PW800** *engines that power the G500 belong to the PurePower® engine family. However, a gearless version has been designed for the G500.*

MTU holds a program share of 15 percent.

In addition to the two Gulfstream jets, the **PW800** *will power the new Dassault Falcon 6X, which is scheduled to enter service in 2022.*



Manufactured by Gulfstream Aerospace in Savannah, Georgia, the new G500 business jet boasts a maximum range of **5,200 nautical miles or 9,630 kilometers.**

The PW800 version for the G500 delivers **15,144 pounds of thrust.** *Mathematically speaking, that's enough power to keep almost seven metric tons of weight vertically afloat.*

With a **maximum operating altitude of 15,545 meters** *or 51,000 feet, the jet soars comfortably above bad weather conditions.*

*Its maximum operating Mach number (***MMO***) lies just below the speed of sound at* **Mach 0.925.**

A total of ten Gulfstream G500 and G600 test aircraft are currently undergoing an impressive flight test program, with over **1,500 flights and 5,200 flight hours** *clocked to date. Type certification of the slightly larger G600 is expected about a year after the G500.*

A double celebration

35 years of the PW2000 and 25 years of the PW4000-112

Pratt & Whitney's PW2000 and PW4000 series are celebrating anniversaries this year.

PW2000

It has been 35 years since the earliest version of PW2000 took to the skies for its maiden flight, receiving certification in late 1983.

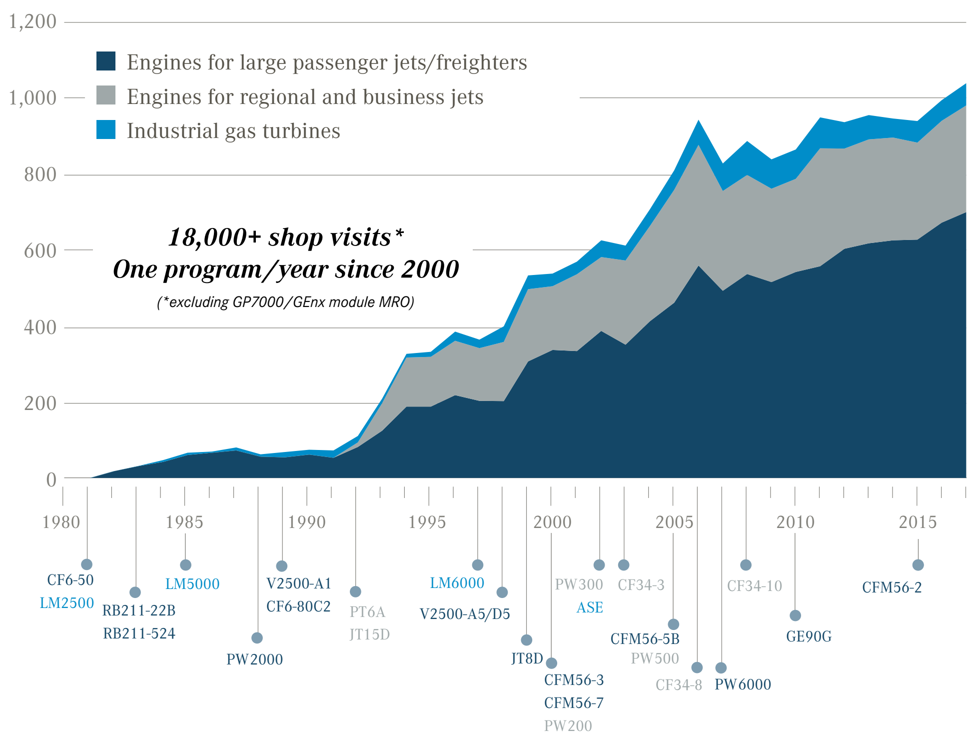
PW4000-112"

Some of the world's most powerful engines belong to the PW4000 series. The fan diameter of the largest variant, which completed its first flight 25 years ago, measures some 112 inches.

	PW2000	PW4000-112"
Program start	1971 as JT10D	1990
First flight	February 1983	November 1993
FAA certification	Late 1983	April 1994
Entry into service	December 1984	1995
Applications	Boeing 757 Ilyushin IL-96M Boeing C-17 Globemaster	Boeing 777-200/-200ER/300
Flight hours	approx. 71 million hours in the air	approx. 20 million hours in the air
Number of engines produced	approx. 2,320	approx. 440
Interesting facts	First engine to have active radial clearance control for reducing clearance losses in the turbine. First commercial engine with a full-authority digital electronic control (FADEC) system.	In May 1993, the PW4000-112" became the first engine to deliver 100,000 pounds of thrust.
MTU workshare	Program share of 21.2 percent: Development of the low-pressure turbine and turbine exit casing, production and assembly of the low-pressure turbine and other high-quality components	Program share of 12.5 percent: Development of the low-pressure turbine and production of high-quality components for the low-pressure turbine

Up, up and away

Number of shop visits at MTU Maintenance since 1981



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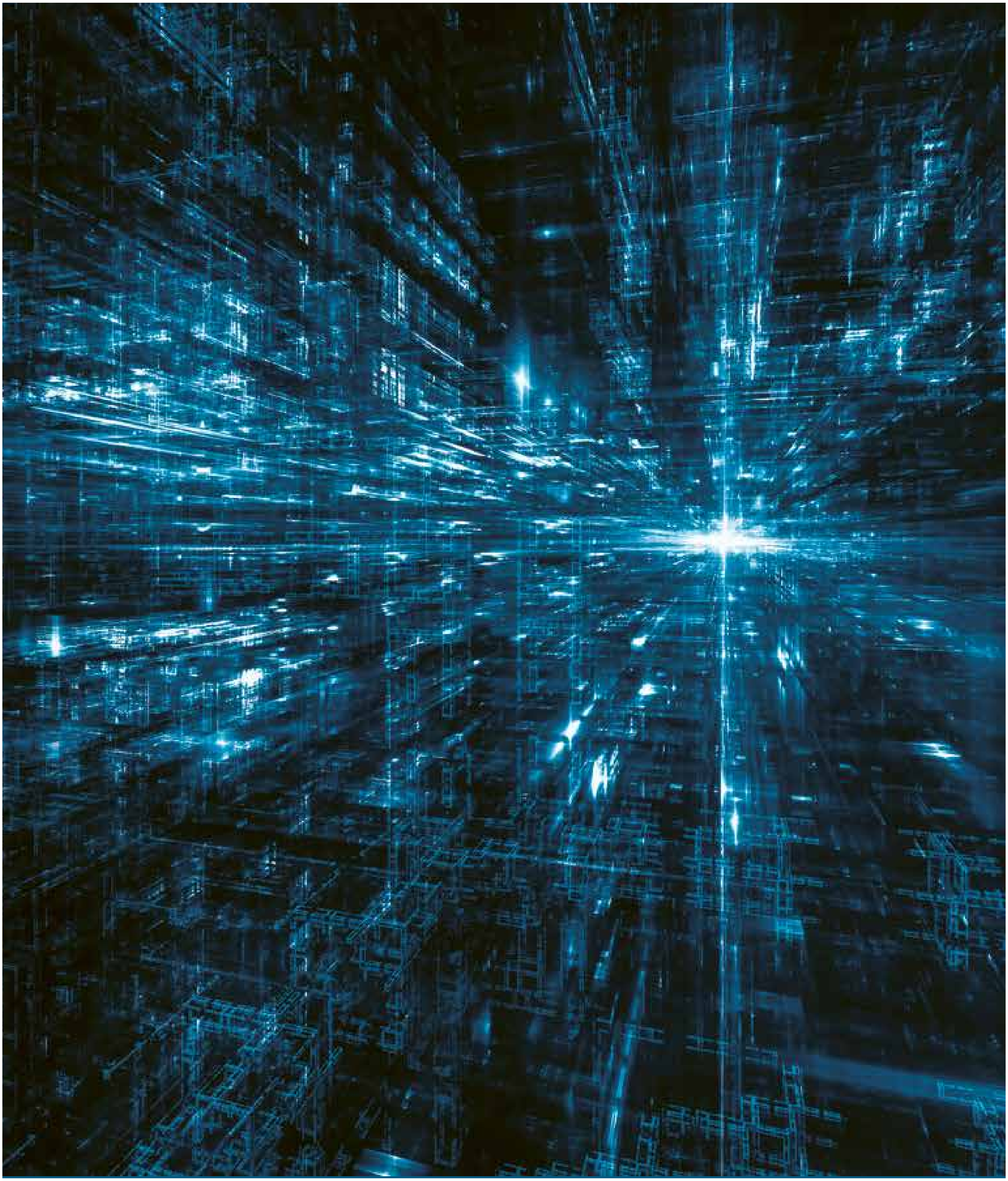

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