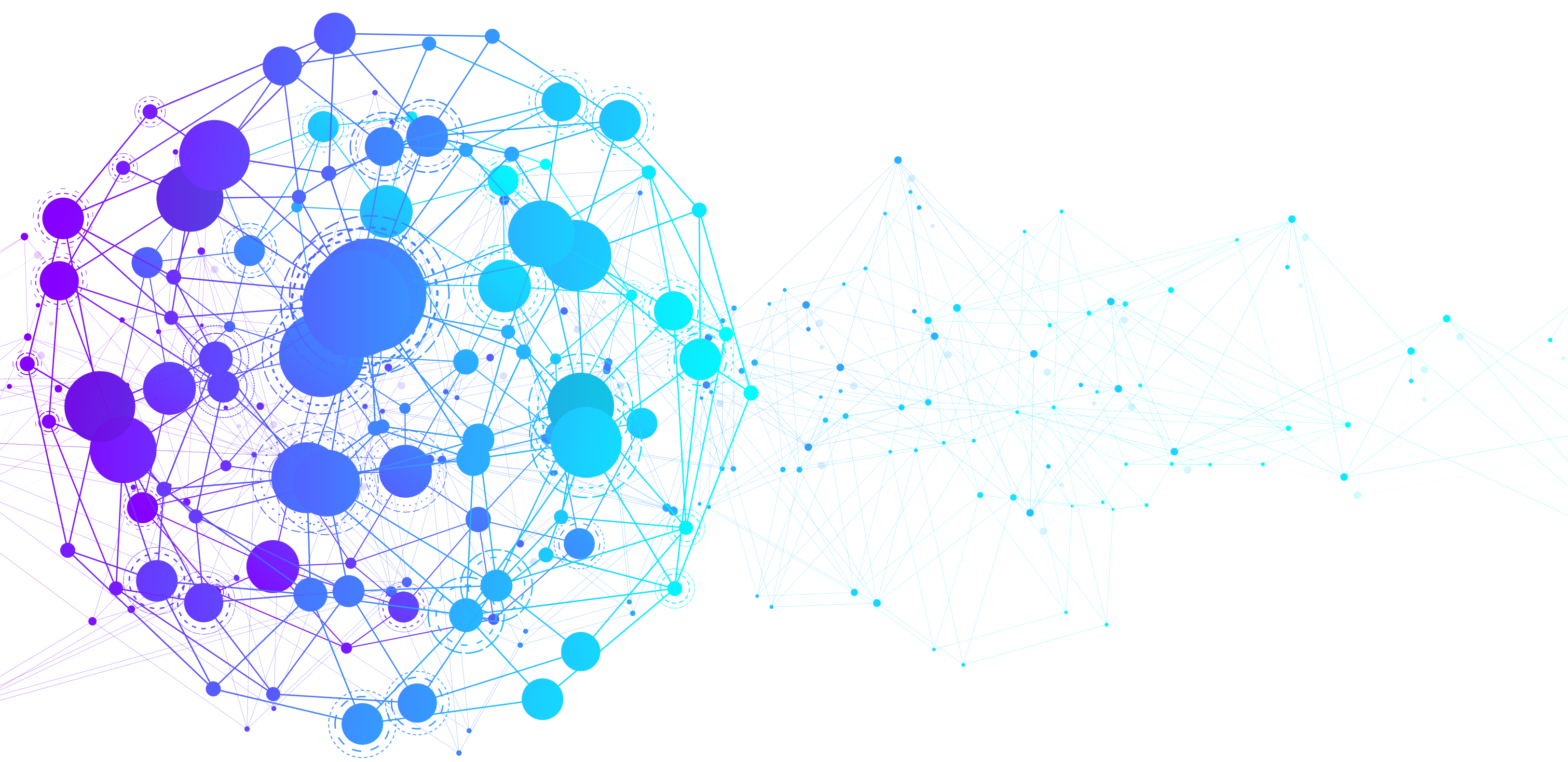
AEROREPORT 02|22

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



Research network for the engines of tomorrow

MTU Aero Engines has been working closely with institutes and universities for decades—constantly on the lookout for the next technological leap forward


MTU
Aero Engines
YOU CAN FIND OUR TECHNOLOGY IN 30% OF ALL PLANES AND YOU GAVE IT 100%.
THE MOMENT WHEN IT TAKES OFF: UNBEATABLE.
Wanted: team players (all genders) who aim high.
Any other desk job is just a strip of concrete. Turn it into a runway and be part of high-flying projects. With us. At MTU.
10,000 people. 16 locations worldwide. One in three planes flies with our technology. The only thing missing: You.
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Our online job market:
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Dear readers,

I would like to take this opportunity to personally say goodbye to you. After 20 years on the Executive Board of MTU Aero Engines, I will be handing over my responsibilities to my colleague Lars Wagner at the beginning of next year. With his extensive experience in technology and management, he will lead MTU into its next period of growth and technological innovation.

MTU is a great company with great future prospects, and I'm proud to have played a part, together with the entire leadership team, in strengthening the company and further expanding its role over the past years and decades. MTU is a vital and valued partner to the global aviation industry and to airlines.

In the coming years, aviation faces some daunting challenges and changes: Despite the current crises, we expect demand for air travel to grow in the long term. Managing the consequent increase in air traffic calls for new, efficient aircraft. Aviation concepts and products that conserve resources and are as climate-friendly as possible are the focus of research and development—for individual companies like ours, but first and foremost in collaborations between global industry and research partners.

Several hundred patent applications and invention disclosures each year attest to MTU's enormous innovative strength. These are largely driven by our work to refine our high-tech components such as the low-pressure turbine and the high-pressure compressor, to develop automated, state-of-the-art manufacturing processes and repair techniques, and to come up with visionary engine concepts. MTU has been working closely with institutes and universities for decades to promote innovation—constantly on the lookout for the next technological leap forward.

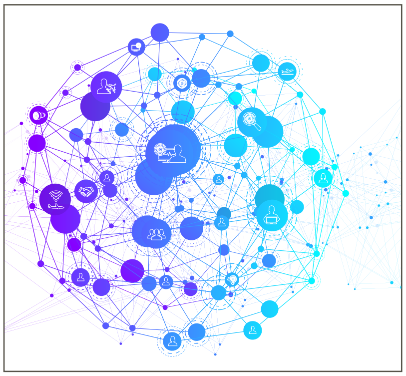
To step up these efforts, MTU has established centers of competence and partnerships in collaboration with leading universities and research institutes. In this issue of **AERO**REPORT, we introduce you to a selection of exciting projects that MTU has realized together with its research partners.

We also provide insight into the world of materials and the requirements they must meet in future aircraft engines. MTU's Dr. Inga Stoll, Director Materials, and Dr. Jörg Eßlinger, Senior Consultant Materials, had an in-depth discussion about this topic.

I hope you enjoy reading this issue!

Yours,

Reiner Winkler
Chief Executive Officer



COVER STORY

Research network for the engines of tomorrow

MTU has set up centers of competence (CoCs) and partnerships with leading universities and research institutes. In this network, the world's keenest minds collaborate on the important topics related to engines of the future.

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INNOVATION

In-flight research

Making aviation cleaner is an important goal. To achieve it, we need answers to two key questions: What pollutants do aircraft release into the atmosphere? And to what extent do new fuels or propulsion technologies reduce these emissions? Research aircraft can help answer these questions.

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AVIATION

Gliding the wave

Professional glider pilot Klaus Ohlmann holds 66 world records and seven world championship titles. He owes these achievements to his skills—and to a phenomenon known as lee waves. While these waves carry Ohlmann to great heights, they can be dangerous for commercial aircraft.

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CONTENTS

AVIATION

Dawn of a new supersonic era

Flying faster than the speed of sound is an old human dream, first achieved 75 years ago. The Concorde began carrying passengers on scheduled flights in 1976, and ceased operations in 2003. As of 2029, supersonic flights could be possible once more.

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PEOPLE

New materials make all the difference

Paving the way for emissions-free flight, future propulsion technologies are creating entirely new requirements for engine materials. Dr. Jörg Eßlinger, Senior Consultant Materials, and Dr. Inga Stoll, Director Materials, discuss the nature of these requirements.

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GOOD TO KNOW

Faster, further, higher

How tall is the world's tallest airport control tower? Between which two places is the longest route flown? And which is the largest engine? Aviation is home to a whole range of fascinating records.

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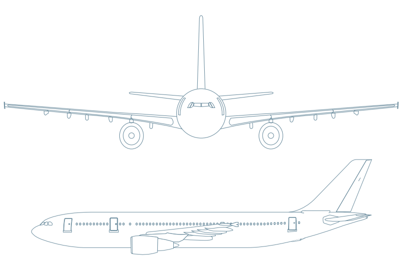
All articles from the print edition and much more are also available online at www.aeroreport.de/en.
There you will find informative videos, photo galleries and other interactive specials too.

ANNIVERSARY

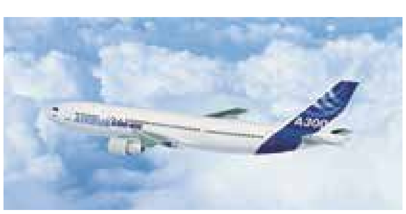
The Airbus A300 turns 50

On October 28, 1972, the Airbus A300—the world's first twin-engine widebody aircraft—took off for the first time. Different variants of the aircraft were manufactured until 2007. The Airbus A300 was the first aircraft made by what was then the Airbus consortium. Today, it mostly serves as a freighter.

A300-600



LENGTH	54.10 meters
HEIGHT	16.5 meters
WINGSPAN	44.84 meters
RANGE	7,500 kilometers
MAXIMUM NUMBER OF SEATS	345
MAIDEN FLIGHT	July 8, 1983 (-600)
NUMBER OF AIRCRAFT MANUFACTURED	561
ENGINES	General Electric CF6-80 / Pratt & Whitney PW4158



A300-600R —— *The A300-600R variant was added to the commercial fleet in 1988, enabling increased range. Since then, all new A300-600s have been A300-600Rs.*

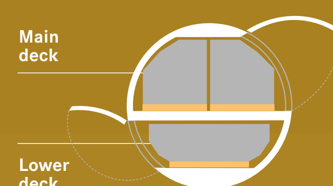
BOEING 777F

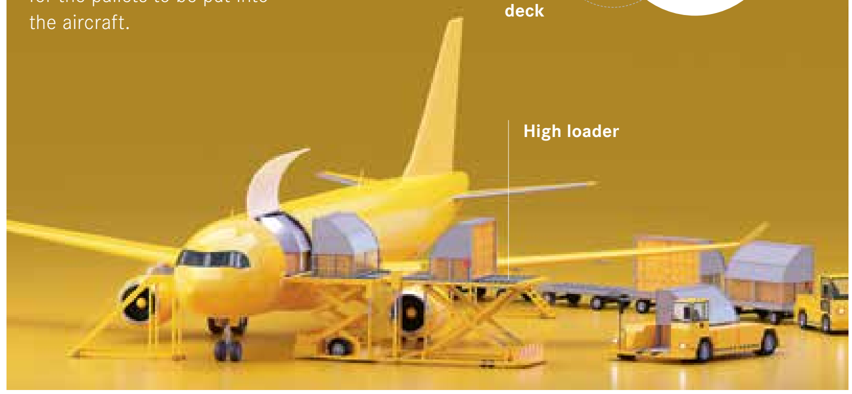
The super freighter

The Boeing 777F is the world's largest twin-engine freighter. Powered by two GE90-110 engines, the freighter can carry a **payload** of up to **103 metric tons.** Under normal weather conditions, the freighter has a range of **9,045 kilometers** when fully loaded, enabling long-haul flights from Frankfurt to Hong Kong or from London to Los Angeles, for instance.

How are freighters actually loaded?

On a Boeing 777F, the cargo bay is divided into a main deck and a lower deck. Loading takes place via cargo doors located at the front and rear of the fuselage. The front lower deck and the main deck are loaded first, followed by the rear lower deck. High loaders lift the cargo to the required height for the pallets to be put into the aircraft.





FACTS ABOUT THE GTF

Over 4 million flights since EIS	Over 15 million engine flight hours	Over 3 billion liters of fuel saved	Over 8 million metric tons of CO_2 avoided

Source: Pratt & Whitney, as of Q3/2022

MTU FIGURES

8,000

In June 2022, MTU delivered its 8,000th engine module to Pratt & Whitney Canada (P&WC). MTU and P&WC have been working together since 1985.

1985 — 1993 — 2010

PW300
Their collaboration began with the PW300 two-shaft turbofan engine, which covers the 4,500- to 6,000-pound thrust range and is used in numerous business jets.

PW500
In 1993, the PW500 program followed, accommodating somewhat smaller business jets with up to 4,500 pounds of thrust. This engine is used primarily in Cessna aircraft.

PW800
The newest member of the P&WC program family is the particularly efficient PW800 for large long-haul business jets with a thrust capacity of more than 12,000 pounds. It features the same core technology as the Pratt & Whitney GTF™ engine.

MTU holds stakes of 15 to 25 percent in the three engine types. Repair work is carried out at MTU Maintenance Berlin-Brandenburg. Component manufacturing and module assembly take place at MTU Aero Engines Polska in Rzeszów.

MTU FIGURES

4,000

In August 2022, MTU Maintenance celebrated the delivery of the 4,000th CF6 engine.

The shop visit was carried out by MTU Maintenance's North American affiliate in Vancouver.

Engines for a jumbo jet *Two CF6-80C2 engines on the wing of a Boeing 747.*

Maintenance *MTU's Hannover and Vancouver sites look after several models in the CF6 family.*

The successful model is among the bestselling engines in its class and was MTU's first engine for commercial aviation 50 years ago.

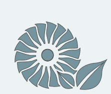
FACTS ABOUT MTU

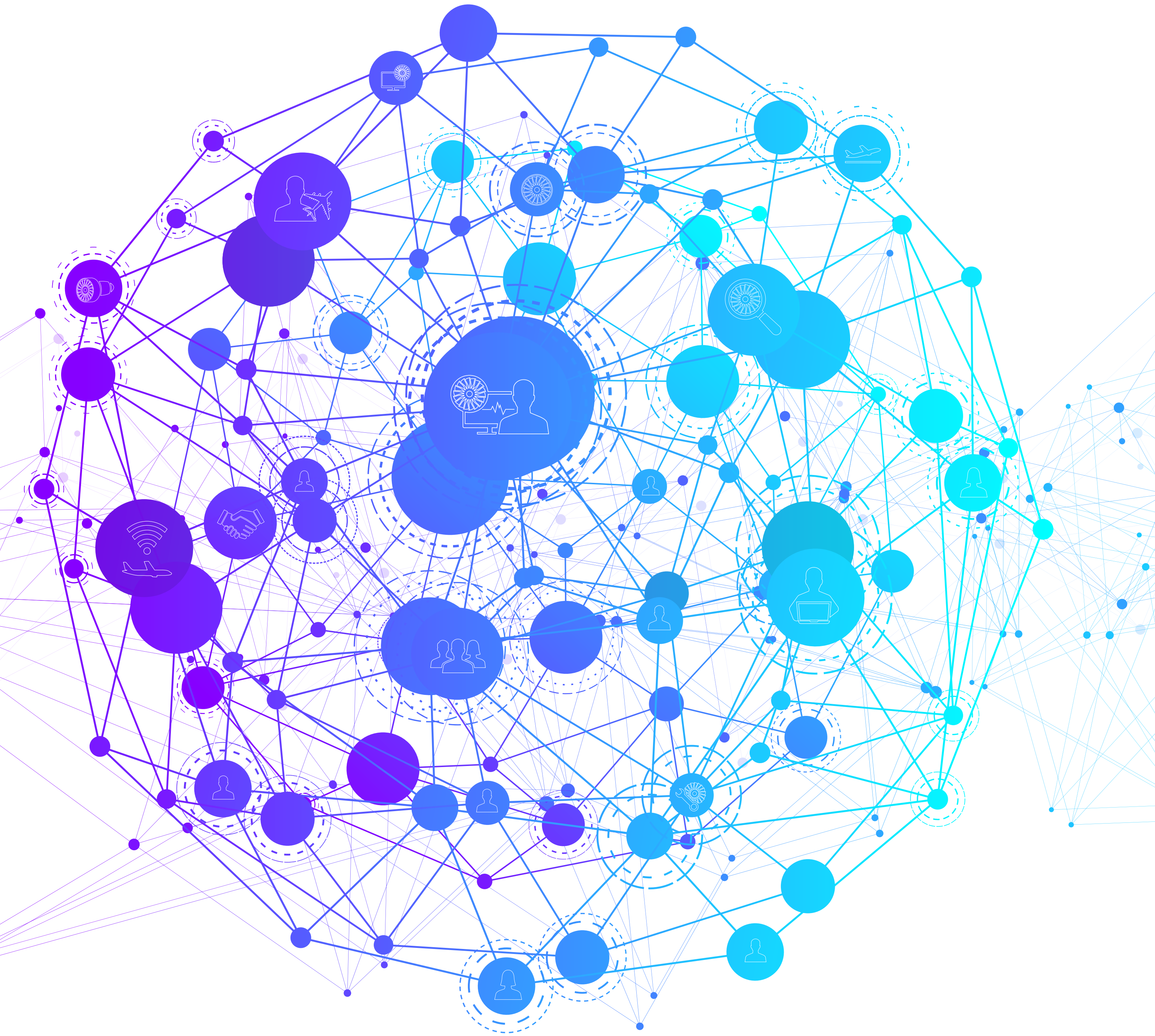
One in **three** commercial aircraft flies with MTU technology

Over **20,000** shop visits in commercial MRO by MTU Maintenance

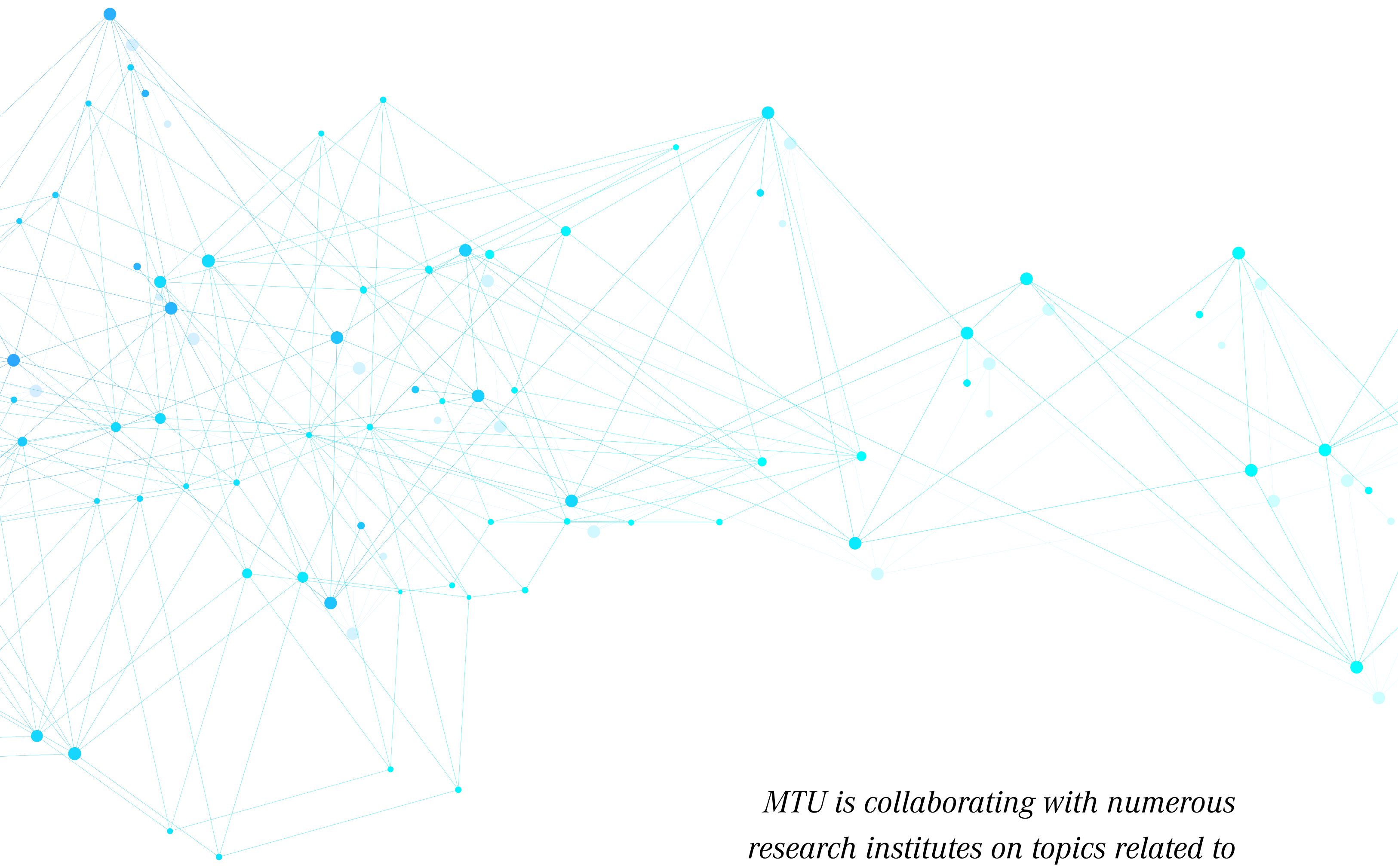
More than 1,500 shop visits in over **40 years** for the LM™ industrial gas turbine series

Approx. **200** technology projects focusing on sustainable flight





Research network for the engines of tomorrow



MTU is collaborating with numerous research institutes on topics related to the engines of the future.

Text: *Isabel Henrich*

Progress requires unconventional ideas and regular injections of fresh momentum. That's why MTU Aero Engines has been working closely with academic institutes and major research institutions for decades—constantly on the lookout for the next technological leap forward. To step up these efforts, MTU has established centers of competence (CoCs) and alliances in collaboration with leading universities and research partners.

"Strategic alliances with excellent research partners is how we ensure MTU can keep innovating over the long term," says Dr. Arne Weckend, Technology Collaboration Representative at MTU Aero Engines. These partnerships serve as a key catalyst and provide new knowledge. "MTU has a lot of expertise within its own ranks, but it can't cover every specialty," he says.

Basic research, trend research and the development of visionary engine concepts

In its research collaborations, MTU focuses on its high-tech components, including the high-pressure compressor, the high-speed low-pressure turbine and the turbine center frame. The collaborative efforts incorporate key technologies such as new materials and automated, state-of-the-art manufacturing processes and repair techniques, as well as virtual design that includes material and production simulation. Basic research, trend research and the development of visionary engine concepts, as well as an exchange of experience with experts from other sectors, all play a major role. Great importance is also attached to the fostering of young talent.

In Germany, MTU cooperates very closely with seven centers of competence (CoCs). This network consists of five top-ranked universities, plus the German Aerospace Center (DLR) and the Fraunhofer-Gesellschaft. The CoCs are home to some of the world's keenest minds as they collaborate on one or several main topics. MTU also works very closely with the Bauhaus Luftfahrt think tank, which focuses primarily on the complex system of aviation as a whole.

Focusing on zero-emission aviation together with DLR

MTU has been collaborating with DLR since the 1990s. It develops solutions tailored to the aviation industry that enhance the current and next generations of technology. The scope of issues that MTU and DLR collaborate on is as broad as DLR's field of research, ranging from researching new materials to developing new engine concepts. "In addition to having exceptional in-depth knowledge, the experts at DLR also have the requisite know-how to assess aviation's impact on the atmosphere and climate," Weckend says.

For example, at DLR's Institute of Propulsion Technology test lab, MTU is testing and optimizing components for the next generation of geared turbofan engines. To this end, the aerodynamic interactions between the high- and low-pressure compressor and the duct that connects them are being tested on what is known as a multistage 2-shaft axial compressor test stand.

Applied research with top-ranking universities

"Collaboration with top-performing universities is a given in research and development at MTU. Since MTU's experts are involved in day-to-day business, they have little time for basic research themselves. That's why MTU relies on collaboration with universities," explains Ann-Kathrin Jung, Program Coordinator Technology Partner Management at MTU.

As centers of competence, five German universities are bringing their specialist knowledge to the table, conducting both basic and applied research. This has the added benefit that MTU can recruit numerous excellent young professionals from these collaborations.

On the path to Industry 4.0

When it comes to production and industrialization technologies, the Fraunhofer-Gesellschaft and its 76 institutes serve as an ideal partner. MTU has been collaborating with several of these institutes for two decades now. The spectrum of joint activities ranges from the development of new materials and propulsion and manufacturing technologies to more efficient engine maintenance. The CoC Industrialization, which was just established in June 2022, will further deepen the collaboration between the two partners in the future.

"The special thing about the Fraunhofer Institutes is that they not only contribute important findings from research, but they also put them into practice together with our engineers," Jung points out.

Simulation professionals at Bauhaus Luftfahrt

When it comes to the complex system of aviation as a whole, the experts at Bauhaus Luftfahrt are the right partners to contact. Launched by MTU together with various partners back in 2005, this internationally oriented think tank aims to develop innovative approaches for future air transport systems. With the help of simulation models, its experts are working with MTU on configurations for future engines. A current example is MTU's revolutionary water-enhanced turbofan (WET) propulsion concept, a gas turbine engine with energy recovery and wet combustion.

MTU and Bauhaus Luftfahrt's collaboration on the WET concept is just one of their many joint projects. "The think tank is extremely versatile," Weckend says. "The team there has an impressively wide range of interdisciplinary contacts and comprehensive skills for evaluating the new aviation and propulsion concepts this network generates."

DLR – German Aerospace Center
CoC Future Propulsion Systems

RWTH Aachen
CoC Compressor and Manufacturing

University of Stuttgart
CoC Turbine Testing and Thermodynamics

Leibniz University of Hannover
CoC Turbine and MRO

Fraunhofer Gesellschaft
CoC Industrialization

Universität der Bundeswehr München
CoC Military Propulsion Systems

Technical University of Munich
CoC Design

Bauhaus Luftfahrt
Think Tank – Future Concepts

Mutually beneficial partnerships

Together with its partners, MTU is addressing long-term, cross-system issues in the field of engine development. This benefits both sides: it adds a more practical element to the basic research conducted by the research institutes, while allowing MTU to draw on their scientists' excellent expertise.

MTU belongs to a strong research network and pursues numerous cooperative ventures at the highest level. A selection of these are featured on the following pages. For more articles, please visit www.aeroreport.de/en.

MORE INFORMATION ON THE TOPIC:

MTU and Fraunhofer:
Research partners for
Industry 4.0
www.aeroreport.de/en

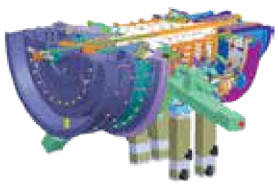
RESEARCH NETWORK: DLR AND MTU

A shared goal: Zero-emission aviation

Computer models, test labs and a fleet of research aircraft—at DLR's Institute of Propulsion Technology, MTU is testing and optimizing components for the next generation of geared turbofan engines.

Text: *Monika Weiner*

Two-shaft rig ___ *In spring 2023, three modules—stages of the high- and low-pressure compressors together with the duct that connects them—are scheduled to arrive at the test stand. These parts are assembled to form a test object, the "two-shaft rig."*



Right next to Cologne Bonn Airport sits the test lab operated by the Institute of Propulsion Technology at the German Aerospace Center (DLR). Inside, two electric motors—each with an output of five megawatts—are purring, oil pumps and measuring devices are hanging on the walls, and strands of cables are hooked up to a ten-meter test station in the center of the room. Everything is in place for real-world testing to begin. What's special about the "multistage 2-shaft axial compressor test facility," or M2VP for short, is that its two shafts can be driven independently from one another by the electric motors. Thanks to a combination gearbox, these motors can generate infinitely adjustable speeds of up to 20,000 revolutions per minute—it's even possible to have the shafts rotate in opposite directions. "This test setup is virtually unique. It enables us to examine and test the operating behavior of each test object under very realistic conditions," says Dr. Christian Tiedemann, Head of the Fan and Compressor department at DLR's Institute of Propulsion Technology. "Testing under these realistic conditions helps developers of new engines optimize the aerodynamics of their components, increase engine efficiency and reduce emissions."

Engine modules headed for Cologne

Researchers from MTU Aero Engines and its long-standing partner GKN Aerospace have already reserved a slot in Cologne: in spring 2023, three modules—stages of the high- and low-pressure compressors together with the duct that connects them—are scheduled to arrive at the test stand. It is hoped that the tests in Cologne, which will take place as part of Clean Sky 2, will verify the sought-after aerodynamic improvements. The components for the modules are currently being produced and packaged for their journey, which will begin in winter.

The inter-compressor duct: Making the interaction visible

When developing a highly efficient engine, it's particularly important to ensure that the high- and low-pressure compressors work in harmony. The two are connected by the inter-compressor duct (ICD), which gets progressively narrower from front to back, and it's essential to optimize the air flow in this duct. To save weight, and thus fuel, the engineers are trying to make the ICD as short as possible. At the same time, the ICD can't be too short because this would prevent the air from flowing along its inner wall as intended. When the air flow strays from the wall, vortices are produced, which in turn cause friction that reduces the engine's efficiency.

"A crucial point in engine development is achieving the balance of an ICD that's as short as possible while also offering optimum aerodynamics," explains Dr. Deni Nakaten, Module Team Leader for the two-shaft rig at MTU. "This balancing act starts with the initial designs and models and continues right though to the end of development, when we measure the interaction of air flows on the M2VP test stand."

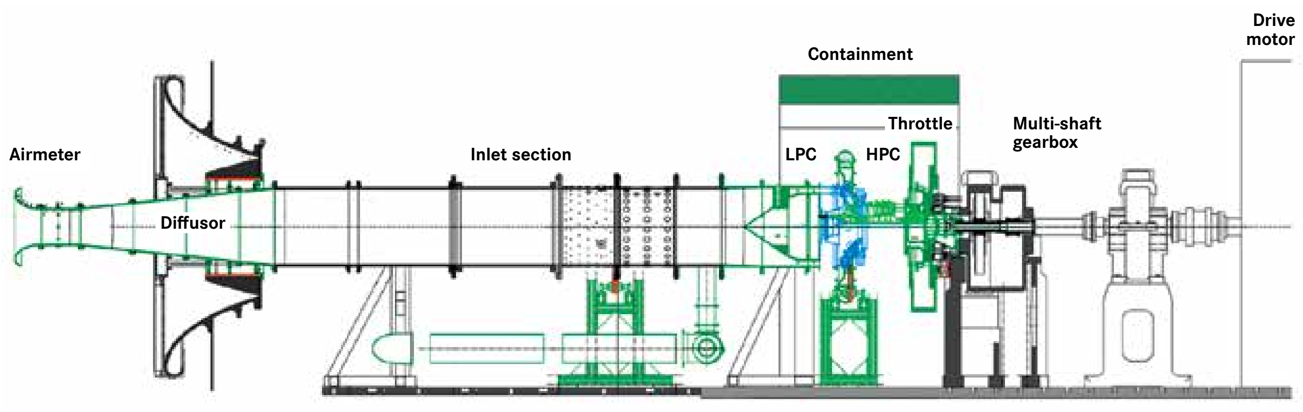
DLR

German Aerospace Center (DLR) ___
DLR is the Federal Republic of Germany's research center for aeronautics and space. It conducts research and development activities in the fields of aeronautics, space, energy, transport, security and digitalization.

DLR has 55 institutes and facilities and employs 10,000 people, who all share the same mission: to research the Earth and space and to develop technologies for a sustainable future. The Center develops solutions tailored to the aviation industry that enhance the current and next generations of technology.

DLR applies its research expertise in aviation as an overall system to pursue the aspiration of developing sound proposals for subsequent technology generations and thus pioneer new perspectives. MTU has been collaborating with DLR since the 1990s.

MULTISTAGE 2-SHAFT AXIAL COMPRESSOR TEST STAND (M2VP)



Stages of the high- and low-pressure compressors together with the inter-compressor duct (ICD) that connects them are assembled on the M2VP to form a "two-shaft rig." This makes it possible to measure the aerodynamic interactions between the modules: How do air flows from the high- and low-pressure compressors influence what happens in the ICD? This duct must ensure optimum air flow and at the same time be as short as possible to save weight and thus fuel.

Collaboration at every stage of development

At all these stages of development, MTU works closely with DLR: together the partners developed the TRACE aerodynamics simulation tool. TRACE can be used to produce 3D simulations of unsteady air flows in compressors and turbine elements, for instance, and help reduce waste and lower noise emissions. MTU engineers also used TRACE software to optimize the ICD for the next-generation geared turbofan currently being tested. Three years ago, the prototypes, which were manufactured in Munich, were assembled at DLR's Institute of Propulsion Technology in Cologne and put through their paces on a test stand specially designed for ICD rigs. "These tests helped us take a close look at the threshold at which the air flow strays. This model validation will be a key step in all future developments," Nakaten says. All that's missing now is an in-depth analysis of how the modules interact: How do air flows from the high- and low-pressure compressors influence what happens in the ICD? Do vortices occur that inhibit performance? Or is the air flow already ideal and increasing efficiency during flight?

The only way to answer these questions is to conduct experiments on the M2VP. At the DLR lab in Cologne, MTU engineers will have to reassemble all the individual parts and connect it to a "two-shaft rig"—the test object comprising the two compressors and the ICD. Once this rig has been integrated into the test stand, and all the modules have been connected to motors and sensor systems, the tests can begin. The first job will be to measure the aerodynamic interactions between the modules. After comparing the results with the computer models, the engineers can further optimize the design as needed.

Increase efficiency, avoid pollutants

"Ultimately, we're looking to minimize our climate-relevant emissions. A significant proportion is carbon dioxide, which can be lowered by increasing efficiency and thus reducing fuel consumption," says Dr. Martin Stadlbauer, Senior Vice President for Advanced Commercial and Military Programs at MTU. "Compared with the already very efficient first-generation models, the next generation of geared turbofans from the Pratt & Whitney GTF™ engine family are expected to emit significantly less carbon dioxide."

But enhancing geared turbofan technology is just one of many projects in which DLR researchers and MTU engineers are developing new technologies to make flying more environmentally friendly. The flying fuel cell (FFC), for example, is designed to convert hydrogen into electricity, which can then be used to power an aircraft. A prototype electric powertrain will be installed in a Do 228 research aircraft operated by DLR. Another pioneering propulsion concept is the water-enhanced turbofan, which utilizes residual heat from its exhaust gas. It uses a steam generator to vaporize water, which is then injected into the combustor. This kind of "wet" combustion increases the engine's efficiency and slashes nitrogen oxide emissions. "Our collaboration with DLR is fundamental to all these projects," says Dr. Arne Weckend, Technology Collaboration Representative at MTU. "In addition to having exceptional in-depth knowledge, the experts at DLR also have the requisite experience to assess aviation's impact on the atmosphere and climate."

Tiedemann adds that DLR also benefits from the collaboration with MTU: "We want to apply our research to make aviation cleaner. So it's important that we work with manufacturers to improve the efficiency of individual parts as well as entire engines and aircraft, and to develop practical solutions that will enable climate-neutral flight."

MORE INFORMATION ON THE TOPIC:

A brief guide: How the flying fuel cell works
www.aeroreport.de/en

A brief guide: How the WET concept works
www.aeroreport.de/en

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.

Collaboration on all levels

The list of collaboration projects is long and getting longer all the time. MTU engineers have been working closely with DLR researchers for many years on everything from researching new materials to developing new engine concepts.

To enhance the design of new engines, DLR and MTU together developed the TRACE simulation program. Its uses include optimizing the aerodynamic and aeroelastic properties of engine blades. TRACE helps improve an engine's efficiency and ensure the stability of the blades, which oscillate during flight due to the movement of the air.

Mathematical trick *The TRACE simulation tool allows engines to be optimized. TRACE can provide aerodynamics designers with a four-dimensional flow model within a matter of hours.*

Complex calculations *Today, the simulation tool helps map both laminar and turbulent air flows as well as their temporal progression, i.e., the fourth dimension.*

Another area of focus for the collaboration between MTU and DLR is researching the properties of new metallic materials and compounds. Simulations and extensive test programs conducted under realistic conditions help ensure that these new materials are suitable for use in engines.

The experts from MTU and DLR also collaborate on developing new kinds of protective coatings for engine parts. These coatings decrease the parts' thermal load during operation and increase their service life.

As part of other research projects, DLR and MTU engineers explore how an engine—or its interaction with the aircraft—affects noise emissions. The findings of this research provide the basis for new designs that help lower noise levels.

RESEARCH NETWORK: UNIVERSITIES AND MTU

High-tech research by the brightest minds

Applied research with excellent university partners serves as a key catalyst and source of knowledge for MTU—for example, for technology development in the field of maintenance.

Text: *Nicole Geffert*

“Technology development certainly isn’t standing still in maintenance either. We’re going to further optimize our overall MRO process and make it even more efficient.”

Dr. Jörn Städing, *Technology Coordinator MRO at MTU Maintenance Hannover*

MTU Maintenance Hannover’s test stands are bustling with activity. Here, overhauled engines undergo the necessary acceptance runs in quick succession. Integrating special tests for research purposes into this tight schedule requires smooth collaboration. Proof that this is possible has now been provided by MTU and teams from two of the company’s research partners: the Institute of Jet Propulsion and Turbomachinery (IFAS) at Technische Universität Braunschweig and the Institute of Turbomachinery and Fluid Dynamics (TFD) at Leibniz University Hannover (LUH).

“Our university partners put in a strong performance,” says Dr. Jörn Städing, Technology Coordinator MRO at MTU Maintenance Hannover. Their program included a complex back-to-back test, which involves comparing the test results of two different high-pressure compressor configurations. The test is part of a joint technology project between MTU and the IFAS. To this end, the IFAS V2500 research engine was set up on the MTU test stand twice within a few months and equipped with special measurement technology. Meanwhile, the TFD research team used the special test for an exhaust gas analysis. The novel method they tested for early detection of damage in the hot gas path involves measuring the exhaust gas stream optically.

Improved repair technologies

This experiment was part of a project in the Collaborative Research Centre (SFB) 871: Regeneration of Complex Capital Goods, located at LUH. Since 2010, an interdisciplinary team of scientists have been using the example of a commercial aircraft engine to investigate how complex capital goods can be repaired in an efficient and resource-saving manner. “This Collaborative Research Centre developed many different technologies relating to engine repair—from novel optical measurement methods to welding repairs and production planning processes,” says Dr. Michael Bartelt, Director Industrial Engineering at MTU Maintenance Hannover. “Working together with our university partners is extremely valuable for MTU as a maintenance specialist, and it shows just how effective an industry setting can be for making the link between fundamental research and practical application,” he continues.

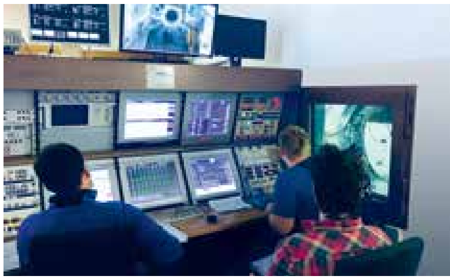
MTU has long maintained communications with SFB 871. “Technology development certainly isn’t standing still in maintenance either,” Städing says. “We’re going to further optimize our overall MRO process and make it even more efficient. What’s more, technological progress can also enable entirely new MRO products—for example, in the form of special maintenance services.”

Collaboration with top-performing universities and institutes is a given in research and development at MTU. These partnerships serve as a key catalyst and provide new knowledge. And because MTU’s experts are involved in day-to-day business, they have little time for basic research themselves. That’s why MTU relies on collaboration with universities.

Long-term, strategic partnerships

“MTU has established centers of competence with selected universities,” explains Ann-Kathrin Jung, Program Coordinator Technology Partner Management at MTU. “We maintain long-term, strategic partnerships with these universities and conduct special research projects in the

Equipped with special measurement technology — *On MTU’s test stand, the universities’ research teams conducted various tests on a V2500 engine.*



View from the control room — *The back-to-back tests carried out on the test stand involve comparing results from further test runs that are still planned.*

Competence and collaboration

MTU has joined forces with top-performing universities in Germany to establish centers of competence that bring the best minds together. Selected on a topic- and product-specific basis, these centers of competence conduct both basic and applied research. In addition, MTU has already been able to recruit numerous excellent young professionals from these collaborations.

RWTH Aachen:
Compressor and Manufacturing
MTU's research partners are the Laboratory for Machine Tools and Production Engineering, represented by the Chair of Manufacturing Technology, and the Institute of Jet Propulsion and Turbomachinery.

University of Stuttgart:
Turbine Testing and Thermodynamics
MTU experts cooperate here with scientists from the Institute of Aircraft Propulsion Systems and the Institute of Aerospace Thermodynamics.

Universität der Bundeswehr München:
Military Propulsion Systems
MTU conducts its research in close collaboration with the Institute of Jet Propulsion, the Chair of Electric Propulsion Technology and the Chair of Sensor and Measuring Systems.

Technical University of Munich:
Design
MTU is working on new technologies in collaboration with the Chair of Turbomachinery and Flight Propulsion, the Institute of Materials Science and Mechanics of Materials, and the Institute for Machine Tools and Industrial Management.

Leibniz University of Hannover / Laser Center:
Turbine and MRO
On the topic of maintenance, repair & overhaul (MRO), the collaboration partners for MTU in Munich and for MTU Maintenance Hannover are the Institute of Production Engineering and Machine Tools, the Institute of Materials Science, and the Institute of Turbomachinery and Fluid Dynamics (TFD) at Leibniz University Hannover (LUH), as well as the Laser Zentrum Hannover and Technische Universität Braunschweig with its Institute of Jet Propulsion and Turbomachinery. On the turbine topic, MTU works closely with TFD and LUH's Institute of Dynamics and Vibration Research.

area of our core competencies." In addition to the centers of competence, MTU collaborates with other top-class university partners on specific issues.

Many years of close collaboration and intensive, personal dialogue are every bit as important as academic expertise. In 2008, MTU joined forces with LUH and the Laser Zentrum Hannover to found the Maintenance, Repair & Overhaul Center of Competence and conduct joint research into future issues in repair development and maintenance strategy. Since 2019, Technische Universität Braunschweig and its IFAS institute have also been part of this center of competence.

"MTU's technological expertise and the high demands it places on us are what make this open and trusting collaboration so appealing," says Professor Jörg Seume, Executive Director of the Institute of Turbomachinery and Fluid Dynamics at LUH. The universities conduct research independently, but also in an application-oriented manner as part of the collaboration. For the research activities in SFB 871, MTU provided not only its test stand but also components that had been subjected to operational stress so that the research teams can study the effects of wear.

Transfer to industrial application

"By collaborating with MTU, we can test our methods in a real industrial environment," Seume says. As a result, over more than 12 years of challenging project work, the TFD team has gained a deeper understanding of the cross-component effects in an engine. Seume says: "Many results have reached a maturity that allows us to transfer them to industrial applications."

MTU is working with another excellent partner in the field of predictive maintenance: in 2006, it founded a joint center of competence for turbine testing and thermodynamics with the University of Stuttgart. MTU's research partners are the university's Institutes of Aircraft Propulsion Systems (ILA) and of Aerospace Thermodynamics (ITLR). At ILA, MTU can connect with scientists conducting research in the fields of lifecycle analysis, condition

Early warning system for engines *Engine Trend Monitoring, developed by MTU, monitors all important parameters in flight. Even the smallest deviations are detected and can be corrected in advance.*

Engine condition monitoring *At the University of Stuttgart's Institute of Aircraft Propulsion Systems (ILA), entire engines or their modules can be put into operation on test rigs. There, they are examined for their behavior at high altitudes using individual measuring instruments and high-performance computers.*

monitoring, structural mechanics and aeronautical propulsion systems of the future.

To monitor the condition of engines, MTU has developed engine trend monitoring (ETM), which monitors and evaluates important engine parameters measured in flight. The knowledge and experience gained from shop visits can be used to identify anomalies at an early stage and prevent engine failures. "The ETM system is being continuously developed, and ILA is an important partner for us in this process," says Jürgen Mathes, an expert in engine health monitoring at MTU Aero Engines.

Highly motivated university partners

In the future, instead of two to five discrete data points per flight, data will be recorded continuously. Experts use the term "full flight data" to refer to the recording of one data point per second. Making this 1 hertz data useful for ETM requires innovative methods from the fields of advanced data analysis and machine learning. Mathes says: "Developing these pioneering methods calls for a combination of expertise in aerospace propulsion and in data analytics."

And MTU can access this expertise at ILA, which is headed by Professor Stephan Staudacher. "At this stage of condition monitoring, algorithms and artificial neural networks both play an important role," he says. "Since we also conduct research in this area, we put MTU in touch with students and graduate students in this field, who develop solutions as part of a master's or doctoral thesis."

Mathes can see how motivated MTU's university partners are: "Together with our university partners such as the ILA, we are continuously developing new, forward-looking projects." This practical approach also enables MTU to secure young talent from universities at an early stage. For Staudacher, collaborating with MTU is part and parcel of a high-quality scientific education: "It lets young people learn the rules of such partnerships, as well as how to act in a reliable and trustworthy way." And he is pleased when graduates from his institute find interesting positions at MTU. "MTU's corporate culture makes it particularly attractive to young people," Staudacher says.

Mathes considers personal contact with the universities to be very important. Accordingly, he has agreed to give a lecture at ILA on ETM in practice—and will also be taking the opportunity to draw attention to MTU as a technology leader and innovative employer.

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.

RESEARCH NETWORK: BAUHAUS LUFTFAHRT AND MTU

Collaborating on the future

In collaboration with Bauhaus Luftfahrt, MTU is developing configurations for new low-emission engines. A current example: the water-enhanced turbofan, or WET for short.

Text: *Monika Weiner*

Water-enhanced turbofan
The WET concept draws on the residual heat from its exhaust gas. It uses a steam generator to vaporize water, which is then injected into the combustor. The water for this is extracted from the exhaust gas by means of a condenser and then separated. This kind of "wet" combustion slashes nitrogen oxide emissions, as well as fuel consumption, CO_2 *emissions and contrail formation.*

What will tomorrow's aircraft look like? Engineers from MTU Aero Engines and the aviation think tank Bauhaus Luftfahrt have been working hard in small online teams to come up with technology and design proposals. They have had full conceptual freedom to explore where their ideas might take them. Now, they have all gathered in the same conference room at the Ludwig Bölkow Campus in Taufkirchen near Munich and the first of nine concepts is being projected onto the wall.

Today is all about tomorrow's propulsion concepts. The evolutionary development of the gas turbine will not be enough to meet the Paris Agreement's ambitious target of limiting global warming to, ideally, an increase of 1.5 degrees Celsius compared to preindustrial levels. What's needed are revolutionary propulsion concepts. One such concept is the water-enhanced turbofan, or WET for short. This is expected to mark a massive reduction in all factors that have a negative impact on the climate: CO_2, nitrogen oxides and contrails. Compared to today's aircraft engines, the gas-turbine-based WET technology would also be significantly more efficient because it harnesses residual heat from the engine's exhaust gas stream.

But what would this kind of turbofan have to look like? And how would it be integrated into an aircraft? Should it be installed on the underside of the wings like a conventional engine? Or will it have to be integrated very differently and thus change the design of the entire aircraft? "The WET concept is a revolutionary idea that is still in the early stages of development, which is precisely the right time to ask these questions," says Fabian Donus, Innovation Manager at MTU. "Our collaboration with Bauhaus Luftfahrt helps us find answers to these questions: the team there has the skill required to integrate our engine designs into the overall aircraft model. This is the only way to identify the optimum design."

Programs that see what does not yet exist

Labs, measurement devices and test facilities are nowhere to be found at Bauhaus Luftfahrt in Taufkirchen near Munich. Instead, employees at the Ludwig Bölkow Campus work in offices, doing most of their research on a PC. "We use programs that let us simulate things like aerodynamic behavior and determine key design parameters such as resistance, weight and efficiency—long before an aircraft is built. This is also how we calculate the WET concept's energy requirements, fuel consumption and climate impact," explains Dr. Jochen Kaiser, Head of Visionary Aircraft Concepts at Bauhaus Luftfahrt. "Changing the design of an aircraft and its engine can either enhance or worsen these KPIs. That's why it's so important that early on in development we simulate whether a concept has what it takes to save energy and reduce climate impact."

The Bauhaus engineers specialize in this kind of simulation, having spent many years building up the necessary skills and methods for creating a conceptual aircraft design. They make it possible to evaluate how new propulsion concepts will

"We use programs that let us simulate things like aerodynamic behavior and determine key design parameters such as resistance, weight and efficiency—long before an aircraft is built."

Dr. Jochen Kaiser, *Head of Visionary Aircraft Concepts at Bauhaus Luftfahrt*

Specialists in such simulations — *Bauhaus Luftfahrt is a nonprofit research institution. Its members are Airbus, IABG, Liebherr-Aerospace, MTU Aero Engines, as well as the Bavarian State Ministry of Economic Affairs, Regional Development and Energy and since 2020, the German Aerospace Center (DLR) as well.*

affect the aircraft's overall design. Ultimately, this also provides early insights into the performance and improved environmental impact of future commercial aircraft.

The experts at Bauhaus have calculated the performance data for all of the engine-aircraft configurations being considered for WET. "The appeal of the simulations is that we can try out anything we like. Since it's all virtual, we can visualize and evaluate the various options. That's a massive help when making a decision," says Dr. Sascha Kaiser, Lead for Water-Enhanced Turbofan at MTU. The winning design features engine nacelles, which—as is customary—can be installed on the underside of the wings. This solution offers several advantages: it requires only slight modifications to the aircraft, it means the engine is easily accessible and it is compatible with existing airport infrastructure.

Support from the multidisciplinary think tank

MTU and Bauhaus Luftfahrt's collaboration on the WET concept is just one of their joint projects. "The think tank is a prime example of multidisciplinary collaboration," says Dr. Arne Weckend, Technology Collaboration Representative at MTU. "Founded by a group of different players in the industry—manufacturers of engines, aircraft and aircraft systems as well as the state of Bavaria—the think tank works closely with airport operators and fuel developers. This means that the team there has an impressively wide range of interdisciplinary contacts and comprehensive skills for evaluating the new aviation and propulsion concepts this network generates."

"The appeal of the simulations is that we can try out anything we like. Since it's all virtual, we can visualize and evaluate the various options."

Dr. Sascha Kaiser, *Lead for Water-Enhanced Turbofan at MTU*

Bauhaus expertise has also helped shape MTU's Claire technology agenda: Bauhaus experts were at the table back in 2007, when the first version of Claire—which stands for Clean Air Engine—was drafted. In addition to reducing noise levels and exhaust emissions that are harmful to people's health, the focus was on the fuel consumption of the various engine concepts. Bauhaus was also involved in this year's update—emissions-free flight is now a Claire goal.

Simulations for emissions-free aviation

But will this actually happen? Together, the partners have come up with a number of ways to dramatically reduce aviation's climate impact in the future, and developing the WET technology is one of them. However, the first product isn't expected to be available until around 2035. First, its potential will have to be proved and its feasibility verified.

In the short term, extensive use of sustainable aviation fuels (SAF) will help reduce emissions; these green fuels can already be added to standard kerosene. SAF can also be used to power the water-enhanced turbofan. In the near future, all aircraft are to run on 100 percent SAF—double the maximum proportion that is currently approved. “The simulations produced at Bauhaus Luftfahrt show that using 100 percent SAF would very likely prove relatively straightforward, requiring only minimal modifications to engines and aircraft,” Donus explains. “What’s more, existing airport infrastructure could probably remain in place.”

In the long term, another concept will also be launched: the flying fuel cell, or FFC for short. Developed by MTU, the FFC converts liquid hydrogen into electricity, which a highly efficient electric motor then uses to drive the propellor. This has the benefit of emitting zero CO_2, nitrogen oxides or soot particles. Since its only emission is water, the FFC is virtually emissions-free. Using hydrogen as a fuel, however, calls for new aircraft designs; hydrogen tanks are much larger than kerosene tanks and must have additional insulation. In commercial aviation, minimizing the volume of hydrogen on board means it must be used in its liquid form—at minus 253 degrees Celsius. In addition to working on a variety of design proposals, the Bauhaus team is currently evaluating how the production, transport and distribution of hydrogen affects the environment and the cost.

“Each approach has its pros and cons and will have to be judged on its own merits,” Jochen Kaiser says. “Our simulations ought to help the decision-making process by revealing the extent to which the various technologies can reduce emissions in aviation and in what timeframe.” Dryly, he adds that not even Bauhaus Luftfahrt can predict that on the spot. “Our goal is to provide the aviation industry with realistic assessments of its technology options for the coming decades. This will indicate ways of making emissions-free flight a reality.”

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.

Bauhaus Luftfahrt
The Aviation Think Tank

Bauhaus Luftfahrt was founded as a registered association in 2005. It is a nonprofit research institution and derives its name from the original Bauhaus in Dessau. Its members are four renowned aviation companies—Airbus, IABG, Liebherr-Aerospace and MTU Aero Engines—as well as the Bavarian State Ministry of Economic Affairs, Regional Development and Energy. The German Aerospace Center (DLR) was added as a funding member in 2020.

Bauhaus Luftfahrt focuses on major societal and ecological challenges of our time and identifies long-term options for a sustainable and climate-neutral air transport. Like a radar system, it identifies relevant and innovative topics at an early stage. With a high level of creativity, the researchers provide radical and disruptive ideas with a foresight and trendsetting function for the entire aviation ecosystem.

Initial integrated potential analyses can be carried out as well as quick assessments in different evaluation dimensions (technical, economic and ecological). This flexibility and interdisciplinarity creates an overall system understanding and a combination capability that is unparalleled in the national and international aviation industry.

In-flight research

DLR's new research aircraft, "Do 228" D-CEFD ___ *The "Do 228" will be used to test a 600-kilowatt electric powertrain that MTU Aero Engines developed to replace one of the conventional engines.*

Research aircraft give us new insights into how aviation affects the climate. By enabling us to test new technologies, they help us accelerate the shift toward emissions-free flight.

Text: *Monika Weiner*

Research in flight — *On each test flight with DLR's HALO research aircraft, four scientists operate the total of twelve instruments on board, which are used to study the chemical composition of the air.*

German Aerospace Center (DLR) — *The German Aerospace Center (DLR) is the Federal Republic of Germany's research center for aeronautics and space.*

NASA — *NASA (National Aeronautics and Space Administration) is an agency of the U.S. federal government responsible for the civil space program and aeronautics research.*

Why are research aircraft an important part of helping reduce aviation emissions?

Making aviation cleaner is an important goal. To achieve it, engineers need more information on the types and quantities of atmospheric pollutants aircraft emit and the extent to which new engines or propulsion technologies can reduce these emissions.

Research aircraft can be used to investigate which substances jet engines release into the atmosphere during flight. By conducting in-flight emission tests, researchers can measure the emissions of various substances, including water, greenhouse gases, particulate matter and soot. As well as determining the timing and quantity of such emissions, these tests also detect the formation of contrails.

What do research aircraft look like?

Research aircraft are like flying laboratories. Equipped with comprehensive sensor systems and analytical tools, they can measure an array of in-flight parameters, including temperature, wind, air quality, pollutants and cloud density. Most research aircraft are commercial or business jets that have been converted to accommodate measuring instruments and computers. Depending on the equipment they carry, they can be used for a wide variety of scientific missions ranging from climate research to Earth observation. However, only a very few research aircraft are able to measure commercial aircraft emissions in the air, among them NASA's McDonnell Douglas DC-8 and the German Aerospace Center's Falcon 20-E5.

Flying in the plume of another aircraft is a major challenge for the crew

To measure the emissions of a commercial jet during flight, a research aircraft must fly directly behind it. Flying so close on the tail of another aircraft is tremendously challenging for both the crew and the aircraft, because the passage of the commercial jet in front of them causes significant turbulence. This wake turbulence—also known as wake vortices—is a result of the lift generated by the wing and is produced by all aircraft during flight. The combination of high pressure under the wing and low pressure on top of the wing leads to the formation of two counter-rotating vortices at the tip of each wing. These vortices can be extremely hazardous to any traffic following in an aircraft's wake. NASA's Douglas DC-8, for example, must maintain a distance of several miles from the aircraft ahead for safety reasons. Only the most robust and highly maneuverable aircraft, such as the German Aerospace

Center's Falcon 20-E5, can measure emissions directly in an aircraft's exhaust plume. Pilots must undergo dedicated, specialist training before they can fly this kind of mission. Aircraft used for this purpose must be inspected after each use due to the high stresses involved.

What measuring equipment do research aircraft have on board?

The specific equipment depends on the type of aircraft and the mission objectives. For example, the Falcon 20-E5 is equipped with a nose boom. This contains meteorological sensors that provide highly accurate readings of the wind direction in three dimensions, as well as humidity, pressure and temperature. During the flight, ambient air is channeled into the aircraft through inlets on the fuselage and analyzed for trace gases. At the same time, underwing probes are used to detect particulate matter including soot and ice particles.

The High Altitude and Long Range Research Aircraft (HALO)—a Gulfstream G550 business jet—has all the necessary equipment on board to study basic atmospheric physics. HALO is a significantly larger atmospheric research aircraft that includes 20 inlets to carry air to on-board instruments. It has viewing windows up to 50 centimeters in size through which lasers can be fired to measure the properties of clouds.

What new insights do emission measurements offer?

Research flights conducted over recent years have confirmed the feasibility of reducing aviation emissions. One way of achieving

Using aircraft for scientific research

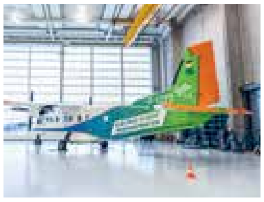
There are only a few dozen research aircraft worldwide. Most of them are operated by research institutions or government agencies such as NASA and the German Aerospace Center (DLR). Europe's largest fleet, comprising 12 research aircraft, is operated by DLR. It includes the High Altitude and Long Range Research Aircraft (HALO), which is specially equipped for atmospheric physics research, as well as the small and extremely maneuverable Falcon 20-E5, which can fly directly in a jet aircraft's exhaust plume at a distance of only a few hundred meters. NASA's DC-8 can also be used to measure in-flight emissions, but it has to remain at a greater distance from the aircraft in front due to its size.

High Altitude and Long Range Research Aircraft ___ *The HALO research aircraft opens a new chapter in the history of German atmospheric research and Earth observation. HALO is based on a Gulfstream G550 ultra-long range business jet.*

Dassault Falcon 20-E5 ___ *The aircraft operated by the research department in Oberpfaffenhofen is for experiments in environmental and climate research. Due to its layout and compact design, this Falcon is highly maneuverable.*

Douglas DC-8 ___ *NASA operates a heavily modified Douglas DC-8 jetliner as an airborne science laboratory. It collects data for projects that serve the world's scientific community.*

Refueling the A350 ___ *At the Toulouse site, the Airbus A350-900 is refueled for its first flight with 100 percent sustainable aviation fuel.*



DLR's new research aircraft, "Do 228" D-CEFD ___ *The new DLR research aircraft will be used to test electric propulsion systems.*

this is by using sustainable aviation fuels (SAF), which contain no aromatics or sulfur and can be produced using renewable energy. During the 2018 mission, in which NASA's Douglas DC-8 followed a DLR Airbus A320 fueled with a 50-percent blend of SAF and conventional jet fuel, the researchers discovered that the soot emissions were lower than those of an aircraft powered solely by conventional fuel.

Even fewer soot particles were measured during the 2021 research mission, in which DLR's Falcon 20-E5 followed an Airbus A350 fueled solely by SAF. This is important, because water vapor from a jet's exhaust and from the atmosphere can condense onto soot particles. If the ambient air at an altitude of 8 to 12 kilometers is cold enough, these droplets then turn into ice crystals that form contrails, which can remain in the sky for several hours. These contrails reduce Earth's radiation of heat into space, thereby contributing to global warming. Thus, less soot ultimately means fewer contrails, which is good for the climate.

Is emissions-free flight possible?

Hydrogen is a clean alternative to conventional fuels. It can be produced sustainably with green energy and then converted into electricity in the aircraft using a fuel cell. The only byproduct of this process is water. The electricity generated by the fuel cell can be used to power a propulsion system consisting of an electric motor and propeller. However, this requires the use of entirely new electric propulsion technology.

MTU Aero Engines is currently working with DLR to develop this technology. MTU engineers are already working on a 600-kilowatt electric powertrain that is due to be tested in a DLR Do 228 research aircraft. For safety reasons, only one of the engines will be replaced by an electric motor; in an emergency, the aircraft will still be able to fly and land using the second turboprop engine. Test flights are scheduled to start in the middle of the decade.

What contribution could research aircraft make to aviation in the future?

As well as achieving emissions-free flight, researchers are also keen to make aircraft more efficient in the future by improving the physics of flight. For example, one way to reduce fuel consumption and minimize contrails would be to improve aerodynamics while simultaneously optimizing flight paths. The Falcon 2000LX ISTAR airborne research platform is designed to help achieve this goal. ISTAR—which stands for

Test of the cloud probe on the Falcon 20E ___ *Prior to a flight of this DLR research aircraft, the cloud probes are tested. These measure physical properties of the ice crystals in the contrail during flight.*

HALO ___ *DLR researchers have twelve instruments on board for a HALO test flight.*

In-flight Systems & Technology Airborne Research—is a next-generation research aircraft that enables researchers to test the properties of new aircraft designs on a digital twin during development and then again under real-world operating conditions. The aim is to make aircraft development faster and cheaper, much as in the automotive industry, which uses computer models to conduct virtual vehicle testing long before the first real-life crash tests take place.

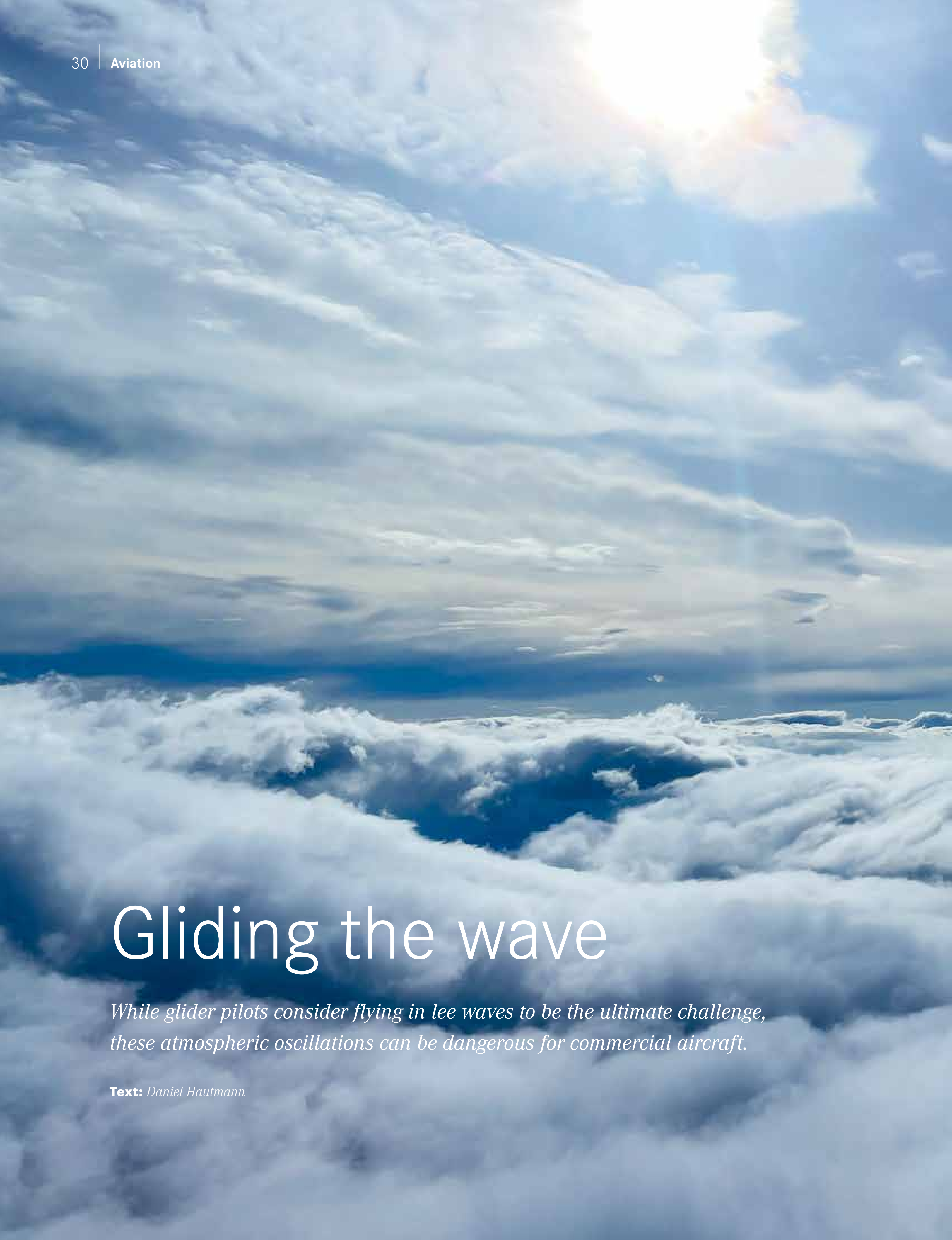
TEXT:

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.

MORE INFORMATION ON THE TOPIC:

SAF on the test stand
www.aeroreport.de/en

DLR tests new quiet approach procedures
www.aeroreport.de/en



Gliding the wave

While glider pilots consider flying in lee waves to be the ultimate challenge, these atmospheric oscillations can be dangerous for commercial aircraft.

Text: *Daniel Hautmann*

Efficiency champions — *Gliders achieve a glide ratio of 1:70, meaning that for each meter of descent, they can glide for up to 70 meters.*

Silence. Heavenly silence. Only moments ago, turbulence shook the aircraft and lifted passengers out of their seats. The wings bent as the wingtips quivered in the wind. Howling and roaring. But, suddenly, above the clouds: silence.

"Now we're in the wave," pilot Klaus Ohlmann explains. But getting there was taxing. After all, the weather conditions in the southern French Alps on this day in May are anything but ideal for gliding: the clouds are low, the wind is weak and there is a risk of thunderstorms. But all that only seems to encourage Ohlmann, the record-breaking pilot. "This is my training," he says. "Anyone can fly in good weather."

And here is how he showcases the high art of flying: After a two-minute engine launch, his glider soars on the ridge upwind of the 1,000-meter-high Arambre in southern France, right next to the airfield. He keeps the aircraft very close to the cliff edge just above the trees. A slight ascent. Then he spirals upward, exploiting the thermal lift. At an altitude of 2,400 meters, Ohlmann finally hits the lee wave.

Lee waves form when the terrain, e.g. mountains, deflects the wind. This creates atmospheric oscillations. The stronger the wind and the higher the barrier, the higher the waves rise—sometimes up to 100 kilometers. It is these laminar flows that glider pilots surf.

Danger for commercial aircraft

Lee waves can be dangerous for commercial aircraft. The turbulence they cause can damage the aircraft and injure passengers. The waves can break—just like ocean waves at the beach. Maps or forecasts are not readily available yet. But this is set to change. The glider pilots in their research aircraft study the phenomenon and collect data.

To illustrate the nature of invisible currents, Ohlmann likes to take other pilots to a stream: "The water doesn't just flow downstream, but whirls and forms swirls behind the rocks. Sometimes it flows in the opposite direction. Air behaves in much the same way."

Twenty years ahead of commercial aviation

Gliders are efficiency champions. They achieve a glide ratio of 1:70, meaning that for each meter of descent, they can glide for up to 70 meters. Modern commercial aircraft don't even come close. The best they can manage is a ratio of 1:20—and even that requires a huge amount of fuel. Motorized flight causes around 2.5 percent of global CO_2 emissions. The industry is working hard to deliver the kind of radical solutions that will improve aviation for the long term.

And it is taking its cue from gliders, among other things. "On the one hand, it's a very technical sport; on the other, we make sparing use of natural resources and clever use of the forces of nature," says Tilo Holighaus, CEO of glider manufacturer Schempp Hirth in Kirchheim unter Teck. In fact, it is gliders that have been showing commercial aircraft the way forward in terms of technol-

26-meter wingspan — *A need for space: The Nimbus 4DM has brought Klaus Ohlmann to record-breaking heights.*

ogy and aerodynamics. "We're 20 years ahead of commercial aviation."

The year 1957 saw the launch of the first aircraft made from synthetic materials: the fs 24 Phoenix glider. And it was fully thirty years ago that gliding underwent the next fiber revolution: carbon. These highly robust yet lightweight aircraft also lend themselves to testing new propulsion systems. Electric, hybrid and fuel-cell powertrains were first installed in gliders.

"Professional pilots who also fly gliders have a much better understanding of weather dynamics because they're directly dependent on atmospheric movements while gliding," Ohlmann says. This means that they are more versed in handling emergency situations, which can save lives, as the spectacular emergency landing of an Airbus in the winter of 2009 demonstrated. After an engine was damaged, Chesley Sullenberger, an experienced glider pilot, safely landed his Airbus A320 on New York's Hudson River—by gliding.

26-meter wingspan, 830 kilos

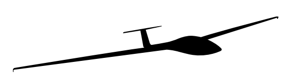
The aircraft Ohlmann steers into the lee wave over southern France is a Nimbus 4DM, a high-performance glider with a wingspan of 26 meters, a weight of only 830 kilos and a glide ratio of 1:60. "It's one of the best gliders in the world. I've done countless record flights in this model," he says, gliding along the outer edges of the clouds—at a speed of 135 km/h while climbing two meters.

Gliders lend themselves particularly well to test and research flights: they are cheap to operate and able to withstand enormous forces. This is evidenced by the 2018 altitude record of 23,200 meters set by "Airbus Perlan Mission 2." In rarefied air, aircraft must fly extremely fast to produce enough lift. While they fly at a speed of 200 km/h when close to the ground, their airspeed at high altitudes is 450 km/h. This entails risks: the aircraft may stall or shake and run into serious difficulties. Add to that freezing temperatures and a lack of oxygen. That's why the two Perlan pilots flew in a pressurized cabin. This particular high-altitude flight served to study lee waves and to collect data for climate research as well.

Higher, further, faster

Ohlmann, too, is interested in more than just breaking records. He is a detective, a researcher looking for "missing links." That's what he calls the paths that connect different lee waves. He is more skilled at this than any other glider pilot. In May 2021, he demonstrated where this can lead.

Nimbus 4DM: one of the best gliders in the world

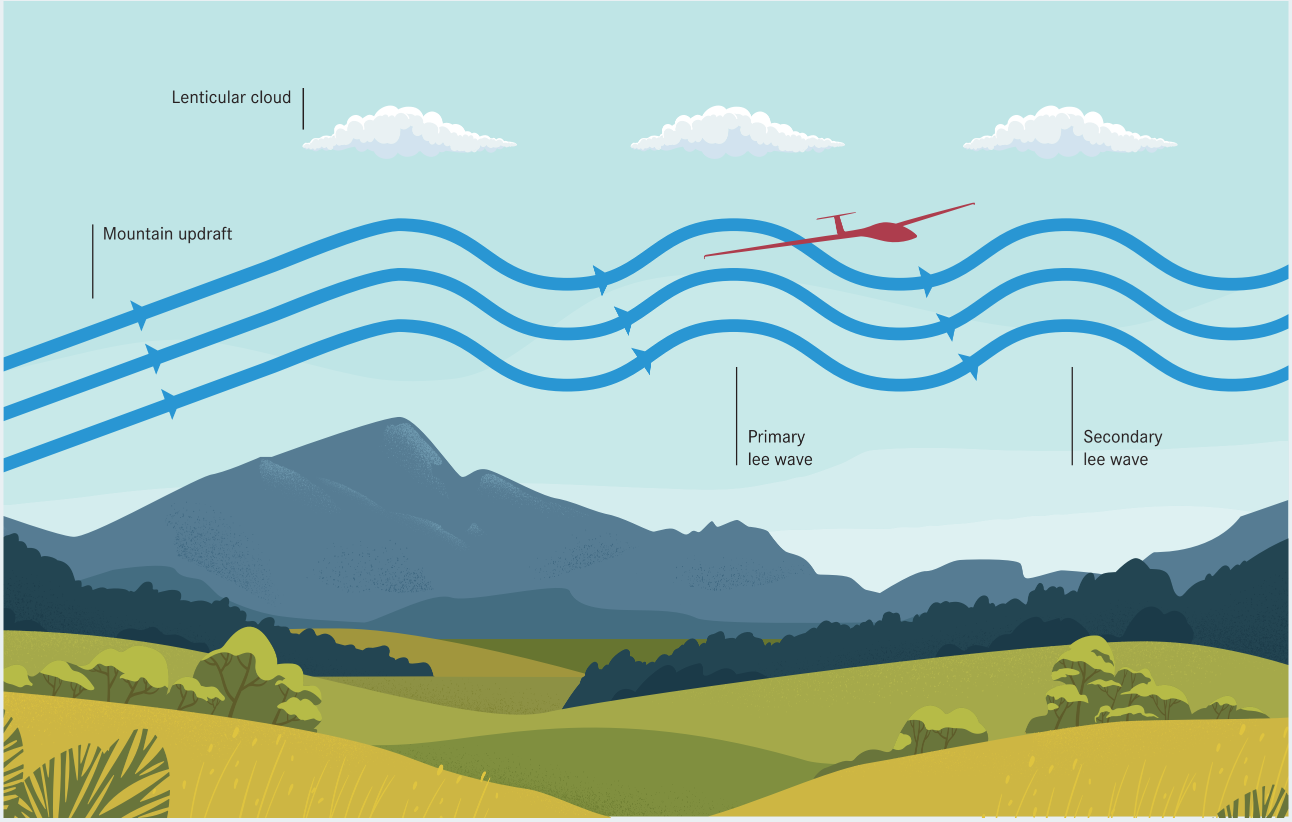


26 meters
wingspan

1:60
glide ratio

830 kilos
weight

Lee waves



Gliding the wave — *If a strong wind blows over an extensive mountain range, air waves can develop on the side facing away from the wind (leeward side), similar to the way water in a stream churns on the other side of an obstacle in the streambed. There the water doesn't just flow downstream, but whirls and forms swirls behind the rocks. The same thing happens in the air: the stronger the wind and the higher the barrier, the higher the waves rise–sometimes up to 100 kilometers. Gliders can thus use the rising areas of these "lee waves" to climb to tremendous heights. Sharply defined, lenticular (lentil-shaped) clouds mark the wave crests.*

Wave crests — *Lee waves can often be recognized by special cloud formations that visually indicate a wave-like air movement.*

Lentils in the sky — *Lenticular clouds get their name from the Latin for lentil-shaped; they are often very elongated and usually have well-defined edges.*

Starting at an altitude of 6,000 meters, he glided from southern France across the sea all the way to Corsica, and then on to the Apennines and down into the toe of the boot of Italy. From there, starting at an altitude of 7,500 meters, he glided the 300 kilometers to Greece—where he caught the next wave, which carried him all the way to Thessaloniki. After 15 hours and 1,750 kilometers, he finally landed. “For a flight like this, the weather has to be perfect, like a custom-made suit,” he says. He had trained years for this, observed the weather, studied the waves. As if that weren’t enough, Ohlmann dreams of doing a 2,000-kilometer flight in Europe: he intends to extend his record flight, continuing from Thessaloniki to Crete, at the next opportunity.

In Lindbergh’s footsteps

For several years, Ohlmann has been committed to electric flight so as to be better able to bridge the aforementioned missing links—and to do his bit to make aviation more sustainable. His Stemme S10 VT glider is currently being fitted with an electric motor and a range extender, a small combustion engine that runs on sustainable aviation fuel and recharges the batteries during the flight. This more than doubles the aircraft’s range to a respectable 3,000 kilometers without changing the tank volume. Ohlmann plans to circumnavigate the globe in this aircraft and set altitude records here and there. For instance, in the Himalayas: “All eight of Nepal’s eight-thousanders in one day!” At a later stage, the combustion engine is to be replaced by a fuel cell—followed by another round-the-world flight.

Ohlmann also has another, very special project up his sleeve, one that follows in the footsteps of Charles Lindbergh. In 1927, Lindbergh flew nonstop from New York to Paris—a distance of 5,808.5 kilometers. On his 33.5-hour flight in the “Spirit of St. Louis,” Lindbergh had 1,705 liters of fuel in his tank. Klaus Ohlmann is certain that his flight will be much more fuel-efficient, requiring no more than 250 liters.

Klaus Ohlmann ___ *The 70-year-old has been flying for 50 years. Born in western Bavaria, he learned how to fly in Braunschweig, where he trained as a dental technician before studying in Göttingen. At the age of 50, he sold his dental practice to become a professional pilot and moved to southern France.*

Today, he holds 66 world records, 7 world championship titles and has over 30,000 flight hours under his belt. He flew across the Andes at an altitude of 12,500 meters, traveling a distance of 3,000 kilometers. Ohlmann was the first person to glide over Mount Everest, and he holds the record for the longest distance flown in an electric plane: over 1,000 kilometers.

“Gliding is constant risk management,” Ohlmann says. “You have to constantly observe and reassess the weather as well as yourself and adapt to changing conditions—that’s what’s so exciting about it.” He describes this as an “accumulation of experience” and refers to himself as an “applied meteorologist.” And he passes on his knowledge: you can fly with him, attend his lectures or listen to him give a keynote address.

Whenever a research institute like DLR or an aircraft manufacturer requires an experienced pilot, they call Ohlmann. As recently as April 2022, he set two new world records flying the e-Genius, the University of Stuttgart’s hybrid-electric research aircraft.

AUTHOR:

Daniel Hautmann is a freelance journalist. He flew gliders growing up, but has since developed a passion for surfing. Even though he now prefers the water, he devoted an entire book to the wind.

Flying the extra mile

The Airbus A321XLR is a new class of long-haul aircraft—for the first time, a narrowbody jet can stay in the air for up to eleven hours.

Text: *Andreas Spaeth*

June 15, 2022:
The maiden flight of the Airbus A321XLR opens up new market potential: in the future, this narrowbody jet will be able to cover distances of up to 8,700 km.


A321XLR
A321 AIRBUS
F-WXLR

A321XLR maiden flight ___ *After landing, a good hundred guests and employees greet the crew with loud cheers.*

“We will see increasing fragmentation of long-haul routes with this new aircraft, which overall leads to increased market potential and growth. This market segment will open up new routes and in turn entice new competitors, for example those in India with flights to eastern Europe.”

Marko Niffka, *expert for Business Development – MRO at MTU*

Employees and guests are lined up close to the apron, and all eyes turn toward the end of the runway close to the Elbe river. Queen Mary 2, one of the world’s biggest cruise liners, passed by there only minutes ago. Soon, there will be an important moment in recent Airbus history to be witnessed here in Hamburg-Finkenwerder: the maiden flight of the new best-selling A321XLR, the first narrowbody aircraft for long-haul routes of up to eleven hours of flight time. From the outside, the A321XLR looks no different from an ordinary Airbus A321 or its successor, the A321neo.

Things suddenly start to move quickly on this sunny morning of June 15, 2022. The plan had been for the chase plane to take off first, but unexpectedly for the onlookers, it’s the A321XLR prototype (serial number 11000, registration F-WXLR) that first gets going at 11:05 a.m. local time, before it accelerates and then takes off practically right in front of the rows of spectators. A total of 1,500 employees from Airbus and its suppliers worked for 18 months to make this happen. “This is something we’ve really been looking forward to. It’s a significant moment and I can truly feel how special it is,” says Michael Menking, Head of the Airbus A320 Family Program, just before the aircraft leaves the nearby runway.

Lower operating costs, less economic risk

Almost three decades after its first flight at the same location, the A321 program is experiencing a boom in its new long-haul version (XLR stands for extra-long range). One reason is that, following the test campaign being launched now, it is expected to be uniquely positioned by early 2024 in a completely new market segment: flying actual long-haul routes of up to 8,700 km with full payload. Even more impressive, it does this as an aircraft with just one aisle, not the usual two of the widebodies normally deployed on such routes. This lets airlines enjoy not only lower operating costs, but also considerably less economic risk: in the cabin configurations planned for long-haul routes (usually offering a luxurious business class cabin with individual lie-flat suites), only 174 or 187 seats have to be filled. In current widebodies, airlines usually need to fill far more than 200 seats, or sometimes even more than 300 or 400.

Long-haul comfort on a narrowbody jet

Only a few kilometers away from the first flight, the Aircraft Interiors Expo is taking place at the Hamburg fairgrounds. Narrowbodies for long-haul routes are a big topic here, too. Many seat suppliers are racing to adapt their premium cubicles—originally conceived for widebodies—to smaller jets, sliding doors and all. Following the example of U.S. airline JetBlue, which serves transatlantic routes with an A321LR (LR stands for long range), many airlines will equip the first row of narrowbody cabins with two spacious suites.

The new long-haul aircraft class enables nonstop routes that were previously unprofitable while also sparing passengers tiresome hub connections. Airbus has named the following possible destinations for nonstop flights from Hamburg or other western European airports: Orlando (USA), Punta Cana (Dominican Republic), Nassau (Bahamas), Mahé (Seychelles), Male (Maldives) or Vancouver (Canada). Airlines such as Aer Lingus, SAS and TAP Air Portugal are already operating the A321LR—the previous model and the first one suitable for long-haul flights, with a range of up to 7,400 km—over the North Atlantic and even all the way to Brazil. On the day of the XLR's maiden flight, exactly 508 jets of the new type were ordered; the most important customers are IndiGo, United Airlines and American Airlines, as well as Wizz Air and Iberia from Europe.

Signs point to increasing fragmentation of long-haul segment

"We will see increasing fragmentation of long-haul routes with this new aircraft, which overall leads to increased market potential and growth," says Marko Niffka, expert for Business Development – MRO at MTU. "This market segment will open up new routes and in turn entice new competitors, for example those in India with flights to eastern Europe." One engine option of the A321XLR is the PW1100G-JM, part of the Pratt & Whitney GTF™ engine family. In September 2022, the A321XLR took off for the first time with the geared turbofan. "This is a very attractive global market segment for us at MTU and will further contribute to the success of the geared turbofan, or GTF, as it will bring new airlines to this market and encourage existing carriers to expand further into this segment," Niffka says. "What makes the GTF so

September 23, 2022 —— *The Airbus A321XLR takes off for its first flight with the PW1100G-JM, part of the Pratt & Whitney GTF™ engine family.*

Flight crew —— *(left to right) Philippe Pupin, Gabriel Diaz de Villegas Giron, Mehdi Zeddoun, Thierry Diez, Frank Hohmeister.*

Powerful engine for the Airbus A321XLR: PW1100G-JM

With a maximum thrust of 35,000 pounds, the PW1100G-JM is already in use with the A320neo family and will also power the new long-haul jet in the future. It is part of Pratt & Whitney's highly successful GTF engine family.

MTU Aero Engines, with a program share of 18 percent, is responsible for the high-speed low pressure turbine and the first four stages of the high-pressure compressor. It also carries out the final assembly of one-third of the production PW1100G-JM for the A320neo at its Munich site. These engines are maintained at MTU Maintenance Hannover, MTU Maintenance Zhuhai, EME Aero and MTU in Munich.

The GTF engines are synonymous with efficiency and economy. Compared to the previous engine generation, the GTF engines represent a reduction in carbon dioxide emissions of up to 20 percent with a noise footprint that is 75 percent smaller.

valuable here is its fuel efficiency. Without the GTF, an aircraft needs to carry more fuel, which wouldn't have been possible in a narrowbody on long-haul routes due to limited space."

Here the MTU expert names the most decisive difference of the XLR versus the standard model: extra fuel tank capacity. An A321 can usually take 19 metric tons of fuel on board, but the XLR adds a rear center tank holding 12,900 liters, or about 10.6 metric tons, of fuel. Additionally, if XLR customers really want to exploit the full range, another tank can be installed in front of the wings like a container in the cargo hold, taking on yet another 3,120 liters or 3.2 metric tons. About half the customers are requesting this option. With almost 14 metric tons of extra fuel, the aircraft can fly much farther, but also gains up to 8 metric tons in weight. That's why the A321XLR needed new landing gear. And to improve its maneuverability in the air, it also features new flaps on the wing trailing edges.

All-around talent for passenger air travel

After crisscrossing northern Germany and the North Sea for three hours and 45 minutes at altitudes between 1,500 and 9,000 meters, the prototype—one of three test aircraft set to obtain certification after roughly a thousand flight hours—performs a spectacular steep bank over the company airfield. Afterward, it touches down and taxies to the front of the delivery center underneath a water salute from the airport firefighters. About a hundred guests and employees greet the crew with jubilant cheers. Captain of the first flight was French pilot Thierry Diez, who has over 8,000 flight hours under his belt. "This aircraft is as universal as a Swiss Army knife and allows us to fly short-, medium- and long-haul routes with the same pilot type rating," he says enthusiastically.

AUTOR:

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 to discuss current events in the sector.

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OVERTURE

Dawn of a new supersonic era

Humans broke the sound barrier for the first time in 1947. The Concorde was retired in 2003—but supersonic passenger flights could return as soon as 2029.

Text: *Andreas Spaeth*

"Queen of the skies" ___ *A British Airways Concorde on approach to Barbados.*

Franco-British collaboration ___ *The Concorde took to the air for the first time in 1969. Here it is in Toulouse for an engine test.*

Yeager's pioneering flight ___ *On October 14, 1947, Chuck Yeager reached Mach 1.06 in the rocket-powered Bell X-1, breaking the sound barrier in level flight for the first time in history.*

According to official records, the first attested supersonic flight in history took place 75 years ago on October 14, 1947. The pilot was 24-year-old U.S. Air Force pilot Charles Elwood "Chuck" Yeager. The Germans, however, had presumably already broken the sound barrier a few times in April 1945 during the final phase of World War II. They achieved this with the Messerschmitt Me 262, the world's first production jet fighter, which debuted in 1943. Yeager was in a Bell X-1, a single-seat rocket-powered plane specifically designed to break the sound barrier for the first time in level flight, not in a dive as had been done before.

Measuring less than ten meters long, the aircraft was painted a striking orange to be more visible in the air or, in the worst-case scenario, on the ground after an accident. It was simple in design and didn't even have an ejection seat—unthinkable in military testing today. The X-1's mothership, a Boeing B-29, took off from Muroc Air Force Base (renamed Edwards Air Force Base in 1950) in California's Mojave Desert east of Los Angeles. After the Boeing reached an altitude of about 6,000 meters, Yeager climbed into the test aircraft through the empty bomb bay and the X-1 was then released. Once he was far enough away from the mothership, he ignited the four-chamber rocket motor, which was based on German rocket technology.

The X-1 rapidly climbed to 12,800 meters. Its fuselage was patterned after a standard bullet because this shape was known to have a stable flight attitude at supersonic speeds, even though it was rather ill-suited to the aerodynamics of ordinary aircraft. At cruising altitude, Yeager accelerated the aircraft to Mach 1.06, equivalent to 1,079 kilometers per hour (km/h). Observers on the ground heard a dull double bang, as would happen from then on whenever the sound barrier was broken over Edwards—the sonic boom that is still unavoidable today. Just 14 minutes after disengaging and successfully completing his pioneering feat, Yeager landed the X-1 back at Muroc.

A victory for the Soviet Union: The Tupolev Tu-144

While supersonic flight was a purely military domain in its early decades, by the late 1960s a race was developing between East and West to see who would be the first to get supersonic passenger aircraft into the air. It was the Soviet Union that achieved this on the last day of 1968 with the Tupolev Tu-144. The elegant aircraft with the white delta wings was a world sensation that could carry as many as 140 passengers at speeds of up to Mach 1.88. The French-British Concorde, the competitor from the West, did not celebrate its maiden flight until March 2, 1969; but then it managed Mach 2.02, twice the speed of sound. At that time, the industry assumed that, within a few years, at least the longer passenger flights would be flown solely by supersonic jets. The Boeing 747, which was developed at the same time, was intended primarily for cargo transport.

But things turned out differently: the 1973 oil crisis made kerosene extremely expensive, and concerns grew about noise and sonic booms. The Tupolev Tu-144 performed only pro forma "regular" flights through the end of 1978. Although the Concorde remained a commercial flop, its scheduled service proved to be a thoroughly popular means of transport between 1976 and 2003 for passengers in a hurry. This was especially true on the route from Paris or London to New York, which could be completed in just about three hours. But with round-trip ticket prices of around 7,000 euros in today's currency, this remained a pleasure for an exclusive group.

60 years after the Concorde's maiden flight—a new supersonic era?

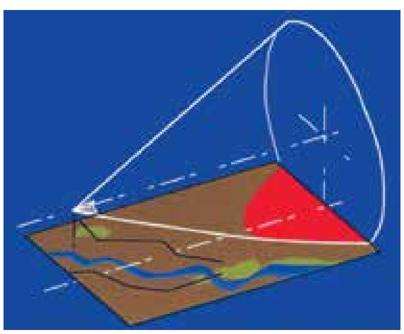
Some 20 years after the Concorde was retired, Boom Supersonic is venturing into a new supersonic era. The company is currently developing a new jet in the U.S. called Overture. Debuting 60 years after the Concorde's maiden flight, it is expected to carry between 65 and 80 passengers and reach Mach 1.7 over water as early as 2029. Over land, however, where supersonic flights

Overture — *Boom Supersonic's new supersonic aircraft currently exists only as a concept. It is scheduled to take off for the first time in 2029.*

have been banned to date because of the sonic booms, Overture will stay just below the sound limit at Mach 0.94. In its QueSST project, NASA is currently researching shapes for supersonic aircraft that should reduce the bang to such an extent that fast flights could also be possible over land in the future. Three major carriers—Japan Airlines, United Airlines and American Airlines—have already ordered a total of 55 Overtures with options for more.

Supersonic flight in the 2030s is expected to have far less impact on the environment than the Concorde did. For example, the Overture engineers are aiming to reduce the noise of both the takeoff and the sonic boom—each of these is to be lower than the Concorde's values by a factor of 30. At the same time, the plan is for the engines to run exclusively on sustainable aviation fuel (SAF). The whole thing is calculated such that a ticket should cost no more than a trip today on the same route in business class. After 75 years, the stage is set for a new era of supersonic travel.

The magic number of the speed of sound



Loud bang — *The sonic boom (here in red) trails the aircraft across the ground like the train of a dress. A jet flying above Mach 1 will pull the boom along behind it for the duration of the supersonic flight.*

A flight speed higher than the propagation of sound waves eludes the usual measurement, especially as there is no fixed value in kilometers per hour (km/h) above which we can speak of supersonic speed. In the physics of flight, therefore, the decision was made to go dimensionless at an early stage and the speed of sound was named after its Austrian discoverer, physicist Ernst Mach (1838–1916). Since then, the unit for the speed of sound has been simply "Mach 1"; everything above that is moving at supersonic speed. Aircraft are designed for Mach values, not for specific km/h numbers. Commercial aircraft today typically achieve about Mach 0.82 to 0.87 when cruising. In the Airbus A380, Mach 0.85 corresponds to exactly 903 km/h at a cruising altitude of 11,000 meters; however, at sea level, this speed of sound would be much higher in km/h. But in these lower layers of air, the atmosphere is much denser and thus the air resistance is much greater, meaning that no passenger aircraft there could fly so fast.

How close aircraft come to the sound barrier is determined by external factors at the location in question—namely, the ratio of the specific heat, the specific gas constant and the thermodynamic temperature of the air. With dry air and a temperature of 15 °C, the speed of sound is 1,225 km/h. Above an altitude of 11,000 meters, however, and due to the cold temperatures that prevail there, it is only 1,062 km/h at minus 56 °C.

Sound barrier — *When moisture is trapped inside shock waves, as here, the sound barrier becomes visible in what is called a vapor cone.*

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 to discuss current events in the sector.

Inspecting a model airplane — *Don Durston helped develop a model of NASA's quiet supersonic X-59 aircraft for use in the project's recent wind tunnel tests.*

INTERVIEW

Research on how to achieve a quieter sonic boom

Don Durston, an aerospace engineer at NASA's Ames Research Center in California, does wind tunnel research for new quiet supersonic aircraft designs such as the X-59. This design is used in the Quiet SuperSonic Technology (QueSST) program, scheduled to start its test campaign in 2023. The program aims to bring the sonic boom in supersonic flight down to such a low level that it becomes acceptable to fly over land. The X-59 is specifically designed to produce a quieter sonic "thump" instead of a boom. One major feature in achieving this is its extremely long nose, which dampens the forward shock wave.

AEROREPORT: ***Making supersonic aircraft quieter—is that a new objective NASA is pursuing with the QueSST program?***

Don Durston: Not at all. NASA has been working on this since the 1950s, ever since we learned from Chuck Yeager's flight that booms are loud. In 1964, the U.S. government ran an experiment in Oklahoma City where they bombarded the city with sonic booms eight times a day for six months. It drove people crazy! NASA, the FAA and the Air Force have been working on this for a very long time.

How did the design of the X-59 evolve over time?

Durston: In 2009, our supersonic project put out contracts with Boeing and Lockheed Martin to design low-boom airliners. They didn't achieve the low boom levels of 75 decibels we try to achieve with the X-59, they were somewhat above that, but it was still progress. They kept on working on their concepts and both presented their designs for a low boom flight demonstrator to NASA in 2016, and we chose Lockheed Martin. They refined the design in several iterations since then, and in November 2018, Lockheed Martin started to build that airframe. We've learned some more things since then, but those will have to be applied to later designs.

How confident are you that the X-59 will actually achieve the low noise results in reality that it does in computer simulations?

Durston: For some test points I'm confident. We're going to fly the aircraft over various communities in hot weather conditions and cold, humid and dry. I think for some of those conditions, the boom may be a little bit louder and for others a little bit quieter. We have four different lifting devices in the aircraft and can adjust three of them; that might result in a boom that is slightly louder or quieter. Our teams are already calculating that.

But the most crucial outcome, one that you can't simulate, will be the reaction of the public subjected to the noise of the overflying aircraft.

Durston: Exactly, we want to hear it from the people. There is a long list of potential communities for this, as we need a variety of climate zones as well as a mix of urban areas. Ultimately, testing will be done in four to six communities around the U.S. Each flight test campaign will take several months. There's a lot of logistics involved: we need all the support equipment, the maintenance staff, we need a chase plane, probably an F-15 or F-18, etc. The X-59 will likely operate out of military bases, but you have to make sure that there are other airports nearby with long runways where it could land in an emergency. And we have to look at the data of one test campaign and decide then if we maybe want to do the next one a bit differently. It all takes time, probably several weeks per community.

Do you expect a new supersonic era with quieter aircraft to begin soon?

Durston: We are likely to enter a phase where we will get a boom quiet enough that we can start to build some supersonic airliners to fly over land. But then the question arises: What happens if we get hundreds of supersonic airliners going across the country? Even if the sound from one airplane may be quiet enough, will it bother people if there are hundreds of those per day? That can be a challenge.

The materials experts at MTU
Dr. Jörg Eßlinger, Senior Consultant Materials, and Dr. Inga Stoll, Director Materials.

New materials make all the difference

Sustainable engines call for advanced materials: MTU's Dr. Jörg Eßlinger, Senior Consultant Materials, and Dr. Inga Stoll, Director Materials, share their expertise.

Text: *Nicole Geffert*

AEROREPORT***: The demand for innovative materials and coatings for engine components is enormous. Existing propulsion systems with MTU technology, such as the highly efficient geared turbofan (GTF), are being refined and powered by sustainable fuels. In addition, new high-performance engines must be developed for military applications. At the same time, MTU Aero Engines is advancing the development of revolutionary propulsion concepts that will continue to drastically reduce the climate impact of aviation. This also calls for advanced materials with new functionalities. What are the challenges facing MTU's materials experts?***

Jörg Eßlinger: For over 50 years now, metallic materials such as nickel and titanium have played a key role in making engines lighter and more efficient. To make future engines even more efficient, these materials are continuously being optimized. In the second-generation GTF, the core engine's thermal efficiency will be further improved, as will profitability in both production and operation. The materials used must be extremely heat-resistant as well as lightweight, durable and robust. It's also important to ensure they can be manufactured and repaired cost-effectively and with process stability.

Inga Stoll: We already have our eye on the best material classes for the second-generation GTF, such as monocrystals, specific protective coatings, high-temperature-resistant disk materials and materials in additively manufactured components. And we're improving our analytic description of these materials. All this enables us to fully exploit their lightweight construction potential, temperature limits and service life.

Jörg Eßlinger: Much the same applies to military engines: the requirements placed on the materials can be met only with special high-performance materials. When it comes to the NEFE, the Next European Fighter Engine, the bar is even higher. To ensure high power density and performance, what's needed are light-

weight construction and materials for extremely high temperatures as well as special coatings for components.

Inga Stoll: This calls for, for example, fiber-reinforced materials and powder metals. Substantial investments from us and our partners are needed to optimize, refine and qualify the properties and manufacturing of these materials for our applications. And it's crucial to begin this lengthy development process in good time.

AEROREPORT***: What other requirements must be taken into account besides use temperature, weight and stable, cost-effective manufacturing?***

Inga Stoll: The materials need to be easy to repair as well in order to bring down MTU customers' maintenance costs. Repairability is something we consider early on in the materials design process. After all, we want to make sure that our customers are able use their engines for a long time. The right material with the ideal protective coating can double or even triple a component's service life. In fact, in the demanding environment of an aircraft engine, it's coatings that make the material usable in the first place.

Jörg Eßlinger: Coatings will become even more important in the future. Over 60 percent of engine components are already coated to protect them against high temperatures, abrasion, chemical attacks and erosion. If the power density in engines is to keep increasing while demand for longer service life continues to grow, then engine materials are going to need even better, higher-performance coatings.

AEROREPORT***: MTU is already working on revolutionary propulsion concepts for the future. What challenges does this entail for the materials?***

Inga Stoll: Future requirements couldn't be higher. Take, for example, the water-enhanced turbofan, which recuperates thermal energy and water from the exhaust gas flow before the water is vaporized by a heat exchanger and injected into the combustor. This means the materials are exposed to a humid environment. It's important not to underestimate the fact that this significantly higher water vapor content accelerates corrosion. Corrosion of any kind impairs a component's performance. We need to find out what special coatings are necessary to protect the materials.

"To speed up development and to produce optimum technological and commercial results, it's essential to employ simulation techniques. MTU's previous experience with such techniques, in particular when it comes to developing and assessing the quality of materials and designing manufacturing processes, has been thoroughly positive."

Dr. Jörg Eßlinger, *Senior Consultant Materials at MTU*

Jörg Eßlinger: These demanding requirements also apply to MTU's flying fuel cell propulsion concept. Here, the issue isn't so much the high temperatures, but rather the fact that the concept involves electrification and the influence of hydrogen, which can be hard on the materials. We're faced with novel components, such as the constituent parts of the fuel cell itself, as well as with new aircraft engine materials and their functions. These include magnets, cryogenic hydrogen as well as electrochemical issues. A fuel cell reacts stored hydrogen with oxygen from the air to form water, thereby releasing electric energy. Hydrogen and oxygen sound harmless enough. However, if hydrogen seeps into the material, it can cause brittleness. That's why we're working hard to determine how severe the impact is and how best to protect the materials against it.

AEROREPORT***: What materials are we talking about?***

Inga Stoll: I'm talking about materials such as special polymers, coatings and functional materials, either with electromagnetic properties or that function as sensors. Just like the new atmosphere within the engine, these are not exactly standard for us. Then there's the matter of having to qualify these materials; here again, stable, cost-effective manufacturability and repairability are important. For new materials and coatings in particular, MTU must provide proof of safety—down to the smallest detail.

AEROREPORT***: Aviation-specific requirements are very high, aren't they?***

Jörg Eßlinger: Indeed. The qualification of new materials and their functions for commercial flight operations is very demanding. Factors such as high mechanical loads, long durability and damage tolerance play a role. All the various plastics, composite materials, metals, magnets, catalysts, films and coatings we'll be working with will be performing functions that in some cases are unprecedented in aircraft engines. In addition, we need to test the new materials, for instance to see how they hold up in a humid or aggressive atmosphere. MTU is building testing facilities for this purpose. With our new component test center, we're already well positioned, and our partners from research and the service industry are supporting us to the best of their ability. There's much to do.

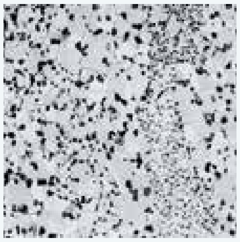
Inga Stoll: This makes our strong, reliable network all the more valuable. Our close ties with universities, research institutes and manufacturers are important as they enable us to share know-how, investments and risks. Above all, we rely on our development partners to actively come up with novel materials and evolve their own manufacturing processes. For instance, the use of fiber-reinforced composites has already led to collaborations with suppliers from industries outside MTU's immediate network, such as the textile industry. What's important for us is for development work

Dr. Jörg Eßlinger
Senior Consultant Materials at MTU

Dr. Inga Stoll
Director Materials at MTU

MATERIALS AT A GLANCE

Robust, lightweight and extra heat-resistant—engine materials have to meet particularly demanding requirements. But what exactly are nickel superalloys and the like? AEROREPORT introduces the most important materials and related methods used in the engines of today and tomorrow.



Nickel-based superalloys:
Nickel-based superalloys are materials that are almost two-thirds nickel. The magnified image shows the characteristic, microstructural property of the cuboid γ' precipitate (precipitation: an intermetallic phase) in the metallic γ matrix. In addition to heavy alloying elements, this special structure enables high strengths even at high temperatures.

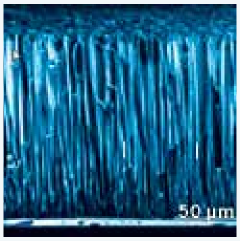
Monocrystalline nickel-based superalloys:
As a special case of nickel-based superalloys, the images show the structure of a single-crystal material. These materials are manufactured in special casting procedures without grain boundaries, that is, as a single crystal. They can be used at ultra-high temperatures close to their melting point.

Titanium alloys:
The main component of titanium alloys is titanium. The alloy elements added in engine construction and the manufacturing parameters chosen enable the creation of very different, typically lamellar or globular microstructures with different benefits. The image shows a mix of both manifestations known as a bimodal structure.

Powder metallurgy materials:
Powder metallurgy produces powder particles from smelt by way of atomization. Quality characteristics include, above all, purity from foreign particles, diameter distribution, shape and surface texture as well as the chemical distribution and structure inside the particles.

Additively manufactured materials:
In additive component manufacturing, material is gradually positioned and combined with the material already present. This can be done by melting wire or powder particles using a laser or an electron beam, and it requires special attention in terms of quality control. Additive manufacturing offers high degrees of freedom when it comes to manufacturing complex structures for lightweight construction.

Fiber-reinforced polymers (composite materials):
Fiber-reinforced polymers are composite materials, which means they consist of two completely different components. High-strength fibers made from different materials, such as carbon, that have been woven together in different ways are embedded in a polymer matrix. This structure can be observed on the surface of an inner ring, as in this example.



Coatings (functional materials):
The coatings in engines are especially diverse in their materials, manufacturing processes, structure and function. For example, polymers, metals and ceramics are sometimes used in combination. Under the microscope, coatings can look homogenous or highly structured. Over 60 percent of engine components are coated. The image shows an evaporation-deposited ceramic insulation layer that has taken on a rod-like structure.

Materials simulations:
Materials simulations encompass all computer-aided analyses concerning the creation of a material and the description of its properties. Since a material's behavior is determined by a combination of structures at different, microscopic scales—right down to the atomic level—different mathematical physics methods are necessary. The image shows the computer-generated γ/γ' microstructure of a nickel-based monocrystal.

to be related to applications. If MTU decides to use a new material in ten years' time, then research activities must be closely aligned with the requirements of the end product.

Jörg Eßlinger: There's no time to lose. To speed up development and to produce optimum technological and commercial results, it's essential to employ simulation techniques. MTU's previous experience with such techniques, in particular when it comes to developing and assessing the quality of materials and designing manufacturing processes, has been thoroughly positive. It's key to connect several simulations at different scales and to not shy away from novel methods. But quality assessments in large-scale manufacturing will also increasingly rely on digital processes.

AEROREPORT***: Which ones?***

Jörg Eßlinger: One example is MTU's deep learning software called Neuronal Analysis Tool To Evaluate Rapid, or Natter for short. It uses AI to classify microscope images of metals with unprecedented speed. This saves days' worth of image editing on the computer. The digitalization of materials engineering calls for specialists with interdisciplinary skills in materials science and IT. We're glad to have been able to strengthen our teams by attracting outstanding experts to join us.

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.

MORE INFORMATION ON THE TOPIC "MATERIALS":

Engine materials
www.aeroreport.de/en

Aircraft through the lens

Konstantin von Wedelstädt is a planespotter. He has been photographing aircraft for over 30 years and talked to us about the perfect image, spotter positions and spectacular scenes.

Text: *Nicole Geffert*

"I specialize in commercial aircraft–business jets and larger–and am one of those planespotters whose work you might call traditional or old-school."

Konstantin von Wedelstädt

AEROREPORT***: How did you get into planespotting?***

K. von Wedelstädt: The first time I traveled by plane, I was still in preschool. It was in 1973 and I flew on vacation with my parents from Düsseldorf to Málaga on a Caravelle operated by LTU. I still remember it really clearly, especially how excited I was to be flying for the first time. In the mid-1980s, I was given my first camera and I found myself going back to the observation deck at Düsseldorf Airport over and over again. Back then, I often didn't know which planes would be taking off and landing on a given day. It was a game of chance and very exciting.

AEROREPORT***: What is it about watching and photographing planes that you find fascinating?***

K. von Wedelstädt: I'm really into aircraft technology and the phenomenon of flight. And when I'm planespotting, I feel the promise of the great wide world. At the moment I'm using a digital SLR camera, which I can attach a telephoto lens to so I can snap close-ups of aircraft even when far away. Planespotting is also about collecting and archiving; I recently digitized a set of 30-year-old slides and it was like traveling back in time.

AEROREPORT***: So planespotters are also passionate collectors?***

K. von Wedelstädt: Absolutely, that's part of the hobby. I started by putting prints of my pictures into traditional photo albums, but I soon switched to slides–that was like the gold standard for planespotters. Then toward the end of the 1990s, I bought a slide scanner and digitized all my slides. It was also around that time that the first online databases for images of aircraft started up–like airliners.net. There are now around 10,000 of my photos on the web. Even into the 2000s, planespotting was mainly a hobby for nerds. But that's changed since more and more people are flying and reaching for their camera to photograph the planes that take them on their Mediterranean vacation or to the other side of the world. The planespotter scene has definitely grown a lot.

AEROREPORT***: What are you looking to capture when photographing an aircraft–its type, its livery or the background?***

K. von Wedelstädt: I specialize in commercial aircraft–business jets and larger–and am one of those planespotters whose

"Instagram, for example, has given rise to a very creative form of planespotting."

Konstantin von Wedelstädt

work you might call traditional or old-school: photographing the aircraft from the side, perfectly lit and, if possible, against an attractive background. Good shots happen during take-off and landing, as well as when the aircraft is parked on the tarmac. Social media has brought a noticeable change to the scene. Instagram, for example, has given rise to a very creative form of planespotting: people are working with filters and taking pictures of planes from underneath or behind. I'm happy to use these as a new source of inspiration and I've created my own Instagram account.

AEROREPORT***: Are planespotters allowed to take photographs anywhere they like?***

K. von Wedelstädt: It's generally a good idea to find out in advance what the rules are for the countries and airports you're planning to visit. For security reasons, there are places you're not allowed to take photos from, such as certain points along the airport perimeter. Some airports require planespotters to procure permits. I've been working at Lufthansa for the past 25 years and once I was lucky enough to photograph a Concorde from the window of the Lufthansa offices at Heathrow Airport.

AEROREPORT***: What is your favorite airport for taking pictures and which of your photos is your favorite?***

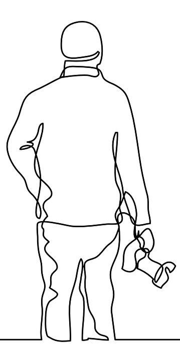
K. von Wedelstädt: One of the best places for taking pictures is Amsterdam's Schiphol Airport. It provides planespotters with the right conditions, meaning many attractive observation points from which to get images. As for my favorite photograph, I have a whole range of personal highlights in my collection. One of these is a shot of a Boeing 747 operated by Lufthansa flying over Frankfurt at sunset. I've never again captured such a perfect sky with my camera.

AEROREPORT***: Are airports like Princess Juliana International, next to Maho Beach on Saint Martin in the Caribbean, really so special?***

K. von Wedelstädt: That one is genuinely spectacular. I went there on vacation ten years ago. A lot of private jets land there, which isn't all that interesting for me as a planespotter. But when a Boeing 747 operated by KLM thundered in a low pass over the beach, it was emotionally and physically exhilarating. What I don't do is hang around at the airport fence like some tourists do, looking to feel the jet blast from an aircraft taking off. That's dangerous and irresponsible, if only because of the rocks that fly around.

AEROREPORT***: What's left on your planespotter to-do list?***

K. von Wedelstädt: I'd love to get to Rio de Janeiro so I can go up Sugarloaf Mountain and photograph planes flying down below me. Japan also happens to be a very planespotter-friendly country, with great spotter positions at its airports. But I'm no longer one of those planespotters who travels around the world for the sole purpose of taking pictures. Instead, whenever I travel for work or pleasure, I'll make sure I have a day to spend at the airport with my camera. Since I've spent the past 30 years photographing aircraft, I've often toyed with the idea of getting my pilot's license. But I never seem to find the time—and planespotting comes first!



Some 10,000 images — *Online databases for images of aircraft contain about 10,000 photos by Konstantin von Wedelstädt. He's active on social media as well.*

On airliners.net:
Photographer: Konstantin von Wedelstaedt

On Instagram:
Konstantin von Wedelstaedt (@flying_high_photos)

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.

01

02

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01 ___ *One photograph that Konstantin von Wedelstädt considers a personal favorite is a shot of a Boeing 747 operated by Lufthansa flying over Frankfurt at sunset.*

02 ___ *When a Boeing 747 operated by KLM thunders in a low pass over Maho Beach on Saint Martin, it's emotionally and physically exhilarating.*

03 ___ *Amsterdam Schiphol Airport provides planespotters with the right conditions–namely, many attractive observation points from which to get images.*

04 ___ *Konstantin von Wedelstädt has been working at Lufthansa for the past 25 years and was once lucky enough to photograph a Concorde from the window of the Lufthansa offices at Heathrow Airport.*

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Cabins featuring cactus leather

Creating an aircraft cabin is like a tricky jigsaw puzzle for designers and manufacturers. What goes in must be lightweight, efficient, occasionally luxurious and always sustainable.

Text: *Andreas Spaeth*

Designing an aircraft cabin is one of the most complex creative processes there is. The cabin floor of a passenger aircraft must rank among the most expensive pieces of real estate in the world—each square centimeter is precious. This is because the space available can't simply be expanded as desired, and airlines must find a design for their cabins that meets the needs of their customers while also being affordable to operators. As if this task weren't already hard enough, it now comes with an additional caveat: not only the aircraft itself but also the fixtures that go into it must be sustainable. For designers, ticking all these boxes is like completing an incredibly difficult jigsaw puzzle—one that imposes a lot of constraints and only rarely allows them to realize their bold ideas. Once a year, the cabin sector converges on Hamburg for the Aircraft Interiors Expo (AIX) trade fair.

One regular visitor to AIX is Italian engineer Gaetano Perugini of the manufacturer Aviointeriors. He often enjoys great success with exceptional solutions: at his company's booth at the fair in June 2022, he once again presented several jaw-droppers, including the Triangle model. In each three-seat row for economy class, the middle seat is positioned half a seat further forward than its neighbors. "This is an ideal distance that also provides each passenger with ample elbow room," says Perugini, demonstrating the seats together with visitors to the fair. The protruding part of the middle seat can be folded up to allow people to pass, and occupants are also partitioned off from each other by headrests that point forward at ear level.

However, Perugini isn't very optimistic that the airlines will be snapping up the Triangle—ultimately, they tend to struggle with all cabin innovations. "All these ideas must first be properly discussed," agrees Anthony Woodman, who is responsible for customer experience at Virgin Atlantic Airways. But there's nevertheless a desperate need for improvements precisely where the vast majority of customers spend their time, as Matt Round, Chief Creative Officer at London design agency tangerine, points out: "In economy class, the passenger experience is borderline throughout the sector."

In focus: Less weight

What really counts in economy class cabins is lightweight construction, because less weight on board means lower fuel consumption and emissions. "This is also the biggest trend right now—our lightest economy seat for medium-haul routes weighs 8.5 kilograms. That's 25 percent less than the previous generation," says Mark Hiller, CEO of German seat manufacturer Recaro, the global market leader in the economy segment. The lightest seat for long-haul routes currently weighs in at 12.0 kilograms, down from 13.5 kilograms, a reduction that is in part due to new materials like titanium and carbon-fiber composites as

01 **Elevate – the cabin concept with floating furniture** ___ *What's visually impressive about this premium cabin concept for narrowbody aircraft—which was created by London design consultancy Teague—is that its seats and other fittings are mounted not on the cabin floor, but rather on the walls.*

02 **Personal compartment for premium customers on narrowbodies** ___ *In the future, narrowbodies could also serve long-haul routes with flight times of up to eleven hours. Safran has now unveiled its VUE seat, which enables personal compartments on these jets to provide a similar level of comfort and privacy to those on widebody aircraft.*

03 **Triangle – more privacy in economy** ___ *Innovations are rare in economy class. Aviointeriors is providing each passenger with more privacy with its Triangle seats. In each three-seat row, the middle seat is positioned further forward than the other two. To make it easier for people to get past, the protruding part of the middle seat folds up like the seats in a movie theater.*

04 **The fire-resistant air freight container** ___ *Safran is addressing a growing risk in aviation by producing fire-resistant baggage containers. Fires on board aircraft are happening increasingly often due to lithium-ion batteries igniting. Safran's containers provide up to six hours of protection.*

05 **Clip table instead of tray table** ___ *Recaro recently presented a small plastic table complete with cup holders that clips onto the seat back and weighs just 185 grams (on the right). Passengers can obtain one from the cabin crew either on request or by ordering something from the trolley service.*

well as new magnesium alloys. Another great way to save several kilograms is to install the new, thin, flexible OLED screens.

"It's equally important to recycle individual materials or even entire seats, but that's difficult when carbon fiber is involved," Hiller says. This is why the industry is currently on the lookout for fresh ideas for manufacturing seat covers in a more eco-friendly way. "There are new, sustainable materials, such as vegan cactus leather or mycelium leather, which are made from sustainable raw materials and, like cacti, don't consume any water," says Matthew Nicholls of Tapis, a provider of fabrics for aircraft interiors. "The question is: Can production of these materials be ramped up enough to meet the demand that comes with widespread commercial use?"

More comfort for the new long-haul jets

In business class, however, the latest trend goes against the quest for lightweight fixtures: "Sliding doors that provide privacy in the compartments are now standard for high-end products," says Vincent Mascré, CEO of Safran Seats. "Passengers expect this, but it does sadly add both complexity and weight." Overall, fitting a sliding door adds eight to ten kilograms per seat. The long-haul market has recently begun to welcome narrowbody aircraft, most notably the Airbus A321XLR, which also celebrated its first flight at AIX in Hamburg in June 2022.

This jet class, formerly dominated by medium-haul aircraft, is now also seeing its first luxurious premium products. The race is on among cabin manufacturers to adapt their premium cubicles—originally conceived for widebodies—to smaller jets. This is proving amazingly successful, including the addition of sliding doors. Following the example of U.S. airline JetBlue, which serves transatlantic routes with an A321LR, many airlines will equip the first row of narrowbody cabins with two suites that offer more space than some of the suites in widebody jets in service today. The seat sector must therefore be flexible, which is one of its strengths—in his office in Naples, Perugini is probably already working on new solutions.

TEXT:

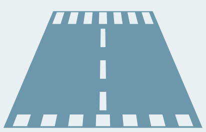
Andreas Spaeth has been traveling the world as a freelance aviation journalist for over 25 years, visiting and writing about airlines and airports. He is frequently invited to appear on radio and TV programs to discuss current events in the sector.

Faster, further, higher

Our love affair with flying is always pushing aviation to break new records.

Text: *Thorsten Rienth*

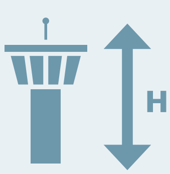
The first aviation record was set on December 17, 1903, the day of the world's first powered flight with a human on board: on the outskirts of the small town of Kitty Hawk, North Carolina, the Wright Flyer remained airborne for 59 seconds and covered a distance of approximately 260 meters before touching down again. That was the day when humanity's dream of flying became a reality. Since then, aviation has set numerous new records and continues to break them: the largest terminal building, the longest route, the most powerful engine or the tallest airport control tower—to name but a few.



Record № 01

The world's longest commercial runway

Each of Munich Airport's two runways is precisely four kilometers long. While this puts them at the longer end of the scale for their type, they are not nearly long enough to match the record. Measuring 5,500 meters in length, the world's longest commercial runway is located at Changdu Bangda Airport, which is 4,334 meters above sea level in the Tibet Autonomous Region. The record for the longest military runway—11,920 meters—is held by Edwards Air Force Base runway 17/35 on Rogers Dry Lake in California.



Record № 02

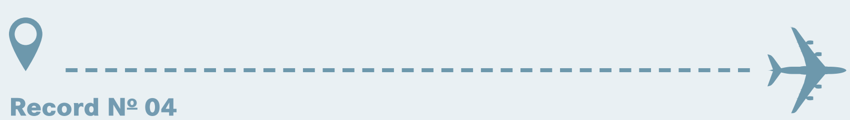
The tallest airport control tower

Air traffic controllers have to make the right call under extreme conditions. To do so, they require the best overview of the entire airport site. Depending how an airport is laid out, its control tower might have to stretch far up into the heavens. The tallest example is at Suvarnabhumi Airport in the Thai capital Bangkok. Standing 132 meters tall, the tower relegates those at Kuala Lumpur (130 meters) and Atlanta (121 meters) to second and third place.

Record № 03

The largest airport by size

King Fahd Airport in Dammam, Saudi Arabia is the world's biggest airport by size. The airport building sits on 36.8 square kilometers of land—however, the entire airport site covers an impressive 776 square kilometers. But no other departures and arrivals hall can compete with the 700,000 square meters of the terminal at the Beijing Daxing International Airport. Once the final expansion stage is complete, which is scheduled to happen in 2040, the airport will be able to handle up to 130 million passengers a year.



Record № 04

The longest nonstop route

The longest nonstop scheduled flight is currently between Singapore and New York. On this 15,349-kilometer route, an Airbus A350-900ULH operated by Singapore Airlines will spend up to 18.5 hours in the air, depending on wind conditions. But it looks like it's only a matter of time before this record will be broken: Australia's Qantas Airways has already tested a direct connection of approximately 17,700 kilometers between London and Sydney and had planned to begin offering this route in 2022. However, the coronavirus pandemic caused the airline to delay.

Record № 05
The most powerful commercial engine

With a fan diameter of a whopping 3.40 meters, GE Aviation's GE9X is the largest commercial engine currently in production. Successor to the GE90-115B, the GE9X will be the powerplant for the new Boeing 777X long-haul aircraft. And there's no end to the superlatives: the GE9X is also the world's most powerful commercial engine. On the test stand, it achieves 134,300 pounds of thrust—the previous record of 127,900 pounds was held by the GE90-115B. In 2019, the GE9X even earned a Guinness World Record as the most powerful commercial engine.

Record № 06
The most punctual airline

Once a year, aviation data specialist Cirium calculates the punctuality of airlines throughout the world. A flight is deemed to have arrived on time if it reaches the gate within 15 minutes of the scheduled time. In 2021, first place went to Japan's All Nippon Airways with a punctuality score of 95.04 percent, closely followed by Japan Airlines with 94.13 percent. In Europe, the top two spots are occupied by Spanish airlines: Vueling Airlines with 92.13 percent and Iberia Express with 91.81 percent.

Record № 07
The largest still flying airplane in the world

The Airbus A380-800 is not only the largest passenger aircraft in the world, but also the largest aircraft still flying. It is an impressive 72.3 meters long, has a wingspan of almost 80 meters and a maximum takeoff weight of approximately 590 metric tons. The A380 inherited the Antonov An-225 cargo plane developed and built in the Soviet Union, the last remaining flying example of which was destroyed in its hangar during the Ukraine war in 2022.

Record № 08
The busiest airport

The coronavirus pandemic sent global air traffic into chaos, reshuffling the ranking of the busiest airports in the process. According to Airports Council International (ACI), old favorite Hartsfield-Jackson Atlanta International Airport regained the top spot in 2021. But the number of passengers that passed through the airport that year—75.7 million—is still nowhere near the record 110.5 million it saw in 2019. In 2020, Guangzhou Bai Yun International Airport briefly stole the top spot by handling 43.8 million passengers.

Record № 09
The most challenging airport

Of course it's not really possible to rank airports in terms of how challenging they are. But Tenzing-Hillary Airport in Lukla, Nepal, is often named as a strong contender for the top spot. Situated 2,843 meters above sea level, its runway is just 527 meters long, has an incline of around 15 percent and ends at a 600-meter cliff. Most of the aircraft flying in and out of Lukla are what are known as STOL (short takeoff and landing) aircraft such as the de Havilland Canada DHC-6 and the Dornier 228.

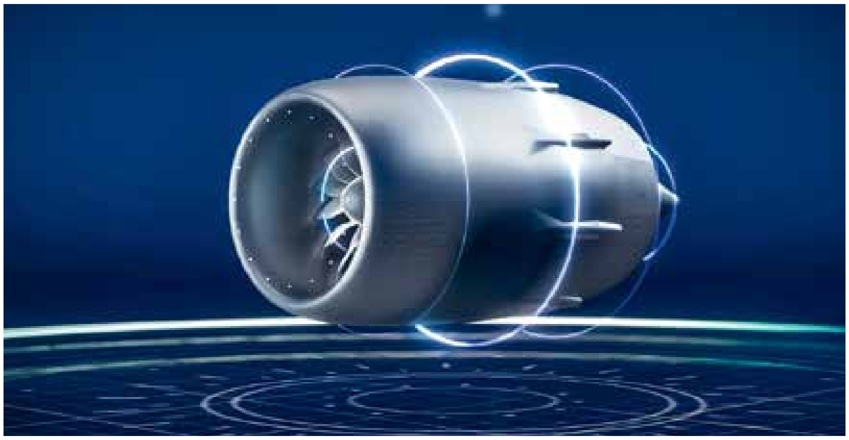
Record № 10
The most expensive airplane in the world

If development costs are added, the U.S. Air Force's Northrop B-2, also called a stealth bomber, produced from 1988 to 1997, cost 1.9 billion euros. Its shape makes it virtually invisible to radar. No other aircraft comes close to it in terms of price. For example, the world's most expensive jet, the U.S. president's Boeing 747 (Air Force One), cost "only" 650 million euros. The modified Airbus A380 of Saudi Prince Al Waleed Bin Talal al-Saud cost 590 million euros.

A BRIEF GUIDE:

How the WET concept works

The water-enhanced turbofan significantly reduces CO_2 and NO_x emissions as well as contrail formation, and can be used in all classes of aircraft.



Virtually climate neutral: *The WET concept slashes nitrogen oxide emissions. It also substantially reduces fuel consumption, CO_2 emissions and the formation of contrails.*

What is the WET concept?
Based on the gas turbine, the water-enhanced turbofan, or WET, is a propulsion concept that takes full advantage of MTU's know-how. Utilizing residual heat from its exhaust gas, the WET concept uses a steam generator to vaporize water, which is then injected into the combustor. The water for this is extracted from the exhaust gas by means of a condenser and then separated.

What are the advantages of the WET concept?
The carbon footprint of WET is unique: it reduces CO_2 and NO_x emissions primarily by recovering exhaust heat and injecting steam into the combustor. It also curbs the formation of contrails by filtering out any particulate matter from the exhaust gas stream. Recovering the exhaust heat, and thus improving thermal efficiency, reduces energy consumption. When powered by sustainable aviation fuels (SAF) or hydrogen, by 2035 the WET concept could reduce the climate impact of aircraft by about 80 percent compared to a gas turbine engine from the year 2000—making it virtually climate neutral.

Following the planned market launch in 2035, the plan is to further optimize the water-enhanced turbofan by 2050. The use of near drop-in fuels (chemically modified SAF) would achieve the maximum reduction in climate impact. And if WET is powered by hydrogen, this would result in further advantages with regard to climate-relevant emissions.

How does the WET concept work?
The engine's efficiency is increased by recovering the exhaust energy that would otherwise be lost—this also lowers fuel consumption and CO_2 emissions. First, a steam generator produces hot steam. The exhaust gas cools down in the process. As it cools further in the condenser, the water it contains begins to condense. The condensation heat is fed to the bypass flow and the liquid water is separated from the exhaust gas in a water separator. Condensation nuclei are also washed out of the exhaust gas in the process, which reduces the formation of contrails. The water is then brought to a high pressure level by means of a pump and delivered to the steam generator. The steam expands in a steam turbine before being channeled into the combustor. The power is fed into the low-pressure shaft. Injecting the hot steam into the combustor not only increases the engine's efficiency, but also reduces nitrogen oxide (NO_x) emissions.

Where can WET be used?
The WET concept can run on kerosene, SAF or hydrogen, and is suitable for use on short-, medium- and long-haul routes. As a result, it covers the factors that are responsible for virtually the entire climate impact of aviation.

Watch the film

Water-enhanced turbofan: Revolutionary propulsion concept based on the geared turbofan

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A BRIEF GUIDE:

How the flying fuel cell works

The FFC does not produce any emissions of CO_2 or NO_x or particulates. Since its only emission is water, this propulsion concept is virtually emissions-free.

Flying fuel cell
Converts liquid hydrogen into electricity–and thus achieves a virtually emissions-free solution.

What is the flying fuel cell?

The flying fuel cell (FFC) is an MTU propulsion concept in which hydrogen and oxygen from the air react within a fuel cell to form water, thereby releasing electric energy. A highly efficient electric motor then uses this energy to drive the propellor via a gearbox.

What are the benefits of the FFC?

This propulsion system does not produce any emissions of CO_2, NO_x or particulates–its only emission is water. In this way, the FFC reduces the climate impact of aviation by as much as 95 percent–i.e., to virtually zero. And since the propeller is then the sole source of noise, the FFC will also help achieve massive noise reductions.

The core of the system is the fuel cell stacks. The electrochemical conversion of hydrogen into electricity is highly efficient. Moreover, the electrochemical reaction takes place under considerably cooler conditions than conventional combustion. While this fact clearly calls for an efficient cooling system, it also makes things a little simpler, for example regarding the choice of materials and integration options. The platinum used in the fuel cell is highly recyclable–when processed properly, it and other metals can be reused almost indefinitely. Also, this energy conversion takes place in the stacks, effectively without moving parts.

How does the fuel cell work?

Each fuel cell contains two plate-shaped electrodes (anode and cathode). At the anode, hydrogen molecules (H_2) release electrons to become positively charged hydrogen ions (H+). The free electrons flow as usable electricity via a conductor to the cathode, where they join with oxygen atoms to form negative oxygen ions (O_2-).The hydrogen ions combine with the oxygen ions at the cathode to form water while releasing heat.

Where can the FFC be used?

The FFC is set to be deployed soon on short-haul routes in regional air traffic. The next-generation FFC is set to be in operation on short- and medium-haul routes, further reducing the climate impact of commercial aviation.

Watch the film

Flying fuel cell: Potentially full electrification for virtually emissions-free flight

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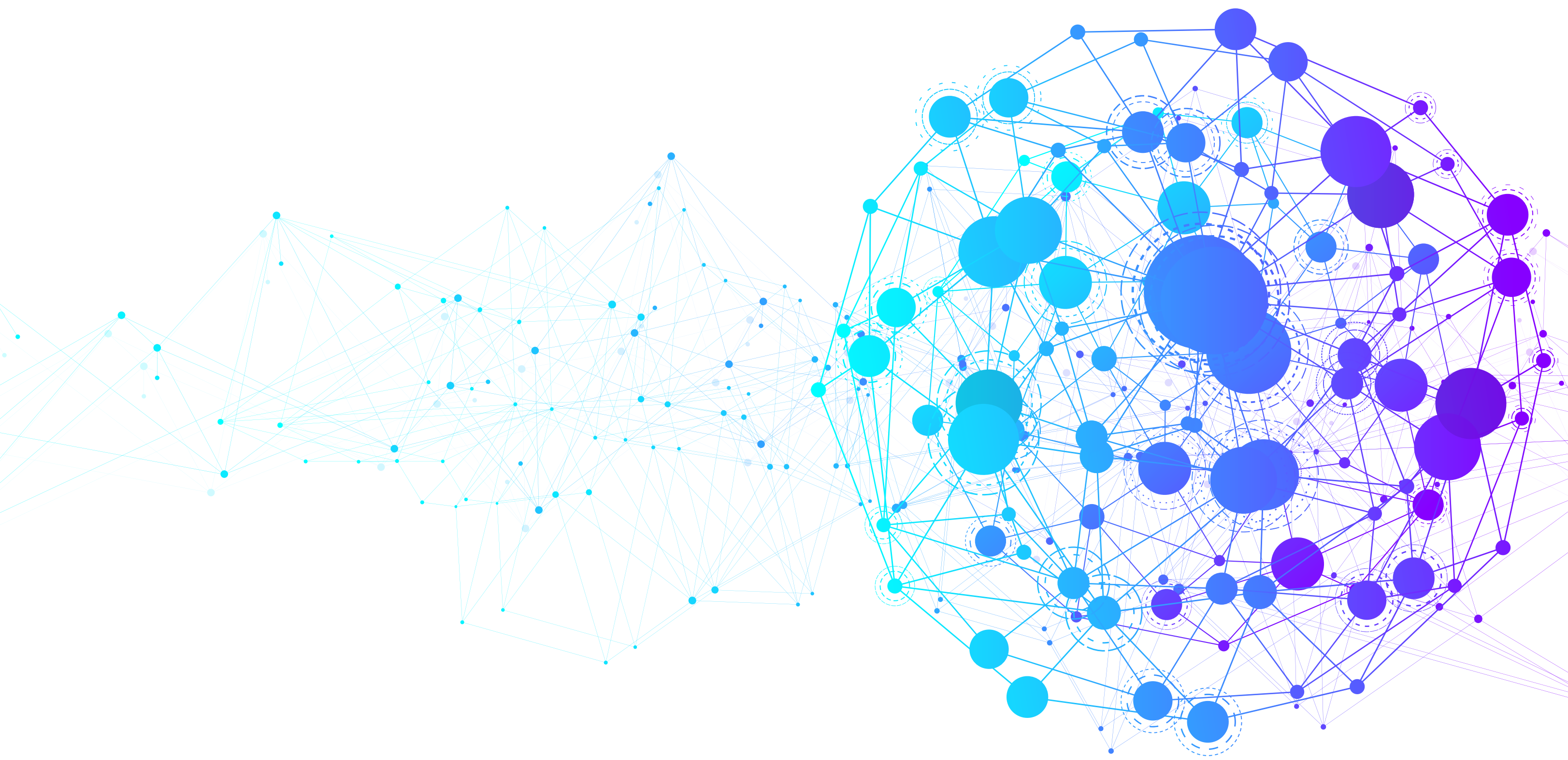

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