AEROREPORT

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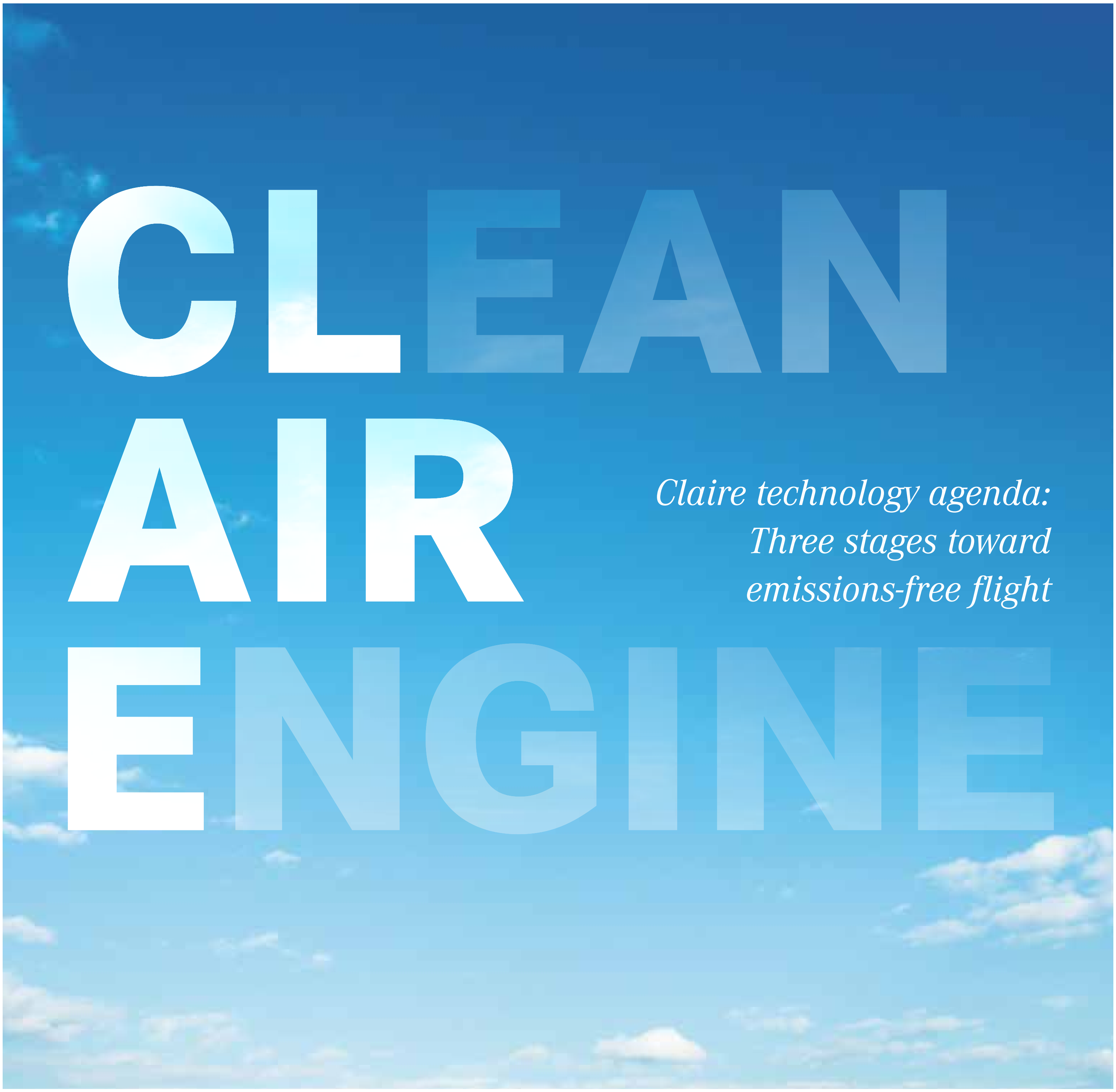
The aviation magazine of MTU Aero Engines | www.aeroreport.de



INNOVATION
Airfoil production with autopilot – on the way to the smart factory

AVIATION
Unique in Europe – MTU and German Armed Forces celebrate their 20-year EJ200 cooperation

GOOD TO KNOW
Going off like a rocket with a booster, and other winged words

Dear readers,

This year began with such promise: the coronavirus situation seemed to be easing and the aviation sector was showing credible signs of recovery. But Russia's invasion of Ukraine on February 24 suddenly placed the global economy, and more importantly world peace, under renewed and considerable threat.

We are greatly troubled by this conflict. Our thoughts are with the Ukrainian people and we support all sanctions the West has imposed on Russia. Our position here is, and will remain, clear and unequivocal.

First the pandemic, and now the Ukraine conflict—these are the issues that overwhelmingly shape the times we currently live in. But amid all the urgency and tragedy, we mustn't lose sight of the fight against climate change. MTU remains fully committed to achieving emissions-free flight.

We've updated our Claire (Clean Air Engine) technology agenda to reflect the latest developments. It was in 2007 that we set out on this ambitious course for the future together with Bauhaus Luftfahrt. Now we've expanded it to include recent accomplishments such as the success of the geared turbofan as well as our new ideas. The agenda lays out potential technological solutions and opportunities for the green engines of tomorrow.

We will be presenting all this to the public for the first time at ILA Berlin from June 22 to 26: the event's theme is "Pioneering Aerospace," and ours is "Driven by visions of tomorrow." In this issue of **AERO**REPORT, we give you an exclusive, in-depth look at Claire.

We'd also like to offer you an inside look at our high-tech production: with the help of SpeedMask®, we've developed techniques that are unmatched in the industry. And with the flexible manufacturing system (FMS), we've even created and launched a complete production line for turbine blades that is smart, highly automated—and the only one of its kind in the world. These are just two of the exciting topics that I'd like to draw your attention to.

But our most important task remains to work together for peace and solidarity in the world and do all we can to alleviate the suffering of the victims of war.

Yours sincerely,

Lars Wagner
Member of the Executive Board, Chief Operating Officer

COVER STORY

On track for emissions-free flight

Emissions-free flight is the overall goal of aviation and the vision of MTU. With its Claire technology agenda, MTU is working hard to vastly reduce the climate impact and fuel consumption of aircraft engines.

Page 8

INNOVATION

Airfoil production with autopilot

MTU has created a flexible manufacturing system for its future airfoil production. Thanks to a number of in-house developments, this system enables a higher level of automation than any comparable production facility in the world.

Page 18

AVIATION

Final departure

In December 2021, the 251st and final Airbus A380 was delivered. While passengers love this giant of the skies, the aircraft itself has not had an easy time on the market. A journey through the history of this superjumbo.

Page 32

CONTENTS

AVIATION

Flying high over the Baltic

Soon, Riga-based airBaltic will have a 50-strong fleet made up purely of Airbus A220-300s. Especially in difficult times, such as the coronavirus pandemic, this gives it a competitive edge—thanks also to the modern jet's efficient PW1500G engines.

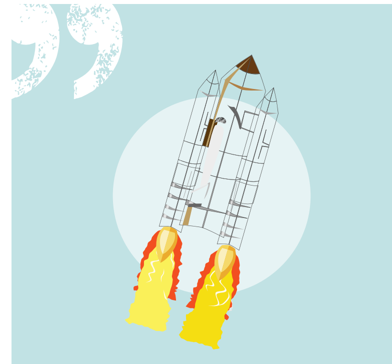
Page 38

PEOPLE

Unique in Europe

For two decades, MTU and the German Air Force have been maintaining the engines that power the Eurofighters of the German Armed Forces—and with great success. The Tornado RB199 and the Tiger MTR390 have also been part of the collaboration for many years.

Page 46



INNOVATION

Winged words

The dream of flight is almost as old as humankind. As aviation developed, so too did a particular way of talking about it. This is reflected in everyday idioms and colloquial language.

Page 54

www.aeroreport.de

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.

DIGITALIZATION

Intelligent fleet management

New MTU software handles planning for entire engine fleets.

MTU Maintenance has launched a revolutionary engine fleet management software. CORTEX combines the company's technological expertise with algorithms, artificial intelligence, and data—for example from engine monitoring, market knowledge, or previous workscopes in the shop.

Highly flexible system —— *CORTEX can automatically generate the optimum maintenance strategies for customers' fleets in real time.*

The new service cuts maintenance and operating costs for airlines while increasing availability. It can be fully tailored to customer needs, making it unrivaled on the market.

MORE INFORMATION ON THE TOPIC

How to plan engine MRO at minimum cost
www.aeroreport.de/en

The GTF Advantage engines are expected to become available as of early 2024.

THE FUTURE OF AVIATION

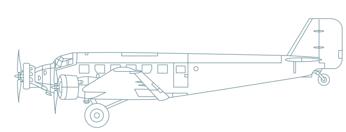
The improved geared turbofan

Pratt & Whitney is launching a technologically improved geared turbofan (GTF) for the A320neo family: the Pratt & Whitney GTF Advantage™.

The GTF Advantage will cut **fuel consumption and CO_2 emissions** by another 1 percent each, leading to an overall reduction in each of **17 percent** compared to prior generation engines. With up to 34,000 pounds of take-off thrust, the GTF Advantage will be the **most powerful engine** for this aircraft family and will enable **increased range** and **payload** for operators. All essential components of the GTF core engine are undergoing technological improvement. In line with its program shares, MTU is working to optimize the high-pressure compressor and the high-speed low-pressure turbine. At market launch, the GTF Advantage engine will be capable of running on **100 percent SAF.** The new engines are expected to become available as of January 2024.

HISTORY

Old but gold: 90 years Ju 52



JU 52	
PASSENGERS	15 – 17
LENGTH	18.50 meters
HEIGHT	6.10 meters
WINGSPAN	29.25 meters
EMPTY WEIGHT	5,720 kg
TOP SPEED	290 km/h
RANGE	1,200 km

Designed as a single-engine transporter, converted into a military fighter jet, and successfully employed as a three-engine passenger aircraft: the legendary Junkers Ju 52 was truly versatile. It was powered by three 600 horsepower BMW 132 or 750 horsepower Elizalde Beta engines.

Whichever the airline, the Ju 52 stood for safety and reliability. Its simple, cleverly thought out design made it very robust. A few Ju 52s are still airworthy today. At 90 years old, this "old-timer" remains among the best known and most popular vintage aircraft in the world.

ENGINES

New GTF family members at MTU Maintenance

MTU is celebrating another geared turbofan milestone: in March 2022, the first shop visit of a PW1100G-JM at MTU Maintenance Zhuhai was completed.

This makes the Pearl River Delta site the third plant in MTU's network that is capable of assembling, disassembling and testing PW1100G-JM engines. In addition, MTU Maintenance now offers MRO services for two other models from the engine family: the PW1500G, which powers the Airbus A220 family, and the PW1900G engines for Embraer E190-E2 and E195-E2 aircraft. In the future, shop visits for both these GTF models will be conducted at EME Aero, an MRO joint venture between MTU and Lufthansa Technik based in Rzeszów, Poland. The first PW1500G engines have already passed through the shop—now preparations for the PW1900G are in full swing.

ENGINES

On-wing giants

At the November 2021 Dubai Airshow, Boeing's new 777X widebody aircraft made its debut in front of an international audience—powered by today's largest and most powerful commercial engine: the GE9X.

- The world's **largest** and **most powerful** commercial engine at rollout
- Fan diameter: a whopping **3.4 meters**
- **Overall pressure ratio: 60:1**—the highest in aviation history, according to GE Aviation
- MTU is responsible for manufacturing the **turbine center frame.** The company has long-term experience with this highly complex component through the GP7000 (Airbus A380) and GEnx (Boeing 787 Dreamliner) programs
- A **10 percent reduction in fuel consumption** (compared to the previous GE90-115B model)
- Substantial **reductions in CO_2, NO_x and noise emissions**

DID YOU KNOW?

What does the turbine center frame actually do in the engine?

High temperatures, enormous pressures, high speeds: the conditions in an engine are extremely challenging. Right in the middle of it all is the turbine center frame (TCF), which plays a key role. Located between the high-pressure turbine and the low-pressure turbine, the TCF performs two important functions. It connects the rear bearing of the high-pressure spool with the housing and acts, aerodynamically, as the inter-compressor duct between the high-pressure turbine and the low-pressure turbine.

TCF experts —— *MTU develops and manufactures the key components, including for the GEnx and GE9X.*

The TCF directs the hot gas flows with temperatures of up to 1,000 degrees Celsius from the high-pressure turbine past structural components and cables to the low-pressure turbine—with minimum aerodynamic losses. In operation, it is exposed to extreme mechanical loads and high temperatures. The material and design must therefore satisfy the highest of standards.

CLEAN AIR ENGINE

Emissions-free flight ___ *This is the prime goal for aviation. MTU's technology agenda elaborates potential solutions at the aero engine level.*

On track for emissions-free flight

With its technology agenda Clean Air Engine, MTU is working hard to minimize the climate impact and fuel consumption of aircraft engines over a number of stages.

Text: *Nicole Geffert*

Claire ___ *Claire stands for "Clean Air Engine" and is MTU's technology agenda. It was first published in 2007 and is about to enter a new chapter.*

CLEAN AIR ENGINE

Whether exploring faraway countries, discovering new cultures, meeting up with business partners or shipping commercial goods and humanitarian aid – flying brings people together. That said, the aviation sector now faces a headwind as awareness grows about the climate impact of air travel. In response, the industry has identified a number of key challenges. Specifically, it is working hard to progressively reduce the climate impact of aircraft and to deliver the kind of radical solutions that will improve aviation for the long term. And MTU Aero Engines is at the forefront of these efforts. With its Clean Air Engine (Claire) technology agenda, the company is busy developing the solutions that will deliver sustainable commercial aviation and so is once again living up to its reputation as a technology pacesetter.

Emissions-free flight is the overall goal and the vision of MTU. It is guided by the Paris Agreement's target of limiting global warming to, ideally, an increase of 1.5 degrees Celsius compared to preindustrial levels. In the past, aviation industry targets focused exclusively on CO_2 emissions. In the future, the climate impact of nitrogen oxide (NO_X) emissions and contrails will also play a role. Taken together, these effects constitute the climate impact of aviation.

Challenging propulsion technologies

Right now, the key players in the aviation industry are facing major challenges. In order to reduce the climate impact of aviation, they need to make further improvements to existing aircraft and engines. This can take the shape of, for example, increased efficiency and further weight reductions. Meanwhile, science, research and industry are already working on new and revolutionary concepts that could drastically reduce the climate impact of aviation. At the same time, the introduction of climate-friendly flight routes and fuel-saving approach procedures should help make air travel "greener" in the future. New energy sources, such as sustainable fuels and hydrogen, will have a key role to play as well. Overall, the focus is increasingly shifting to the total lifecycle of an aircraft—from development and production to operation, maintenance and decommissioning. All of these aspects now feed into a thorough assessment of the air transport system. "This gives us a holistic analysis of how aviation, in all its facets, impacts the environment and, in particular, the climate," writes the German Aerospace Center (DLR) in its strategy paper "The route to emissions-free aviation."

Action is required now. When it comes to the development and production of aircraft, cycles are measured in decades rather than years. If we are to shape the future of aviation, a number of key developments must be set in motion today. Yet the technologies required for this are challenging, and the underlying conditions complex. For example, a host of new technologies are needed before we can burn hydrogen as a fuel in a gas turbine engine or electrochemically convert it in a fuel cell. Fuel cells themselves, electric motors and tanks for liquid hydrogen stored at minus 253 degrees Celsius—all these first have to be developed and designed for integration in aircraft. Moreover, we will need to produce hydrogen for global aviation in sufficient quan-

Climate impact *CO_2 emissions, NO_x emissions and contrails make up the climate impact of aviation.*

CO_2 *Carbon dioxide is a greenhouse gas that results from the combustion of carbon-containing materials.*

NO_x *Nitrogen oxides are formed in combustion processes with gaseous nitrogen (N_2) and oxygen (O_2).*

Contrails *These result from the water vapor emissions of an aircraft engine.*

tities, to do this in a sustainable and cost-effective manner, and to create the requisite infrastructure for producing and supplying this new fuel.

SAF – Alternative fuels with potential

In the short term, the use of sustainable fuels could substantially reduce the climate impact of aviation. Known as sustainable aviation fuels (SAF), these result in a largely closed carbon cycle. In the best-case scenario, the CO_2 released during combustion is then fully recaptured from the atmosphere for use in further fuel production. In addition, initial studies indicate that the use of SAF significantly reduces the formation of contrails.

SAF can be produced from biomass or from renewable energy via, for example, a power-to-liquid (PtL) process. They can already be used for current aircraft fleets in admixtures of up to 50 percent as a “drop-in” fuel, without the need to adapt the aircraft or engine. This has huge potential to reduce the climate impact of aviation. However, only a few industrial-scale plants are currently in operation, despite the fact that suitable manufacturing processes have been developed and approved. Sufficient production capacity must therefore be created as quickly as possible. Another key challenge will be to make this process more cost-effective. Though not a fuel manufacturer itself, MTU is pressing hard for the use of SAF. For example, it is supporting a number of projects to set up PtL production facilities. Furthermore, MTU Maintenance is the world’s first maintenance company to perform acceptance runs with SAF on the test stand.

New engine technologies from MTU

With its technology agenda Clean Air Engine (Claire), MTU is working hard to reduce the fuel consumption and climate impact of aircraft engines over a total of three stages. Claire was launched in response to global climate goals and the need to reduce aviation’s climate impact. The solutions and concepts elaborated in this agenda push boldly beyond existing technology in order to provide pioneering answers and exploit new potential.

A key element of this program is an evolutionary enhancement of the gas turbine engine based on the geared turbofan (GTF) and combined with revolutionary propulsion concepts. Here, MTU favors the water-enhanced turbofan (WET) engine, which reduces both CO_2 and NO_X emissions and also significantly restricts the formation of contrails. The revolutionary concepts to emerge from MTU also include an electric propulsion system: the flying fuel cell. In the long term, this hydrogen-powered fuel cell has the potential to deliver virtually emissions-free flight.

For MTU, one thing is clear: in light of the Paris Agreement, any developments designed to deliver climate-neutral flight will need to be market-ready well before 2050. The company has therefore stepped up its work on revolutionary propulsion concepts, in partnership with players from industry, science and research. In parallel, MTU is working to enhance existing propulsion systems, such as the highly efficient geared turbofan, and to couple these with sustainable fuels so as to achieve a significant reduction in the climate impact of aviation as quickly as possible.

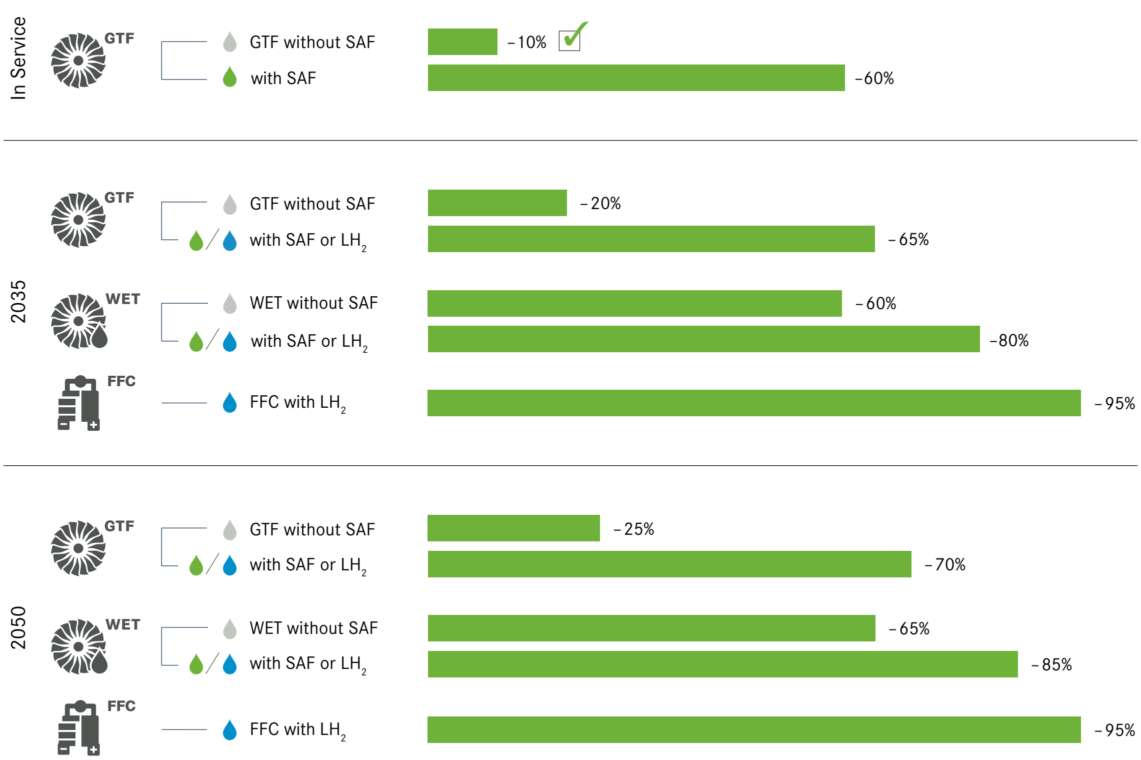
MTU's technology agenda was launched in response to global climate goals and the need to reduce aviation's climate impact. It elaborates potential solutions at the aero engine level. In the past, aviation industry targets focused exclusively on CO_2 emissions. In the future, the climate impact of nitrogen oxide (NO_x) emissions and contrails will also play a role. Together, these effects make up the climate impact of aviation.

MORE INFORMATION ON THE TOPIC

Link to the video:
Claire technology agenda
www.aeroreport.de/en

MTU'S TECHNOLOGY AGENDA

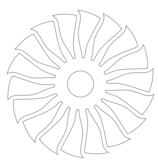
Reducing climate impact*



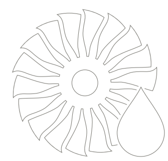
Reducing climate impact * (global warming potential)
Climate impact is a result of CO_2 and NO_x emissions and of contrail formation[1]

Reducing energy consumption*
Energy consumption refers to the energy required for a standard mission[1]

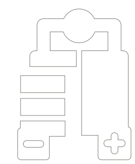
GTF = *Geared turbofan*
WET = *Water-enhanced turbofan*
FFC = *Flying fuel cell*
SAF = *Sustainable aviation fuel*



Geared turbofan ____ *Thanks to its high efficiency, this engine already delivers climate-friendly aviation–and offers lots of potential for the future.*

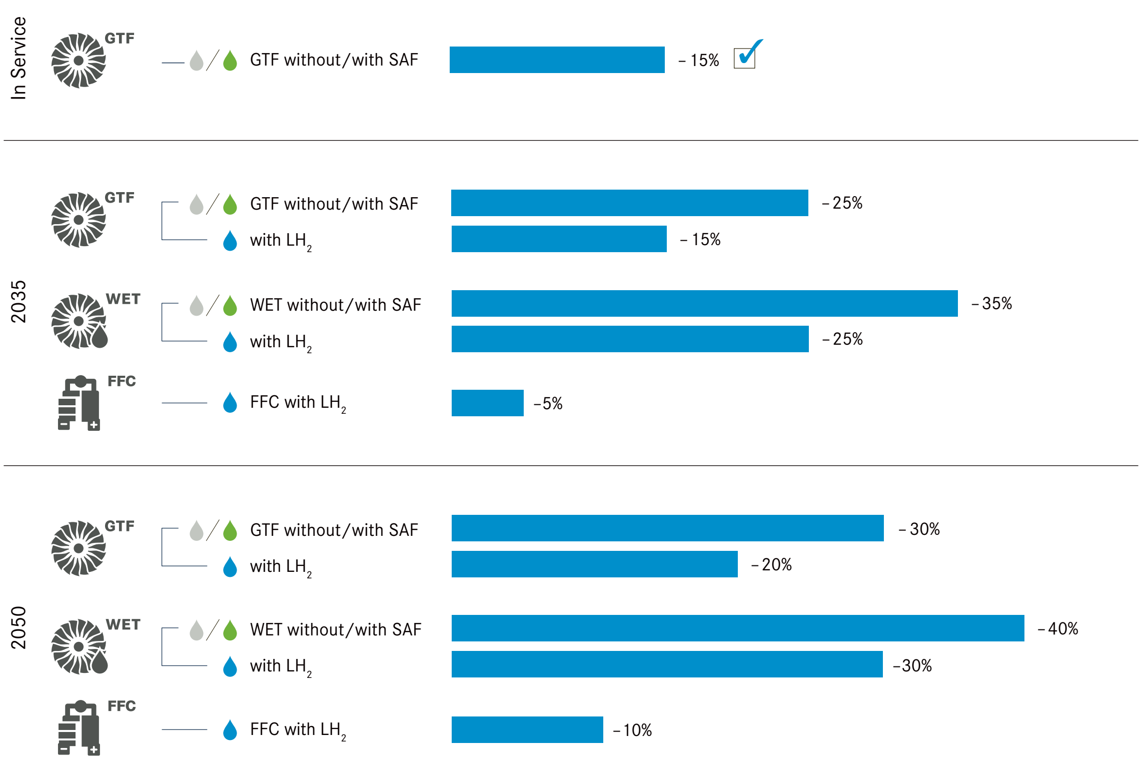


Water-enhanced turbofan ____ *This gas turbine-based concept achieves near climate neutrality combined with simultaneously reduced energy consumption.*



Flying fuel cell ____ *Produces no emissions of CO_2, NO_x or particulates. The only emission is water.*

Reducing energy consumption*



Fuel
- = *Kerosene without SAF*
- = *100% SAF*
- = *LH_2 = Liquid hydrogen*

Noise reduction
All concepts meet future noise emission limits

[1] *compared to a kerosene-powered gas turbine from the year 2000*

Cleaner, quieter, more fuel-efficient
The Pratt & Whitney GTF™ engine family comprises the world's most eco-efficient engines currently in operation.

Three stages to emissions-free flight

The first stage of the Claire program was the development of the highly efficient engines from the Pratt & Whitney GTF™ engine family. These engines were developed in collaboration with U.S. partner Pratt & Whitney. They are used in modern narrowbody aircraft such as the Airbus A320neo and A220 and the Embraer E-Jet E2 family. The first GTF generation was already regarded as a technical masterpiece. Compared to the previous generation, it reduced fuel consumption and CO_2 emissions by 16 percent—one percentage point more than was targeted.

Meanwhile, a new chapter in the GTF success story is about to commence. In January 2024, the launch of the Pratt & Whitney GTF Advantage™ will deliver a technologically enhanced version of this engine for the A320neo family. The GTF Advantage will cut fuel consumption and CO_2 emissions by a further percentage point, thereby leading to an overall reduction in both of 17 percent compared to previous engine generations.

The key improvements here stem from MTU, which is supplying the high-speed low-pressure turbine and the forward four stages of the high-pressure compressor for the GTF Advantage. In addition, MTU also manufactures the brush seals and nickel blisks for the high pressure compressor—components for which it does not have development responsibility. By contributing these new components, MTU is helping to improve the engine's fuel efficiency, which reduces the consumption of resources and thereby aviation's impact on the climate.

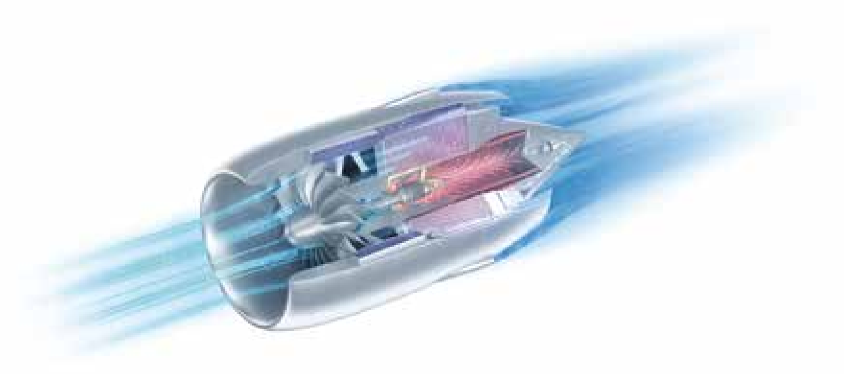
Second-generation GTF engine will be even better

Since the geared turbofan engine went into production in early 2016, it has helped aircraft operators save more than two billion liters of fuel, thereby avoiding more than six million metric tons of carbon emissions. Meanwhile, GTF-powered aircraft are now licensed to operate with a 50 percent admixture of SAF, meaning a further reduction in CO_2 emissions. Upon its market launch, the GTF Advantage engine will be licensed to run on 100 percent SAF.

To unlock the full potential of this technology, MTU is already working on the second generation of the geared turbofan. This includes a program to further reduce the fan–pressure ratio and thereby further increase the bypass ratio. At the same time, it should be possible to further improve the core engine's thermal efficiency, for example by increasing pressure ratios, integrating compressor and turbine components, undertaking further aerodynamic improvements and using new materials. Any new materials for this purpose must be lightweight, extremely resistant to heat and able to withstand environmental influences. In this instance, MTU is focusing on the very best materials such as sixth-generation monocrystals and powder metals for the turbines. When powered by SAF or liquid hydrogen, the second-generation GTF engine could reduce aviation's climate impact by as much as 65 percent.

WET engine scores points through wet combustion

The experts at MTU are well aware that this evolutionary enhancement of the gas turbine engine will not be sufficient, on its own, to meet the goals of the Paris Agreement. It is revolutionary propulsion concepts, developed on the basis of the geared tur-



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

bofan, that will unlock the door to climate-neutral aviation. But to develop them, innovative technologies are required. Together with industrial partners, universities and research institutes, MTU is working hard to deliver the kind of solutions that can reduce climate impact by 80 percent. This is the second stage of Claire, which is scheduled for completion by 2035.

MTU's favored technology is the water-enhanced turbofan (WET) engine, fueled with SAF or hydrogen. Utilizing thermal energy from the exhaust gas stream, the WET engine uses a heat exchanger to vaporize water, which is then injected into the combustor. The water for this purpose is extracted from the exhaust gas by means of a condenser. This kind of "wet" combustion slashes nitrogen oxide emissions. It also substantially reduces fuel consumption, CO_2 emissions and the formation of contrails. In reducing the climate impact of aviation by around 80 percent, this concept will already be approaching climate neutrality in 2035.

As a gas turbine-based concept, the WET engine profits from the vast know-how at MTU. It is suitable for short-, medium- and long-haul aircraft and therefore covers the sector that is responsible for virtually the entire climate impact of aviation. In addition, its enhanced efficiency cuts costs and saves valuable resources.

Flying fuel cell: virtually emissions-free

In another revolutionary propulsion concept, MTU is investigating options for a full electrification of the powertrain. This, too, forms part of the second stage of Claire and is scheduled for completion by 2035. The most promising of these options is the flying fuel cell (FFC), which is set to be deployed first on short-haul routes in regional air traffic. This propulsion system does not produce any emissions of CO_2, NO_X or particulates. The only emission is water. The FFC reduces the climate impact of aviation by as much as 95 percent—i.e., to virtually zero.

In the long term, hydrogen will serve as the basis for climate-neutral propulsion of the future. MTU has identified three potential applications: it can be burned directly in a gas turbine engine, converted into SAF or converted into electrical energy by means of a fuel cell. The key advantage of hydrogen as a fuel is that it would make aviation carbon free. Per kilogram of fuel, hydrogen contains around three times as much energy as kerosene, which also makes it an extremely attractive proposition for aviation. On the other hand, liquid hydrogen has a larger volume than kerosene. One of the key challenges in the design of hydrogen-powered aircraft will be to accommodate larger fuel tanks. However, it is only when hydrogen is produced with renewable energy that its use becomes genuinely climate friendly. Therefore, alongside the introduction of sustainable fuels in aviation, one of the major tasks over the coming decades will be to ensure a sufficient supply of renewable energy.

Zero emissions within reach

The third stage of Claire is scheduled for completion by 2050. This may seem a long way off—but not for MTU, which is already working hard to further improve the overall efficiency of the geared turbofan and the WET engine. The use of near drop-in fuels (SAF that are chemically modified) would reduce climate impact to a maximal degree. Yet this will also require minor modifications to the aircraft and the engine. If the WET engine

Hydrogen ___ *MTU has identified three potential applications: it can be burned directly in a gas turbine engine, converted into SAF or converted into electrical energy by means of a fuel cell.*

H_2

is powered by hydrogen, this will bring further advantages—not only lower CO_2 emissions but also potential reductions in the weight and drag of the propulsion system resulting from a more compact design.

As efficiency improves, the flying fuel cell should be in operation on short- and medium-haul routes as of 2050. This will further reduce the climate impact of aviation. To help achieve this goal, MTU will be looking to further increase the efficiency of individual components so as to reduce energy use while in flight and thereby take another decisive step towards the vision of zero-emissions flight.

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.

Further articles on the topic of emissions-free flight can be found on www.aeroreport.de/en

MORE INFORMATION ON THE TOPIC OF "CLAIRE"

Claire technolgoy agenda: Three stages toward emissions-free flight
www.aeroreport.de/en

MORE INFORMATION ON THE TOPIC OF "HYDROGEN"

How hydrogen is revolutionizing aviation
www.aeroreport.de/en

MORE INFORMATION ON THE TOPIC OF "SAF"

Alternative fuels: Producing kerosene from renewable energy
www.aeroreport.de/en

SAF on the test stand

MTU is the first MRO provider to have performed acceptance testing using sustainable aviation fuels (SAF) on the test stand. The test runs were carried out with V2500 engines.

Text: *Isabel Henrich*

The V2500 on the test stand —— *At the end of 2021, MTU performed acceptance tests on behalf of JetBlue. The engine was run with a 10% admixture of sustainable aviation fuel.*

At the end of 2021, MTU Maintenance and launch customer JetBlue Airways performed acceptance runs on V2500 engines using sustainable aviation fuel (SAF) for the first time. In March 2022, another customer, LATAM, also had an engine tested on MTU's test stand using SAF. Initially, the partners used a fuel mixture containing up to 10 percent SAF. The fuel used is sustainably sourced from recycled cooking oils and waste, and emits up to 80 percent less greenhouse gas over its entire lifecycle than the conventional kerosene it replaces. This makes MTU Maintenance the world's first MRO service provider to offer acceptance tests using SAF.

Thorsten Kleine Sextro, V2500 systems engineer at MTU Maintenance Hannover, has spent the past four years working toward using sustainable alternative fuels on MTU test stands.

Mr. Kleine Sextro, what needed to be done before SAF could be used on the test stands?

We conducted negotiations with various fuel suppliers in advance to clarify the technical specifications and the availability of SAF. From a technical point of view, the SAF used meet all the requirements of the specification for standard kerosene, which means they can be used on our test stands without any problems. We also made the necessary arrangements in-house to get the site SAF-ready so we could use the fuel.

As the first MRO provider to perform this kind of acceptance testing, MTU is also setting new standards.

Absolutely. Our customers are keen to do what they can to reduce their climate impact. We're very pleased to be able to support them in this by using SAF during the acceptance runs. We saved around 0.6 metric tons of CO_2 as a result, significantly reducing the carbon footprint. So far, we've been using a 10 percent SAF admixture for the testing. In the future, we can bring this up to 50 percent—the maximum currently permitted.

TEXT:

Isabel Henrich studied political science and communications. At MTU, she coordinates the editorial process of **AERO**REPORT and is responsible for the conception and development of its content.

Airfoil production with autopilot

MTU has developed an automated airfoil production process that operates autonomously for up to 66 hours and will now provide the basis for larger smart factory projects.

Text: *Tobias Weidemann*

The robot places a blank in the clamping device, secures it with numerous screws, and loads it into one of the five tool machines. The machines drill and mill, grind and gauge—everything is fully automated, a value creation process that appears to be guided by an invisible hand. And it's efficient: while the machines are hard at work, the robot is already attending to the preparation and post-processing of the next parts and tools. “With the new system, we have proven that Industry 4.0 meets the requirements of even the extremely sophisticated high-tech production of engine parts,” says Christiane Müller, Head of High-Pressure Turbine Guide Vanes at MTU Aero Engines, describing the new flexible manufacturing system (FMS). For the connected production of rotor blades, guide vanes, and structural components, this marks an enormous leap toward the smart factory. Assisted by a control system, the facility's five tool machines manufacture components in parallel, working flexibly and, above all, autonomously for days at a time without human intervention. “And they take up just a third of the space needed for conventional production in the past,” Müller adds.

Fully autonomous production over the weekend

Six potential work systems were for the taking—but rather than modernizing its existing production, MTU wanted to take manufacturing to the next level with state-of-the-art, progressive automation. So the company chose to go with a production unit that can work autonomously for as long as possible. “66 hours—this is the exact amount of time it takes to comfortably bridge a whole weekend,” says Marc Weiß, FMS Project Manager. And that's how long the flexible manufacturing system should be able to operate without human intervention. The machine's built-in autonomous correction function and extensively planned preventive maintenance ensure the necessary process stability. This sets the stage for even more efficiency gains in the future.

Employees still have to mount and subsequently remove grinding wheels and other tools by hand—95 percent of the work steps required to manufacture turbine blades involve grinding. But

Flexible and automated ___ *The FFS is a production line for turbine blades that is unparalleled anywhere in the world.*

drill bits and milling cutters are automatically switched out and gauged by the robot cell.

From 7 hours to 15 minutes: downtime reduced

This system has also made the order processing side of production a lot more efficient and flexible—a welcome development, given how the general trend seen in recent years of producing increasingly smaller batch sizes and enabling the extensive tailoring of customer orders hasn't stopped at turbine blade production. Although production may not have been reduced to a batch size of one in practice, orders are usually placed for batches of between 70 and 120 workpieces. And with the new system, these batch sizes can be reduced further without incurring high retooling costs.

15 minutes
instead of 7 hours:
downtime significantly reduced

66 hours
autonomous production:
can bridge whole weekend

A double structure is in place here to keep downtime to a minimum. For example, one milling cutter is used in the tool machine while another is being prepared for the next step. The same goes for the robot cells: a component is clamped in place on one fixture while a processed component is removed from another before a new blank is mounted. "This means we can plan orders more flexibly and we don't have to worry so much about retooling times—on balance, our production is more efficient in several respects," Müller says. While conventional production lines had previously needed between seven and eight hours for retooling, the new system is ready to go in just 15 minutes.

It certainly took a lot of time and effort to reach this stage of flexible manufacturing: "But by the same token, we've benefited from a successful, if steep, learning curve," Weiß says. Continuing to run the old system while setting up the new one proved to be particularly challenging logistically. Then, in July 2021, the FMS was able to move into the final stage of the project, with its five tool machines and fully automated processes. "Additional components are currently being coordinated for FMS production to ensure it is completed and goes into full operation by the end of 2022," Müller says.

Pioneering production of engine parts

"This has essentially become a lighthouse project, not just for MTU but also for the wider industry. We've never seen an automated production system like it anywhere in the world, especially not for this type of component or extremely sensitive manufacturing situation," Weiß says. The high level of in-house knowledge that has gone into the project is certainly a first: for one thing, MTU programmed the tool machines itself; for another, even the clamping station with its robot-operated screw fitting is an element that was specially developed by MTU. The company's work on the tool changing cell was also groundbreaking. Together with its partners, MTU devised and developed solutions that didn't yet exist in the same form, not even in other industries. Müller also emphasized the importance of the expertise offered by the company's employees, who were able to draw on their experience

"This has essentially become a lighthouse project, not just for MTU but also for the wider industry. We've never seen an automated production system like it anywhere in the world, especially not for this type of component or extremely sensitive manufacturing situation."

Marc Weiß
FMS Project Manager at MTU

FMS team ___ *Christiane Müller, Head of High-Pressure Turbine Guide Vanes and Marc Weiß, FMS Project Manager at MTU.*

of conventional systems. "Incorporating this knowledge into the new system means that it, too, represents a balanced partnership between humans and machines."

FMS as a blueprint for bigger digitalization projects

The system may have gone live, but the FMS chapter is far from complete. There are plans to build another, much more extensive production facility at MTU's Munich site in the future—essentially based on the same concept and with production equipment from the same manufacturer. "All of this creates a blueprint for other systems, which will emerge over the next few years on a much larger scale and take up an entire hall," Weiß says.

The "Improvement & Digitalization" cross-functional department set up last year pools, among other things, ideas and topics related to the smart factory. Fabian Lindermer, who is responsible for the area of digitalization, is confident that the flexible manufacturing system, with its high level of automation, is a valuable element on the road to digitalizing production at MTU. "In the future, we as MTU will connect the many individual initiatives we have relating to smart systems in assembly or production and link them to an overall digital system—transforming island solutions into a truly smart factory."

TEXT:

Tobias Weidemann has been working as a journalist and content consultant for more than 20 years. He writes about technology and business topics, often with a focus on business IT, digitalization and future technologies.

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FLEXIBLE MANUFACTURING SYSTEM (FMS)

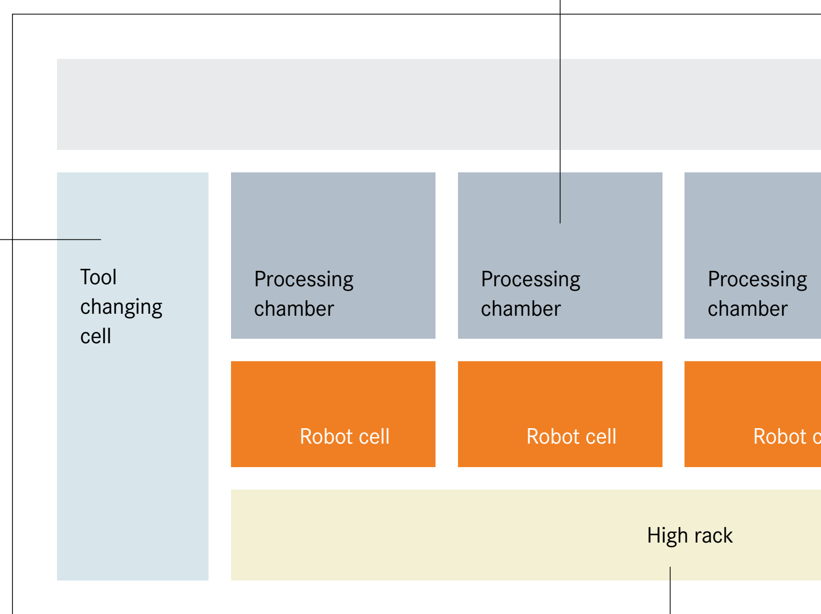
A step-by-step guide to autonomous production

In the Flexible Manufacturing System, the production of components runs fully automatically–from tool preparation and component processing to storage of the finished components. The system can operate for up to 66 hours without human intervention. Here's how it works:

05 **Transfer into the processing chamber**
The part is then transferred to the machine's processing chamber with the zero point clamping system.

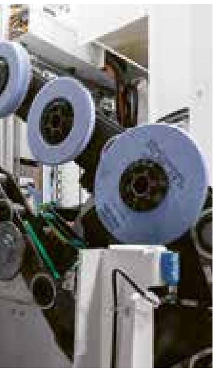
07 **Tool proc**
The to from t proce

01 **Tool preparation**
The tools are prepared in the presetting cell. The setup process can be reduced to around 15 minutes. One tool-carrying unit is in use while the other is being prepared.



02 **Filling the racks with the blank parts**
The employee fills the wireframe racks with the blank parts. These are fed into a high rack before making their way into the machine.

09 **Component in the high r**
The finished co ed into a high r for (manual) pr term, this proc automated.



08
Component processing

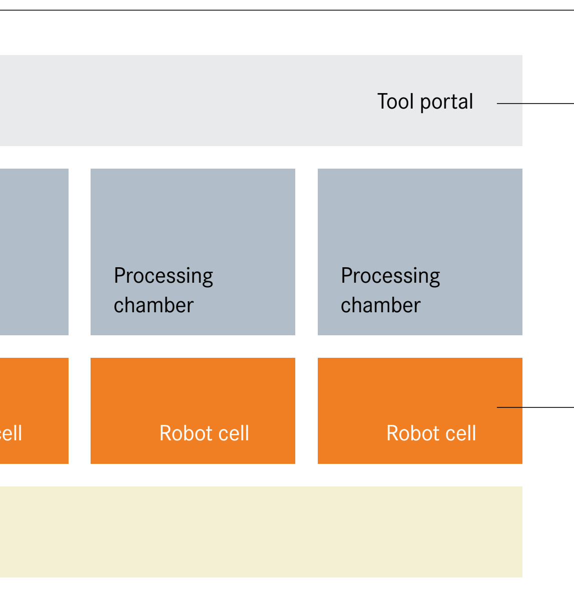
Within the machine, the exact position of the blank part is determined and the part is precisely calibrated. Then the actual processing can take place, in this case grinding. The NC program for the tool machines was also developed at MTU.

transport in the essing chamber

ools are then transported he chain magazine into the ssing chamber.

06
Tool transport in the chain magazine

The tool portal transports the required processing tools into the chain magazine located in the processing chamber.



03
Fixture elements on the clamping station

Inside the robot cell, the fixture elements are placed on the clamping station. The robot picks up the equipment it needs from the tools and jigs provided.

storage ack

mponent is then transport- ack. From here it is stored ocessing. In the medium essing is also planned to be

04
Clamping the part

The clamping of the part is also automated; the robot picks up the next part and inserts it into the clamping station. Both the clamping process and assembly were developed at MTU.

Beneath the mask

How MTU is using an elastomer to revolutionize its surface processing.

Text: *Thorsten Rienth*

Meticulous preparation ___ *Thomas Kaltenecker and his team poured their hearts and souls and a lot of their time into developing the process and adapting the high-tech machine to their purposes. After 1.5 years, the machine was ready—it exists in this form nowhere else.*

When Thomas Kaltenecker, a production planner at MTU Aero Engines, wants to explain the purpose and utility of his futuristic dispensers, he places two photos side by side. The picture on the left shows a large storage facility with multiple floors of silicone rings in dozens of different colors, shapes and sizes hung over, under and alongside each other. The picture on the right shows a few cartridges filled with a gel-like elastomer lying on a table. "Ultimately, both fulfill the same task," Kaltenecker explains, "namely covering over certain areas of engine components with masking material while other areas that are subject to particularly strong stresses and strains are given, say, a thermal spray coating. The masking makes sure the spray coating doesn't get onto areas where it's not supposed to be."

Kaltenecker's colleagues manually attach, pull on, fit and clamp the adhesive tape, silicone rings, masks or metal covers to these areas at a precision down to fractions of a millimeter. By contrast, the dispensers apply the elastomer in a fully automated manner to the respective sections on the component. Then the fully automatic masking machine's UV lamp cures the material in seconds. After the masking has passed through the respective manufacturing process, such as thermal coating, shot blasting or electroplating, it can be pulled off the component without leaving any residues behind.

Shorter throughput times, improved quality and reduced costs

SpeedMask® is the brand name of the viscous gel, and DYMAX GmbH is the name of the manufacturer. This company's UV light curing adhesives are used primarily in the domain of medical engineering; Kaltenecker heard about the product by chance. "Stuff like that could really be useful in our coating processes," he thought to himself.

Step by step, Kaltenecker began to experiment with SpeedMask®. He tried out various material blends and masking processes—at this point still working manually. Initial tests yielded promising results. Gradually, he found himself spending more and more time not just planning production, but also developing a new masking technique. At the same time, student research projects were busy investigating elastomer 3D printing on engine parts. They attested to its technical feasibility and broad range of applications in MTU production. Shorter throughput times, improved quality and reduced costs deliver first-rate added value.

For over three years now, Kaltenecker's working day has revolved largely around SpeedMask®—and as he tells his story, a blisk revolves in the robot cell behind him. The machine's optics have recognized that it is dealing with the fourth stage of a specific high-pressure compressor. The control unit loads the corresponding program, sets up the correct dispenser and moves it into position. While the rotary table turns, tilts, lifts and lowers the component, the dispenser unit continuously conveys elastomer from the cartridge. The material is applied along edges with exactly the high precision that is required for tasks like masking on thin blisk blade tips. But the machine can also fill drilled holes or apply masking over broad areas. This process and the fully automatic machine make for an almost endless range of possible applications and variations. "The exact shape of the specific mask is defined by the respective process parameters, such as the type of dispenser attachment, the distance and angle of the dispenser to the component, and the flow rate," Kaltenecker explains. Then the UV lamp buzzes past and cures the elastomer.

Finally, the machine's optics come into play again: "They can spot, for example, whether there are unwanted little air bubbles or imperfections in the masking." That means quality control is included—and there's a benefit in sustainability terms, too: "Up to now, we've been rejecting around 14,000 silicone rings a year at incoming goods on account of deviations. These rejects end up as scrap."

Surfaces masked to virtually zero tolerance levels

Last summer saw the delivery of a prototype system—one that is quite probably unparalleled worldwide—that enables MTU production to use the innovative material for masking turbine components in a fully automated and effective manner. After putting the system through testing, attention turned to its industrialization: in other words, setting up the masking and curing programs for the first components. While this summary of the machine's life story up to the present day sounds pretty brief, in fact the backstory is already lengthy: "The prototype was definitely one of our most challenging projects to date," explains Pascal Malischek, mechatronics and robotics engineer for the Austrian manufacturer Robooptic Systems. "The machine's entire control system is built in a sort of modular design with free parameters, so that MTU can adapt the masking programs independently."

This programmability was decisive from MTU's perspective. Several hundreds of components from the portfolio often pass through various coating stations during their production. Occasionally, component geometries change in the course of design improvements. "In those instances, we have to be able to adjust the respective SpeedMask® masking programs quickly and easily," Kaltenecker says.

The production planner points to the efficiency aspect of the new system, as regards both OEM and MRO business: "The areas that need to be masked off have become so fine and intricate that masking them by hand takes huge concentration and an inordinate amount of time." Tasks that took what felt like an eternity to do manually, the SpeedMask® robot gets done in a fraction of the time. "Especially now, with the sharp increase in production for the new programs, this is a big relief for colleagues." In addition, the material can be processed mechanically, meaning that surfaces can be masked virtually to zero tolerance levels and there is scarcely any limit on the contours that can be produced.

But the advantages of the innovative masking process don't end there: in certain situations, the masking is applied just once and then used for several successive production steps. This also saves a lot of time and money. And in the MRO sector, the machine could help create customized maskings for the repair of worn engine parts.

The new masking method opens up new potential in engine development

Finally, one other aspect is sure to have a general effect on engine efficiency of engines. "There are places inside the engine that developers would like to improve," Kaltenecker explains. "But some of their clever ideas were impossible for us to implement before now, because we were unable to get the masking done precisely enough with the adhesive tapes, silicone rings, masks and metal covers we were using." Of course, validation is required case by case, he notes. But at least now there is a suitable process and a suitable machine on hand.

01 **Careful scrutiny:** *Before masking of the component begins, the camera recognizes from above the respective component and specific features such as diameter, edges and drilled holes. This is a precondition for precise covering with SpeedMask®.*

02 **Step 1:** *The SpeedMask® process allows masking to be precisely applied. The dispenser unit on the robot arm doesn't miss a single corner or gap, thus ensuring that the component has 100% protection in places where conventional masking processes reach their limits.*

03 **Step 2:** *After the masking has been applied, a second robot arm travels to the component and cures the SpeedMask® with UV light.*


01

02


04


05


03

04 **Intricate and time-intensive work:** *Before now, preparation work for tasks such as thermal coating often involved covering the sensitive areas with old-fashioned adhesive tape.*

05 **Speed by name, speed by nature:** *Sometimes it used to take over 4 hours to mask this complex component. With SpeedMask®, it takes just 14 minutes.*

TEXT:

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

On the ground —— *Aircraft on ground (AOG) situations can be critical and expensive for operators. That's why all around the world, MTU has teams on standby around the clock to quickly get engines up and running again and the aircraft back in the air.*

Service without delay

MTU's on-site services ensure engine operations remain smooth. MTU's site in Ludwigsfelde now has a new hangar and a specialized team for smaller, extremely urgent jobs.

Text: *Nicole Geffert*

Some jobs never become routine—and nobody knows this better than the mobile teams for MTU Maintenance's on-site service (OSS). The time pressure alone is enough to turn every assignment into a challenge: there was no time to lose, for example, when one MTU customer's aircraft had to make an unscheduled stop after an engine bird strike meant it was unable to continue flying. For the operator, such an aircraft on ground (AOG) situation can be critical and expensive.

MTU Maintenance's OSS team responded quickly and flexibly to keep the aircraft's time on the ground as short as possible. However, due to the coronavirus pandemic, there was no regular flight to the airport where the plane with the defective engine was stranded. "After consulting with the customer, we simply went ahead and chartered an aircraft to get our team, along with special tools and spare parts, to the engine as quickly as possible," says Arne Straatmann, Director On-Site Services at MTU.

Once the team had repaired the damage, the aircraft was able to take off again and the customer could breathe a sigh of relief. To ensure that MTU customers around the world can call on this service without delay, MTU has set up highly qualified on-site service teams at locations in Brazil, Canada, the U.S., Germany and China. An around-the-clock on-call service ensures that the teams are ready to roll as soon as a customer reports engine damage that calls for repairs. MTU's customer service organizes the deployments, including all technical, logistical and customs handling.

"We serve customers on their first inquiry, even if they don't yet have a contract with MTU Maintenance—and we respond to every call by getting a specialized team to the site quickly and reliably," Straatmann says. The on-site service portfolio includes borescope inspections, minor repairs such as boroblending on high-pressure compressors, as well as top case repairs or even the replacement of entire modules.

If an upgrade is required, MTU will take care of all additional services within its network of worldwide MRO shops. Engine needs replacing? No problem: MTU Maintenance Lease Services B.V. in Amsterdam can have one ready on short notice, and the same goes for comprehensive materials solutions.

Preventive maintenance

Not every on-site deployment is an AOG. The OSS team also performs planned engine maintenance at airports, customer locations or in the shop. "Our aim with planned repairs is to make shop visits as cost-effective as possible for the customer," Straatmann says. "For example, whenever our specialists replace a component or carry out important modifications, the customer is benefiting from preventive maintenance since more serious damage, not to mention more extensive shop visits, are avoided as a result."

Engine trend monitoring also comes into play here, enabling predictive maintenance planning and condition-based engine maintenance. Moreover, MTU Maintenance has developed CORTEX, a tool for reducing its customers' operating and

"After consulting with the customer, we simply went ahead and chartered an aircraft to get our team, along with special tools and spare parts, to the engine as quickly as possible."

Arne Straatmann
Director On-Site Services at MTU

"Our primary aim is to ensure smooth engine operation for our customers by implementing the best solution either on-site or in one of MTU's worldwide shops."

Arne Straatmann, *Director On-Site Services at MTU*

More space for urgent jobs *Since the end of 2021, Ludwigsfelde has had a new hangar in which smaller jobs can be handled quickly.*

maintenance costs. Unlike any other tool on the market, CORTEX can automatically generate the optimum maintenance strategies for customers' fleets in real time. "It's a way for us to help keep our customers competitive," Straatmann says.

Whenever possible, MTU Maintenance's OSS teams perform repairs on-wing—a form of on-site service in which the engine is repaired without first having to be removed from the aircraft wing. Since this saves time, it is particularly attractive for customers. However, some repairs can't be done this way—for example a top case repair, where the top half of the high-pressure compressor housing is removed to allow the compressor's blades or vanes to be replaced. For these kinds of repairs, the engine is removed from the wing, repaired, and then reattached.

New hangar, independent team

"Our primary aim," Straatmann says, "is to ensure smooth engine operation for our customers by implementing the best solution either on-site or in one of MTU's worldwide shops." For example, at MTU Maintenance Berlin-Brandenburg, where a new 1,200 square meters hangar went into operation at the end of 2021. Five special engine docks for smaller or particularly urgent jobs, known as quick-turn docks, and a highly qualified team are on hand to get CF34-8/-10, PW800, CFM56-7 and soon also CFM56-5 engines back in working order as quickly as possible. The spectrum of jobs ranges from minor repairs to work on the hot section of an engine.

"What we do here doesn't take the place of major shop visits; our on-site service team specializes in minor repairs between the more extensive shop visits," says Jan Bierkamp, who heads OSS Europe at MTU. "Here in our shop, we also follow the maxim that says we want to reduce downtime as well as overall costs for our customers and extend the service life of their engines." MTU Maintenance Berlin-Brandenburg is being

Predictive maintenance *Intelligent tools like engine trend monitoring enable better maintenance planning.*

On-wing inspection
Whenever possible, MTU Maintenance's OSS teams perform repairs on-wing.

expanded to become the central point from which MTU provides on-site services for Europe.

The MTU location already has many years of on-site service experience and expertise: each year, its experts perform hundreds of jobs in the shop and on-site for the CF34, the PW200, PW300, PW500 and PT6 as well as the LM series industrial gas turbines. These services are now being expanded further, as is the portfolio. "We've strengthened the already independent team and expanded it with additional competencies. It will focus exclusively on on-site service in the future," Bierkamp says. In addition, there are Customer Support and Engineering teams, who also work in the new hangar to ensure that the customer receive the best possible support around the clock. This ensures the availability of the customer's fleet.

This expansion comes at just the right time: demand for on-site service is on the rise. "Customers, airlines and lessors are all feeling increasing cost pressure, which has only intensified during the pandemic," Bierkamp says. As a result, demand is growing for smaller, more specific work scopes that can keep fleet operations cost-efficient.

It's good to know that not only the engine but also the aircraft is in the hands of experienced maintenance specialists. That's why MTU relies on collaborations with selected, competent partners. Starting this year, for instance, MTU Maintenance has been working more closely together with the Nayak Group, which specializes in line and base maintenance.

For Straatmann, the advantages of this partnership are obvious: "MTU Maintenance can now offer its customers not only comprehensive MRO solutions for engines but also line and base maintenance services on aircraft. In return, the Nayak Group will be able to expand the range of services it offers its customers in collaboration with MTU Maintenance to include engine MRO." Customers benefit from these partnerships, since it means their engines are up and running again more quickly and the aircraft is back in the air. Mission accomplished!

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.

Final departure

It set new standards and still delights passengers around the globe. Now, the final Airbus A380—the world's largest commercial aircraft—has been completed and delivered.

Text: *Andreas Spaeth*

Goodbye! —— *Since entering service, the A380 has completed more than 800,000 flights and carried more than 300 million passengers. Now, 14 years after the first delivery, the last aircraft of its kind leaves the factory in Finkenwerder.*

> *"The A380 has touched the lives of so many passengers by taking the experience of flying and traveling to a whole new level. I am sure that this will continue to be the case, at least with Emirates, for decades to come."*
>
> **Guillaume Faury**
> *CEO Airbus*

Boeing's monopoly — *Since they first entered commercial service in 1971, CF6 engines for the Boeing 747 have completed almost 430 million flight hours.*

New strategy — *Boeing's much smaller and more efficient 787 Dreamliner began serving secondary airports on nonstop services back in 2011.*

Plenty of thrust for superjumbos — *The Engine Alliance's GP7000 engine is one of two variants for the Airbus A380.*

On a clear afternoon in December 2021, onlookers gathered on the viewing area next to the runway at the Airbus plant in Hamburg-Finkenwerder. There, on the banks of the Elbe, they happily waited for hours to watch the 251st and final A380 take off. Airbus supplied the first A380, the world's largest commercial aircraft, to Singapore Airlines back in 2007. Now the last one was being delivered to Emirates, bringing the airline's total to 123 and cementing its place as by far the largest customer. The moon had already risen in the winter sky when, at 16:41, this last ever A380 took off on its delivery flight to Dubai. Much to the disappointment of all involved, this farewell took place without any guests of honor or festivities—the pandemic made this impossible. Fourteen years after the first one was delivered, production of this flying double-decker has drawn to a close.

It's actually because of the A380 that the runway in Finkenwerder was extended to where the planespotters and Airbus employees were standing. The program forever changed the face of that part of the city; at the beginning of the new millennium, an entire bay of the Elbe was reclaimed to provide land on which to erect the new A380 production building. And it wasn't just in Hamburg that the superjumbo left its mark but also in Toulouse and elsewhere; the logistics of having A380 production distributed across Europe were extremely complicated. This included operating several fleets of sea and river vessels as well as Beluga XL transport aircraft to move segments of the A380 from location to location.

Finally a counterpoint to Boeing's monopoly

As the new millennium dawned, Airbus wanted to finally have an aircraft to rival the Boeing 747. In commercial service since 1970, this legendary jumbo jet was scheduled to be taken out of production in 2022. Even though sales of the 747 were stagnating, Airbus decided to commit to building a superjumbo in the hope of finally disrupting Boeing's lucrative monopoly. Airbus predicted that there would be considerable demand for an aircraft that could service the world's major hubs and potentially accommodate up to 853 passengers on two decks. After substantial delays, the A380 entered commercial service in 2008, but things were soon to take a completely different turn. In 2011, Boeing launched its 787 Dreamliner—much smaller, much more efficient, and an economically viable way of serving nonstop long-haul routes out of secondary airports. Airbus countered with the A350. Suddenly, people could depart from, say, Düsseldorf and fly directly to destinations like Tokyo or Hong Kong.

Passengers were no longer keen to change at the busy hubs, and serving direct connections with these new twinjets proved to be a good business for the airlines. Larger, heavier and powered by four engines, the A380 was left out in the cold. For one of the A380's engine options, the GP7000, MTU Aero Engines is responsible for developing, manufacturing and assembling the entire low-pressure turbine and the turbine center frame as well as manufacturing high-pressure turbine components. Most A380 customers had trouble filling their aircraft, each with more than

End of an era ___ *In December 2021, the final superjumbo took off for Dubai–Emirates' A380 fleet will be flying for many years to come.*

500 seats, which made them expensive to operate. Only for a full-service carrier like Emirates, with its mega hub in Dubai, did the A380 prove to be the perfect aircraft.

An unexpected rise in late fall

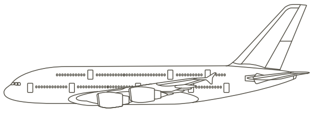
But in fall 2021, the number of people traveling rose so sharply that several airlines pressed their A380 fleets back into service as the ideal solution to an urgent problem. An unexpected rise for the superjumbo in late fall. "But as soon as business travel picks up again, there will be renewed demand for more frequent flights, which in many cases will see a daily A380 flight exchanged for multiple flights performed by more efficient twinjets," says Marko Niffka, Director Business Development – MRO at MTU.

At the same time, passengers' love affair with the A380 endures to this day, with many willing to take a detour if that means flying on one. This is largely due to the extremely quiet cabin and—depending on cabin class and equipment—the generous amount of space on board. On the occasion of the final aircraft's delivery, Airbus CEO Guillaume Faury said: "The A380 has touched the lives of so many passengers by taking the experience of flying and traveling to a whole new level. I am sure that this will continue to be the case, at least with Emirates, for decades to come." Emirates plans for its still young A380 fleet to be flying at least in and out of Dubai until the mid-2030s.

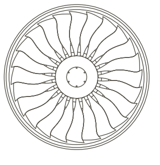
A final bow

The A380 encountered its fair share of obstacles. One of the major problems were the years of delays in developing and manufacturing the A380, which sadly revealed that the Airbus factories in Germany and France weren't working with compatible computer systems. When the A380 did finally enter service in 2008, this proved to be

Airbus A380



Airbus A380



GP7000

Four-hauler ___ *The giant with a wingspan of almost 80 meters is powered by four engines.*

Technology from two worlds ___ *The GP7000 is based on proven engine technologies from GE Aviation and Pratt & Whitney, which the two companies pool together in their Engine Alliance joint venture.*

Smaller aircraft exerting competitive pressure on larger ones

MTU experts predict that the market segment for large commercial aircraft will diminish in the future. “This is because they now face competition in the form of narrowbodies like the Airbus A321XLR, which can also serve long-haul routes,” says Marko Niffka, Director Business Development – MRO at MTU Aero Engines. MTU is excellently placed in this segment, in particular thanks to its involvement in geared turbofan engines such as the PW1100G-JM for the A321XLR.

“Narrowbodies suitable for long-haul routes reinforce the trend toward fragmentation of the market,” Niffka explains. He expects that this will put yet more pressure on the major hub airports, which have up to now also represented a potential market for the A380. MTU experts believe that even though the market for large aircraft will continue to shrink, the segment will hold its own at the top end of that market.

“These large jets—and the Boeing 777-9 will be one of them—are especially important to busy airports, which have hardly any takeoff and landing slots available. This area will sustain the market for large aircraft,” Niffka says.

extremely bad timing: the SARS outbreak and the financial crisis that followed meant that demand for large aircraft plummeted. However, and on this point aircraft manufacturers and industry experts agree, the learning effects of the A380 were immense. Airbus was forced to consolidate and for the first time act and present itself as a unified company.

As the final A380 left the Finkenwerder plant, the mood among the onlookers was a mixture of melancholy and defiant enthusiasm. “So honored to bring her home,” Captain Dwayne Walker posted on social media prior to takeoff. At dusk, he took the last A380 up to begin the journey to Dubai, turned the aircraft and completed a “go-around”; with headlights on full beam, Walker performed a spectacular near-landing in front of the illuminated factory building. It almost looked like the superjumbo was taking its final bow at one of its birthplaces.

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.

The GP7000 for the A380

GP7000 ___ *MTU is responsible for the development and manufacture of the low-pressure turbine and the turbine center frame, as well as for the production of high-pressure turbine components for the GP7000.*

Aviation history allows itself the occasional ironic twist. One of these is that the company that Airbus and all A380 customers actually have to thank for the very existence of the GP7000—one of the two engine variants for the world's largest commercial aircraft—is Boeing. Back in the mid-1990s, Boeing staged the first of many attempts based on the 747-400 to bring a commercial aircraft with even greater capacity to market. The only problem was that none of the three major engine manufacturers offered a powerplant that would be suitable for the planned suberjumbos—the 747-500X and 747-600X—nor were particularly interested in developing such an engine.

So as 1995 moved into 1996, GE Aviation, Pratt & Whitney and Boeing began talks about a possible joint venture between the two U.S.-based engine manufacturers with the aim of developing at least one suitable new engine. In May 1996, the collaboration agreement for the Engine Alliance was signed, immediately followed by the start of work on a new engine with the designation GP7000.

Even though the 747-500X/600X endeavor was soon shelved, the money invested wasn't wasted. In May 1998, a memorandum of understanding established that the Energy Alliance would develop the GP7000 for what would become the world's largest commercial aircraft, which at that point had the designation A3XX.

A further milestone for MTU

The GP7000 brought two worlds together: GE was responsible for the high-pressure turbine and high-pressure compressor, which borrowed significantly from those of the GE90 that powered the 777, but with certain components adjusted for the lower thrust requirements of the A380. Pratt & Whitney followed suit, capitalizing on its own product for the 777, the PW4000, for the low-pressure turbine and low-pressure compressor.

However, even though the Engine Alliance is a joint venture between GE and Pratt & Whitney, this doesn't mean that those two companies manufacture the entire engine themselves. On the contrary: MTU Aero Engines secured most of the remaining program share. Germany's leading engine manufacturer has a 22.5 percent stake in the GP7000 and is responsible for developing, manufacturing and assembling the entire low-pressure turbine and the turbine center frame as well as manufacturing the blades and disks for the high-pressure turbine. In addition, maintenance of the low-pressure turbine takes place at MTU in Munich.

The GP7000 program is yet another milestone in MTU history. It gave the Munich team a foothold in the next generation of widebody engines: the contract to develop and manufacture the turbine center frame for the GP7000 was followed by corresponding work on the GEnx (Boeing 787, Boeing 747-8) and the GE9X (Boeing 777-8X and Boeing 777-9X). Last but not least, MTU Maintenance benefited from contracts and gained valuable expertise from maintaining widebody engines.

An impressive 2.9 meters ___ *Mounting fan blades calls for highfliers—the GP7000 fan has a diameter of almost 3 meters.*

Sophisticated components ___ *MTU is particularly experienced when it comes to turbine center frames, having developed and built the one for the GP7000.*

Maintenance professionals at work ___ *MTU maintains the low-pressure turbine of the GP7000.*

Full power ___ *Each GP7000 provides just under 80,000 pounds of thrust—as tested at full capacity here on the test stand.*

Airbus A220 — *This jet combines state-of-the-art aerodynamics, advanced materials and latest-generation technologies and engines, and has a range of up to 6,390 km. The A220-300 is one of the two models available from the family. airBaltic operates 32 of the aircraft.*

Flying high over the Baltic

As the world's first airline with an all-Airbus A220 fleet, airBaltic is better off than others in times of the coronavirus pandemic. Innovation is a hallmark of the Riga-based airline.

Text: *Andreas Spaeth*

CEO and A220 pilot ___ *Martin Gauss has a special relationship with the modern Airbus aircraft.*

"Climate action will remain the big issue. We want to be a pioneer in this area and in this respect, the A220 is just the type of aircraft we need. The engine is already exceeding our expectations. Its performance and savings in fuel consumption and CO_2 are higher than we thought."

Martin Gauss
CEO airBaltic

Among the world's airlines, airBaltic has a unique selling point: the head of the company sometimes flies passengers personally—probably the only CEO of a major airline to do so. Martin Gauss is a pilot by training and used to fly the Boeing 737-300. And in the middle of the pandemic, of all things, he reached another personal milestone by earning his type rating as an Airbus A220 captain. "I already have almost a hundred flight hours on the A220, all of them under the supervision of a check pilot," Gauss explains. Depending on the schedule, he completes a rotation on the airBaltic route network once or twice a month. To complete the remaining hours he needs to keep his license, he uses the company's own simulator.

Market leader in the three Baltic states

"Home of airBaltic" is written in big black letters on the roof of the airline's administrative building at Riga Airport. In recent years, airBaltic has become the market leader in the three Baltic states, a region home to a good six million people. The airline understandably projects a healthy amount of self-confidence. Under the sign is a wall of windows, behind which stands Pauls Cālītis, the airline's chief operations officer and also a pilot. Large screens on the wall list every flight of the day with all the important data, including the current passenger numbers. Cālītis smiles as he reports the airline's high punctuality rate of well over 90 percent. "These are world-class figures."

"In love with airline and country"

The words on airBaltic's building are also fitting for Gauss, because Riga and Latvia have become home to the airline's CEO. The 53-year-old German started his aviation career in 1992 as a co-pilot on the Boeing 737-300 at Deutsche BA in Munich, where he later became a managing director. He then led Cirrus Airlines and Malév before becoming head of airBaltic in November 2011. "I completely fell in love with this airline and this country. This is my home, and that's what motivates me. I have a strong team who helped us get through the crisis," he says.

Right at the beginning of the coronavirus pandemic, airBaltic did pretty much everything differently than other airlines. "At that time, we locked ourselves in here at headquarters," Gauss recalls. "We had to develop a new strategy and a product that would be acceptable to passengers after the crisis. Initially, we of course had doubts about whether we would survive," he admits. Fortunately, airBaltic had large cash reserves (which the airline is still drawing on), plus a total of 340 million euros in capital increase from the Latvian government.

In March 2020, flight operations were completely suspended for two months, so radical cuts were necessary. The airline was downsized by 40 percent—almost 700 employees had to go, but all with a guarantee of reemployment when business picked up again. Some are already back. The fleet was also downsized and the three aircraft types whittled down to one. Here, airBaltic benefited from the fact that back in 2012, it had already decided to rely heavily on what was then the Bombardier CSeries. The company ordered up to 20 of the aircraft in its extended version, now called the Airbus A220-300. Today, there are 50 firm orders from the Baltic on the books, with a total of 33 aircraft delivered by March 2022 and seven more to follow in 2022. All 50 A220s on order will have arrived in Riga by 2024. "Since the coronavirus pandemic, it's become apparent that a 145-seat aircraft is just the right size, as this capacity is now suitable for a great many routes on which larger aircraft used to fly," Gauss says. "The crisis has accelerated our move to an all-A220 fleet. We've now accomplished what wasn't supposed to have happened until 2023."

The youngest fleet in the world

airBaltic now has the youngest fleet in the world, with an average age of 1.9 years. That is set to go down still further as more A220s are added. airBaltic is also the world's only operator of an all-A220 fleet and the airline with the most A220-300s. These serve its route network from all three Baltic capitals. The airline already operates its own A220 simulator and preparations are underway to build the region's largest hangar as a new maintenance center. "It will accommodate up to seven A220s. We'll then carry out all maintenance ourselves, apart from the engines, and we'll be the only airline to perform the C check for this aircraft type. In the future, we intend to offer this service to third-party customers as well," Gauss says.

airBaltic ___ *The airline is the world's only operator of an all-A220 fleet and the airline with the most A220-300s.*

airBaltic and the Airbus A220 have a special symbiotic relationship. The airline has always believed that this aircraft would show its advantages in a crisis, because it can be used on short-haul as well as long-haul routes. "We're already seeing that works. Take our new longest routes, for example. Since fall 2021, we fly from Riga to Tenerife and to Dubai, with each route taking around six hours," Cālītis explains.

Becoming a green airline

From the outside, airBaltic's corporate colors already make it a "green" airline—but as an airline based amid the stunning natural beauty of the Baltics, sustainability is an important concern as well. "Climate action will remain the big issue. We want to be a pioneer in this area," Gauss explains, "and in this respect, the A220 is just the type of aircraft we need." As a CEO with his own experience in the cockpit, he is in a better position than almost anyone else to get an idea of the performance of the new PW1500G, the member of the Pratt & Whitney GTF™ engine family that powers the A220. "The engine is already exceeding our expectations. Its performance and savings in fuel consumption and CO_2 are higher than we thought. And the technology will get even better," Gauss says. In addition, 6 percent of the kerosene consumed by airBaltic already consists of sustainable aviation fuels (SAF).

At any rate, the view from Riga is that they are in a strong position, even in difficult times: "It's clear that aviation is making a comeback," Gauss says. "We're happy with the current development and carried 1.6 million passengers in 2021. That follows the 1.34 million we had in 2020 and 5 million in 2019." And Cālītis is already arranging the next flights to collect the new A220s from Montreal. One of them was recently brought across the Atlantic by Gauss himself—a special treat for him, too.

MORE INFORMATION ON THE TOPIC OF "A220":

Take the long way to Tenerife – experiencing the A220 on its longest route.
www.aeroreport.de/en

GTF™ engine family ___
The new engines offer double-digit percentage reductions in fuel consumption, pollution and noise emissions as well as operating costs.

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.

Minimally invasive work on the multirole transporter

COVID-19 patient transports, relief supplies for crisis areas, the Kabul air bridge: How the Airbus A400M performs as a multirole transporter—and what MTU does to keep its engines in service.

Text: *Thorsten Rienth*

The most powerful turboprop in the West — *Four propellers with an impressive diameter of 5.33 meters power the transporter.*

Through an opening just a few millimeters wide, Stefan Zager feeds the borescope thirty, forty, fifty centimeters into the engine. Next to each other at the end of the device are a tiny light and a small camera. Zager is up a ladder, a good five meters above the hangar floor. To his right is a tablet showing high-resolution images of what the camera is seeing inside the engine: small metal components shaped like gearwheels and surfaces in different tonal gradients.

Zager is a Customer Service Representative for the TP400-D6 engines that power the Airbus A400M, which explains why MTU Aero Engines dispatched him to Wunstorf. Not far from Hannover, this military air base is home to Air Transport Wing 62 of the German Air Force. Zager, who has worked at MTU for 25 years, and his colleague Steffen Eckert are on-site to ensure the A400M's engines run smoothly. This involves the on-wing check with the borescope.

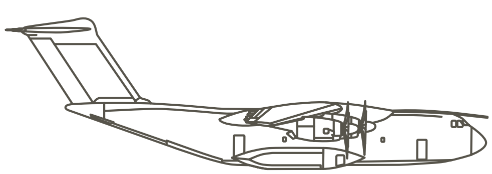
4,000 kilometers carrying a 25 metric tons – and still enough kerosene to keep flying

"This aircraft is designed to handle a vast array of missions," says Roberto Ungericht, Director TP400-D6 at MTU. "The A400M is the first multirole military transporter truly worthy of the name." It has already demonstrated its versatility on missions all over the world, for instance in crisis areas in the Middle East and North Africa, transporting patients in Europe at the beginning of the COVID-19 pandemic, and as part of the air bridge to Kabul in summer 2021.

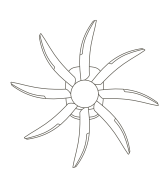
Air Transport Wing 62 ___ *All the Airbus A400Ms of the German Air Force have been stationed at the Wunstorf location with Air Transport Wing 62.*

Airlift ___ *Forces deployed to Afghanistan for the military evacuation mission land at Wunstorf Air Base in an Airbus A400M transport aircraft.*

MULTIROLE TRANSPORTER



Airbus A400M



TP400-D6

MTU is responsible for the TP400-D6's medium-pressure compressor, turbine and shaft, among other things. It also handles final assembly of all volume production engines at its Munich location.

Refueler, troop carrier, flying intensive care unit: the Airbus A400M can be deployed in a variety of ways and can be converted to specific mission scenarios within a matter of days. Powered by four three-shaft turboprop engines, the transporter can carry 25 metric tons payload over a distance of 4,000 km.

What could be described as a toolbox allows the aircraft to be modified for specific mission scenarios within just a few days. For instance, it might be converted from a troop transporter to a refueler, complete with two additional 7,200-liter tanks in its belly. Its system is designed for the aerial refueling of everything from slow-moving helicopters to high-speed fighter jets. The A400M might also be converted from a medevac—a flying intensive care unit—into a tactical transporter capable of moving a 25-metric ton payload over 4,000 kilometers to a 750-meter dirt runway and still have enough fuel to travel another 930 kilometers.

The trick with the gearwheel

At sea level, each of the four three-shaft engines delivers 10,680 shaft horsepower. That makes the TP400-D6 the most powerful turboprop engine ever built in the Western world. Only the Kuznetsov NK-12 engines, which powered aircraft like the Tupolev Tu-114 made in the former Soviet Union, surpass it. The diameter of the TP400-D6 propeller is also an impressive 5.33 meters.

"TP," as it is affectionately referred to by the mechanics who work on it, was developed by MTU, ITP Aero, Rolls-Royce and Safran Aircraft Engines as part of the Europrop International (EPI) consortium. MTU is involved in the TP's medium-pressure compressor, medium-pressure turbine and shaft, and the engine control unit. In addition, MTU handles final assembly of all volume production engines at its Munich location and looks after the TPs mounted on the A400M aircraft operated by the German

Maiden flight ___ *The TP400-D6 powers the A400M military transport, which completed its maiden flight in Spain's Seville in late 2009.*

TP400-D6 production engines ___ *Final assembly takes place at MTU Aero Engines in Munich and acceptance testing at MTU Maintenance Berlin-Brandenburg.*

Air Force. MTU Maintenance Berlin-Brandenburg is home to the world's only production test stand for A400M engines, which also happens to be the largest production test stand for propeller engines in Western Europe. In other words, every engine that takes to the skies after maintenance has been through the test cell at the Ludwigsfelde site south of Berlin. The first shop visits are scheduled for when the engine has completed between 3,000 and 3,500 flight hours.

A special feature of the TP is that on each wing, one engine rotates clockwise and the other counterclockwise. The two counterclockwise-rotating propeller engines are equipped with an extra gearwheel that changes the direction the propeller rotates. The counterrotation trick ensures equal lift on both wings and thus avoids premature stalling.

Minimally invasive control for efficient flight operations

The job Zager is doing up the ladder also has to do with the wings, or rather with the mounting of engines on them. Demounting and remounting the engines can easily take a week to complete. "All that time, the aircraft remains out of service in the hangar," Zager says. The millimeter-wide borescope boss provides a minimally invasive shortcut, one that can be taken for scheduled maintenance as well as for ad hoc checks performed because the flight crew noticed something unusual. "This allows us to give the all-clear right away," Zager says, "or to say that it's worth taking the engine off the wing." In this way, Zager's critical glance through the borescope boss is essential in ensuring efficient flight operations.

TEXT:

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

MORE INFORMATION ON THE TOPIC OF "TRANSPORT AIRCRAFT":

The Transall flies off into the sunset
www.aeroreport.de/en

Unique in Europe

This successful maintenance collaboration between MTU and the German Air Force integrates both military personnel and MTU employees into the workflows.

Text: *Thorsten Rienth*

The two of them are colleagues, that much is clear: Together, they inspect the wiring harness of an engine that has just arrived for a shop visit at the MTU Aero Engines operational facility at the Erding airbase. Nevertheless, the well-rehearsed tandem differs in one essential detail: He is wearing German military gear. She's in MTU overalls.

20 years of successful collaboration

“A good 20 years ago, this kind of collaboration was virtually unthinkable,” says Lieutenant Colonel Stephan Schmidt. “Military and industry were understood as customer and service provider. One paid and the other delivered.” But in 2002, the lines separating the two shifted and a new chapter began—at least in the history of repairing the EJ200 engine for the Eurofighter. The EJ200 marked the dawn of a new kind of collaboration between the German Armed Forces and MTU, one that integrated military personnel alongside MTU employees into the company’s workflows. Today, Lieutenant Colonel Schmidt is the military coordinator for this collaboration, which is unique in Europe. Schmidt’s “civilian” counterpart is Mario Külgen, who manages the agreement between the engine manufacturer and the German Armed Forces and oversees the systematic integration of military personnel into MTU processes. “Although MTU bears the overall responsibility for the repair package, the military personnel—predominantly technical officers and engine mechanics—still report to the German Air Force,” Külgen explains.

Engine specialist — *As a rule, MTU's involvement in the German Air Force's military engines stretches back to their development–as here with the EJ200 for the Eurofighter.*

Eurofighter engine EJ200 — *With up to 20,000 pounds of thrust each, these two engines power one of the world's most advanced fighter aircraft.*

Tornado engine RB199 — *These engines have logged more than 7 million flight hours in Europe's most successful military aircraft program to date.*

Tiger engine MTR390 — *This turboshaft engine featuring a free power turbine delivers a maximum thrust of 1,094 kilowatts to power the support helicopter.*

Completing the trio is Michael Hergeth, who heads MTU's operation facility in Erding and is responsible for ensuring the repair work is performed. "In addition to actual engine repairs, the work package covers spare parts management and forecasting, damage inspections, product monitoring, and quality assurance," Hergeth explains. "But these take place at MTU's location in Munich, where military personnel assigned to the collaboration are also integrated into the relevant teams." Besides the switching out of engines at the aircraft, the only other tasks handled by military personnel at German Air Force locations are smaller checks and the exchange of accessories.

When looking for an industrial partner, MTU is the first choice for the German Armed Forces

Back in the late 1990s, the German Federal Ministry of Defence, the German Air Force, the BWB (which was then the procurement office for the German Armed Forces), and the German Aerospace Industries Association (BDLI) laid the foundations for the collaboration. From then on, it was not just the fighter's price tag that was relevant: its operating costs were now also being examined. Engine maintenance represents a large portion of those costs.

Up to that point, the German Armed Forces had always maintained some of its engines itself, with the others going to its industry partner. This meant that two separate infrastructures existed for the same job–one in the MTU shops, the other at Air Force locations. Wouldn't it be better to consolidate operations at a single location, to pool expertise instead of everyone doing their own thing?

"Of course," answers Lieutenant Colonel Schmidt. He highlights what the priorities of the German Armed Forces are: "It relinquishes the maintenance work, but not the skills. It is still involved in the engine types and remains a knowledgeable customer." This is important because the German Armed Forces must possess the skills it needs to get the job done in any situation at any time, even in remote places.

When looking for an industrial partner, MTU is the first choice for the German Armed Forces. The company's collaboration with the German Armed Forces dates back to 1959, the same year that the J79 engine for the Starfighter was first produced under license. Then came the RB199 for the Tornado, the Tyne engine for the Transall and the TP400-D6 engines for its successor, the Airbus A400M. There was also another factor that impacted the selection: as a rule, MTU was already involved in developing these engines. "And who could be more suitable to maintain the engines than the manufacturer itself?" Hergeth says.

A partnership of convenience to one of excellence

Hergeth, Schmidt and Külgen all agree that the collaboration provides the German Armed Forces with plannability and cost-effective maintenance, and MTU with a system partnership and a stable contractual arrangement.

Beyond the EJ200, this also now applies to the RB199 as well as the MTR390 for the Tiger helicopter, which were incorporated into the collaboration in subsequent years. Every month, the

Hand in hand *In this highly successful maintenance collaboration, German Armed Forces personnel and MTU employees work closely together.*

repair collaboration handles up to nine EJ200 engines, up to five RB199 engines and up to three MTR390 engines.

It's no secret that the collaboration started out essentially as one of convenience. "But we've long since become real partners—not just in the way we act, but also in the way we think," Hergeth explains. "Our goals are absolutely in sync: to get the engines back on the wings—or, in the case of the Tiger, back under the blades—as quickly and cost-effectively as possible and in the best quality we can achieve." What's more, the collaboration can also claim to be measurably successful: "In the first ten years, for instance, we doubled the RB199's on-wing time," Hergeth reports. "Its reliability increased by 20 percent over the same period. And these values have remained stable to this day."

"We always arrive at a joint solution."

Touring the hangars at Erding airbase with Schmidt and Hergeth, it quickly becomes clear that much of the collaboration's success lies in the chemistry between the partners. "I've known the German Armed Forces since I did my own military service. I like the mutual respect and the pragmatic mentality that you encounter there," Hergeth says. For his part, Schmidt values Hergeth's appreciation of how the German Armed Forces works and that he understands why a military operation sometimes has to follow different rules than an industrial one. Their offices are within hailing distance of one another. Not that anyone's barking orders here.

Külgen also sees the close ties between MTU and the German Armed Forces as being one of the collaboration's key success factors: "I've had one foot in the military for 25 years now as a reserve officer. Here we just really know where we stand with each other."

Fan, combustor, turbine, afterburner—one after another until the engine, which has been dismantled for the shop visit, is reassembled. On their way back to the Eurofighters, the engines just have to make one minor detour. The newly repaired engines still have to go through acceptance testing at the EJ200 test stand at MTU in Munich.

"Our goals are absolutely in sync: to get the engines back on the wings—or, in the case of the Tiger, back under the blades—as quickly and cost-effectively as possible and in the best quality we can achieve."

Michael Hergeth
Head of MTU's operation facility in Erding

TEXT:

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

MORE INFORMATION ON THE TOPIC

Link to the video: MTU and the German Armed Forces - cooperation built on a strong partnership
www.aeroreport.de/en

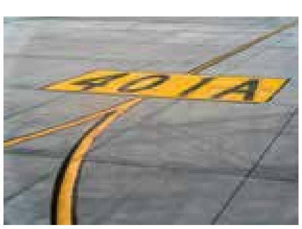
BEFORE THE FLIGHT

Taxiing – the high art of ground maneuvers

Before an aircraft can take off, it often has to taxi for miles. This taxiing is a challenge for pilots and air traffic controllers.

Text: *Monika Weiner*

Airport traffic police *Tractors and follow-me vehicles are used to ensure that traffic at the airport remains safe and orderly.*



Clear regulations *Taxiway signage is standardized worldwide and referred to using the international spelling alphabet.*

How does an aircraft get from the gate to the runway?

The overhead bins are all closed, the passengers' seatbelts fastened, the doors locked. With the tiniest of jolts, the aircraft starts moving. While the passengers are already dozing or observing the hustle and bustle at the airport, the cockpit is a scene of the utmost concentration: to get the aircraft to leave its parking position at the gate, a special pushback vehicle is needed to reverse it onto the tarmac, usually with the help of special rods attached to the nose wheel. Only when there's enough space for the aircraft to start taxiing forward is the pushback vehicle uncoupled. From that point on, the pilot steers the aircraft to the runway. This is a challenge—not only because of the wingspan, but also because of the many regulations that have to be observed during taxiing.

What does taxiing mean?

The word "taxi" meaning a car that carries paying passengers ultimately derives from the ancient Greek for payment. Its aviation sense comes from a flying machine built over 100 years ago in Paris in which early student pilots would practice taking off and landing; because this aircraft spent most of the time slowly rolling around the flight school grounds like a taxicab looking for a fare, it acquired the name "taxi." Today, taxiing applies solely to moving an aircraft on the ground. It's an activity that can take up quite a bit of time: on average, it takes ten minutes to taxi out from the gate to the runway for takeoff. At the end of a flight, it takes another five minutes to taxi in from the runway to the gate. To prevent aircraft from getting in each other's way during taxiing, large airports have multiple taxiways. These taxiways are named after letters and, if necessary, additional digits. Taxiway signage is standardized worldwide: black traffic signs with yellow lettering indicate which taxiway you are on; yellow signs with black lettering are indications of turnoffs.

How is traffic organized on taxiways?

Operations on the taxiways are regulated by the air traffic controllers. They give instructions to the pilots according to the international spelling alphabet. "Taxi via Mike one and Papa three," for example, means that an aircraft should use taxiways M1 and P3. Each decision as to which aircraft is sent to which runway—especially at large airports, where hundreds of aircraft are directed from the terminals to the runways and back every day—relies on a sophisticated logistics system. To prevent congestion and collisions, controllers must take into account not only the aircraft's taxiing speed, but also the duration of the stops needed to start the engines, perform system checks, and work through checklists. In addition, depending on the type of aircraft, there is the length of the runway required for takeoff. This value determines at which intersection an aircraft is sent from the taxiway to the runway.

Who controls the aircraft when taxiing?

At most airlines, taxiing is the job of the pilots. There are good reasons for this: maneuvering on the ground requires a lot of experience and the ability to keep an overview when navigating. Pilots must be aware of the traffic situation and know which aircraft they should follow to any given take-

What does the future look like?

Technical developments can make taxiing more sustainable

Aircraft engines are optimized for flight, not for slow maneuvers on the ground. So airport operators, airlines, and aircraft and engine manufacturers are looking for new, energy-saving propulsion systems for ground maneuvers. Various concepts for both ground-based and on-board systems have already been developed and, in some cases, tested.

The simplest way to reduce energy consumption in taxiing doesn't require any additional equipment: in **single engine taxiing, or SET**, the pilot runs only one of the engines while on the tarmac; all the others go into operation only shortly before takeoff. Estimates suggest that this can cut fuel consumption at the airport by more than 20 percent.

The flagship of the ground-based systems is the TaxiBot, an autonomous aircraft tractor with a hybrid diesel-electric powertrain, which has already been tested at Amsterdam's Schiphol Airport. A driver maneuvers the **TaxiBot** backwards to the nose landing gear of the aircraft and docks there. This turns the vehicle into an external propulsion system that the pilot can control from the cockpit. With the help of the TaxiBot, the pilot can now drive to a holding position just before the runway, then switch on the engines for takeoff. This achieves fuel, carbon dioxide and nitrogen oxide savings of over 50 percent.

On-board systems are based on electric motors that could be installed in one or more landing gears. Such **e-taxiing systems, or ETSs,** would improve aircraft maneuverability, eliminate the need for pushback vehicles and greatly reduce noise emissions at airports. The power needed to operate the electric motors could be generated on board the aircraft either by the existing auxiliary power units, or APUs, or by fuel cells. According to developers, e-taxiing has the potential to reduce emissions of air pollutants by more than half.

off or parking position. The co-pilot could theoretically also control the aircraft, but usually does so only for training purposes or while the pilot is making an announcement to the passengers.

What happens when things get tight?

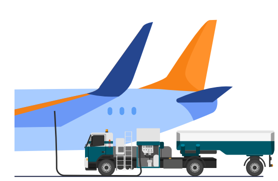
It is rare for aircraft to get too close to each other on taxiways. But if it does happen, for example after a pilot goes the wrong way, it gets complicated because aircraft are very difficult to maneuver: while reversing is possible using reverse thrust of the engines, it leads to high noise emissions. In addition, pilots can't see the area behind the aircraft from their seat in the cockpit. This means the crew is dependent on outside help for maneuvering: depending on the situation, a follow-me vehicle is called, whose driver can observe the wingtips and ensure that they don't come into contact with any obstacles. In an emergency, a pushback vehicle must come and push the aircraft back until it has enough room on the runway to continue forward.

From taxiing to flying

Taxiing isn't over until air traffic controllers give permission for takeoff, at which point the aircraft turns from the taxiway onto the runway and accelerates.

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 OF "BEFORE THE FLIGHT":

The math problem of refueling:
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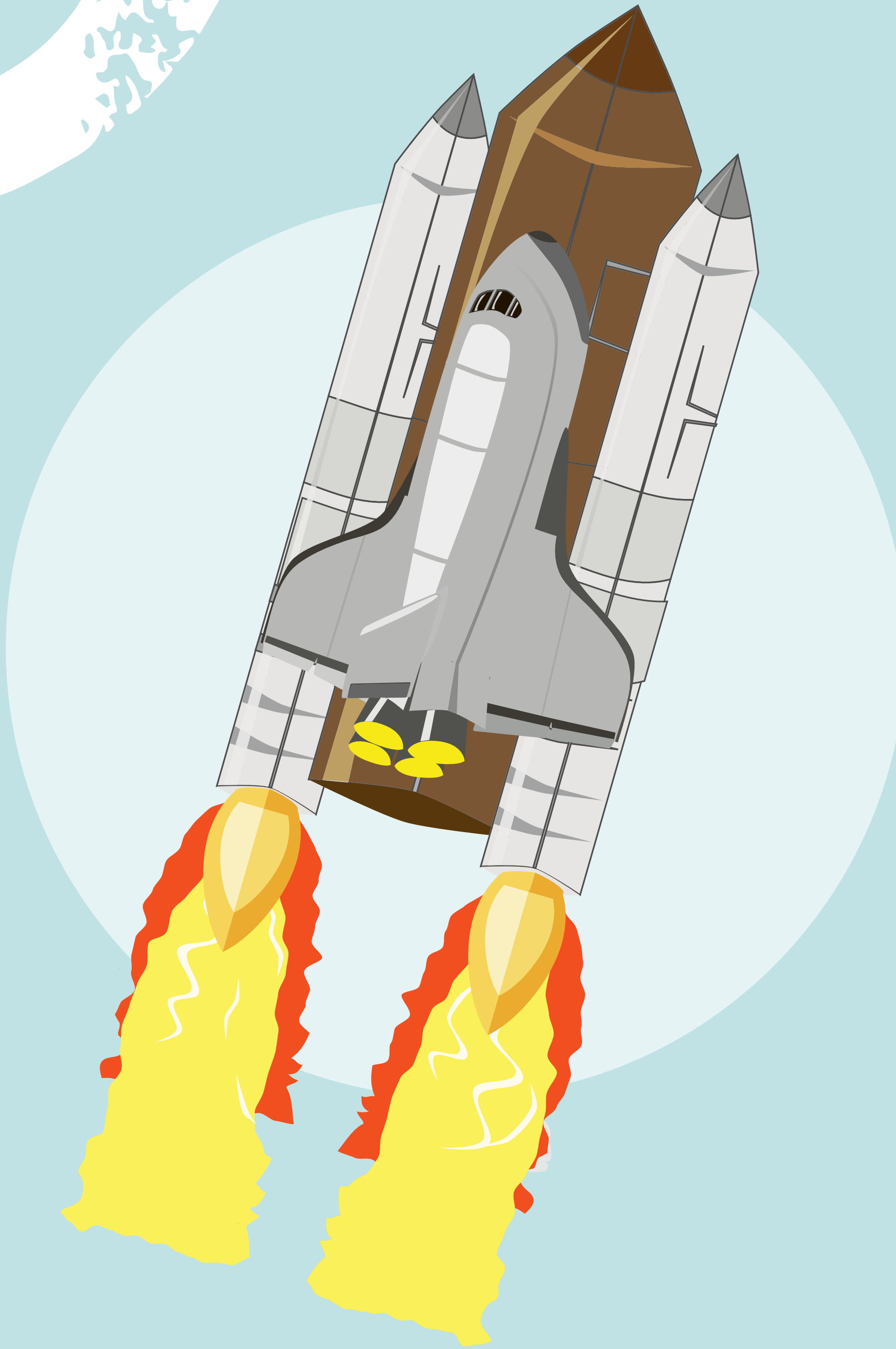


Winged words

Our everyday language is full of expressions with origins in aviation hardly anyone knows. We track down the unexpected background to some familiar phrases.

Text: *Andreas Spaeth*

WINGED WORDS NO. 01:

“Helicopter parents”

Flight has had a surprisingly big impact on our everyday language. “It wasn’t long before hovering and flying had found their way into idioms—or winged words, you might call them,” explains Rolf-Bernhard Essig, curator of “Bombenwetter,” an exhibition dedicated to this language phenomenon. The title is a German term for perfect weather conditions enabling a bombing raid—a phrase with obviously wartime origins. Instantly the curator points out some classic examples: Ambitious but unrealistic ideas are known as lofty plans. And many cultures recognize that people who fly too high have far to fall. Even time itself flies by. Such aerial references are part of our everyday language; Essig even claims that everybody uses such idioms about a hundred times a day. Many of these expressions have quite concrete origins in First or Second World War aviation, but some came into being only in recent decades. **AERO**REPORT presents a few selected examples.

Helicopter parents

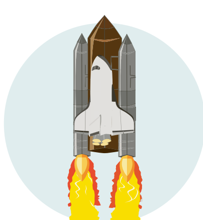
This species of parent is notorious for its overwhelming surveillance and overly attentive behavior toward its offspring, creating challenges for others on the way. The exhibition quotes a former president of the German teachers’ association, who distinguishes between three kinds of helicopter parents: “The transport helicopter, the attack helicopter and the rescue helicopter.” As a noun, the term is recognized in several major language dictionaries; in 2020, Germany’s standard reference work Duden even added it as a verb, so it has definitely reached mainstream vocabulary. Duden defines it as: “to constantly survey your own children due to being overly attentive.” It was about 30 years ago that US child psychologists first used the term “helicopter parents.” Its origin was very fittingly explained at the Miltary History Museum at Berlin-Gatow next to the VIP version of the Mil Mi-8S helicopter, which was still in active use at the time the expression emerged.

Going off like a rocket

Rockets have a surprisingly long pedigree in colloquial expressions. The German phrase for “going off like a rocket” made it into the dictionary back in the 19th century, where it was understood to mean making a sudden, hasty movement. Rockets firing into the sky have long inspired poetic turns of phrase with their proverbial speed and explosive nature. But the meaning of “rocket” has changed over time. Earlier uses focused on the negative consequences of pride and arrogance; for instance, Germans used to say: “When the rocket is at its highest, that’s when it explodes.” At the turn of the 20th century, someone with a short temper would be referred to as a “rocket.” Since the 1950s, though, “going off like a rocket” has tended to describe behavior that is particularly lively, fast and spirited.

WINGED WORDS NO. 02:

“Going off like a rocket”

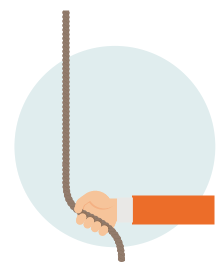


To pull the rip cord

The timeline of terms that can be traced back to aviation starts with “to pull the rip cord.” In German, this is a well-known expression meaning to stop a dangerous development in time, which translates as “pulling the plug” in English. It stems from the turn of the last century and has its origin in ballooning. At the end of the 19th century, a Berlin-based aero club was operating meteorological research missions with a balloon called “Phoenix.” This is where the modern rip cord premiered: a red cord, which helped to instantly let gas out of the balloon by rapidly tearing off a strip of its fabric previously applied for that purpose. This would prevent the balloon from being dangerously dragged along the ground after landing and possibly suffering serious damage to its cover. Today, this term is very common in German economic jargon, for example when a company terminates a project or product it had initially invested a lot of money in to prevent it from becoming a liability.

WINGED WORDS NO. 03:

“To pull the rip cord”



Booster

If there’s one term that sees almost inflationary use in product branding, it’s “booster.” There are booster energy drinks, hydro boosters in face masks for skin care, immune boosters as a food supplement or the booster mascara in cosmetics, and that’s only a small selection. A “booster” means an auxiliary device for increasing force, power, pressure, or effectiveness. Originally, however, it was the first stage of a multistage rocket providing thrust for launch and initial flight. Boosters are also used in aviation to enhance an aircraft’s thrust on take-off. For instance, in 1960s Ger-

WINGED WORDS NO. 04:

“Booster”

many, attempts were made to equip the Luftwaffe’s Lockheed F-104G Starfighter bombers so they could get airborne even without their normal 1,700 meters of take-off run, in the event runways had been destroyed. Thanks to a solid rocket booster, the aircraft could accelerate to 500 km/h and reach 200 meters of altitude in under eight seconds with only a minimal take-off run.

Murphy’s Law

When an open-faced sandwich falls to the ground, naturally it will land upside down. Or if you’re waiting in a line, yours will always be the slowest one inching forward. This is the essence of a realization that “anything that can go wrong will go wrong.” It’s an assertion that has been called Murphy’s Law in common language for decades—and it goes back to a US Air Force test campaign between 1946 and 1958 to research the impact of acceleration forces on the human body. Using rocket-propelled sleds, these tests assessed the biomechanical effects of high speeds on the human body. The objective was to define the physical limits for pilots bailing out with ejection seats. As the legend goes, for one specific test run, the sensors were wrongly attached after an assistant had to choose between two options—and picked the wrong one. This prompted Air Force engineer Edward Murphy, part of the team, to make his famous comment, which then spread quickly. It became a pillar of the “fail-safe” principle that has guided aviation designs ever since, calling for system backups and redundancies, just in case.

WINGED WORDS NO. 05:

“Murphy’s Law”

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.

MASTHEAD

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Journey into an engine

On with the virtual reality (VR) headset and into the dynamic engine model.

How does an engine work? —— *Apprentices can use a VR headset to explore how an engine operates.*

MTU Aero Engines has developed a VR training solution that allows apprentices to explore a digital engine that runs just like a real one. The model is based on the PW1100G-JM—a member of the state-of-the-art Pratt & Whitney GTF™ engine family—which powers the A320neo.

"The VR model shows the engine at full scale as well as a detailed cutaway. Apprentices can turn the engine on to study the way the air flows and the parts move," explains trainer Markus Voag. In addition, it's possible to remove the entire housing so they can then take out and inspect the individual modules. The explosion diagram showing the separate components also features infoboxes containing technical data. The headset adjusts the 3D image with each head movement, revealing further technical details about the commercial engine. Apprentices can either don a headset themselves and move freely around the model, or use a headset hooked up to a large display to deliver a presentation on the individual elements.

"It would simply be too expensive to have a real one of these engines available for training purposes," Voag says. He also acknowledges the 3D model's educational value: "Allowing young people to experience the benefits of this kind of technology might make them more open toward virtual reality applications later on in their career." The training shop does possess an older real engine, and the digital model is intended to supplement rather than replace it.

The model has been used in the MTU training shop since March 2022. In the future, this solution will also be used to provide new employees with their first insights into how an engine works—and bring the technology more to life.


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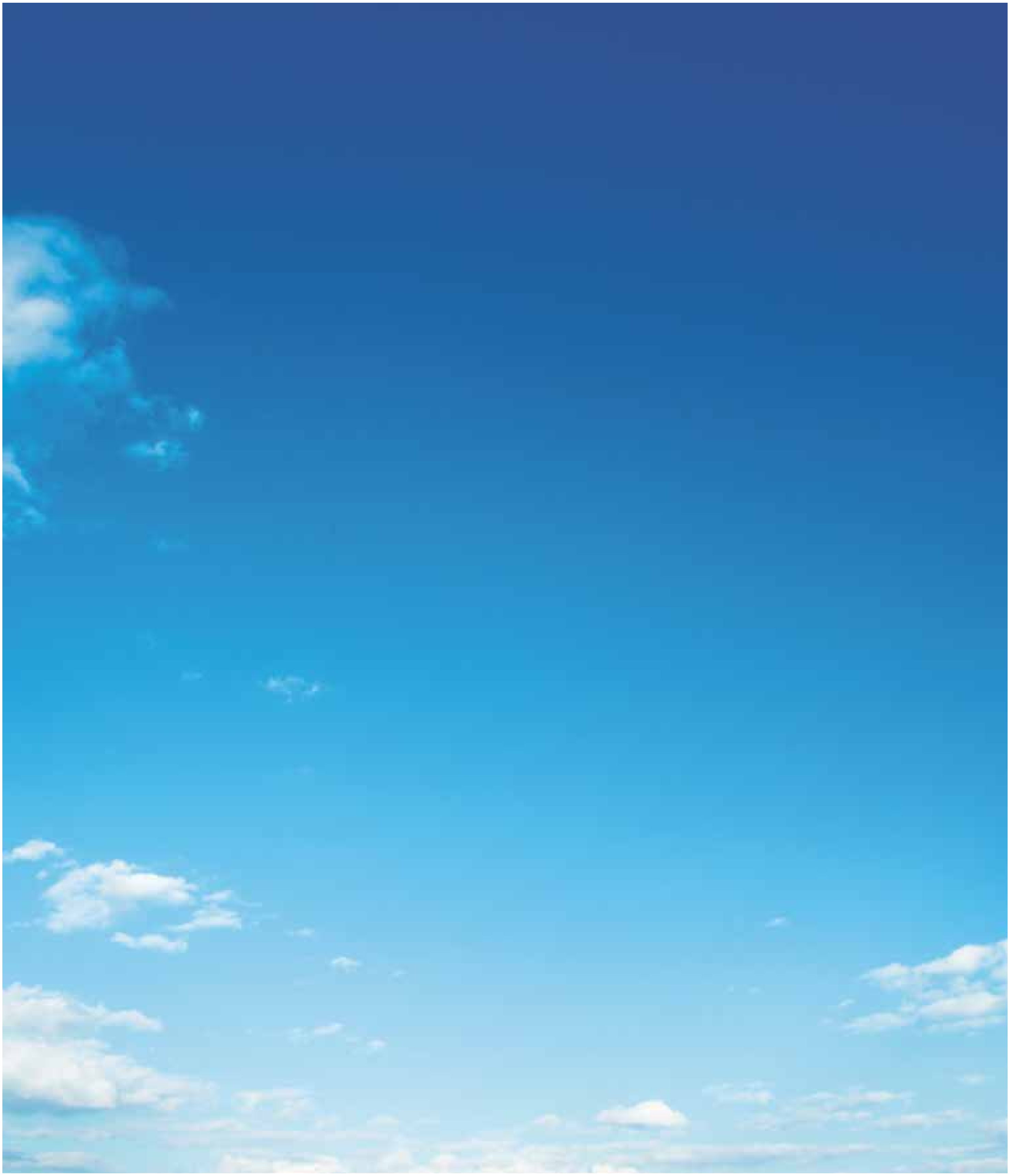

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