

# AEROREPORT 01|19

The aviation magazine of MTU Aero Engines | [www.aeroreport.de](http://www.aeroreport.de)

## The spirit of invention

*Innovation for aviation engines:  
Yesterday, today and tomorrow*

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### COVER STORY: 2050

Thrust for  
the future

### INNOVATION

Bionics make  
engines quieter and  
more efficient

### AVIATION

New long-haul business  
jets give the market  
new momentum



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Special feature in this issue of **AEROREPORT**:

## **Innovation for aviation engines—yesterday, today and tomorrow: since 1969, the MTU name has stood for technological progress in engine manufacturing**

*From the first engine developed as a pan-European effort, to additively manufactured components, and beyond: six stories highlight milestones in MTU Aero Engines company history, culminating in a look ahead at future developments that MTU experts are already working on today.*

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*Dear readers,*

The year 1969 saw a whole host of important events in aviation history, including flight testing of the Concorde and Tupolev Tu-144 supersonic aircraft and the maiden flight of the four-engine Boeing 747. On May 29, 1969, a joint development contract for the A300 signed at the Paris Air Show marked the launch of Airbus, and on July 11, the aircraft engine and large diesel engine divisions of Daimler-Benz and MAN Turbo merged to form a company called MTU, short for MTU Motoren- und Turbinen-Union München GmbH M.A.N. Maybach Mercedes-Benz. Today, MTU Aero Engines is Germany's leading engine manufacturer.

For 50 years, the MTU name has stood for the constant drive to innovate, to push the limits of technology—and to embody a culture of innovation. Today, the company leads the world

in a number of key technologies. Our high- and low-pressure turbines, turbine center frames and not least the innovative repair techniques used by MTU Maintenance are among the best out there.

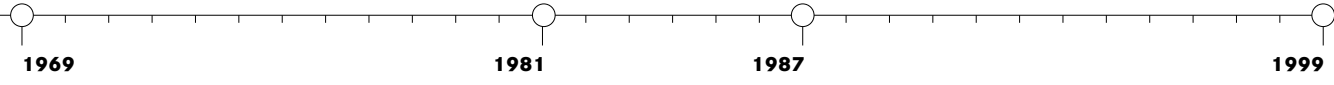
With a global population of several billions, mobility demands continue to rise. Aircraft engines must become more economical, cleaner and quieter. As in the past, MTU will continue to have a major impact on engine development in the future, too.

In this issue, join us on a journey through 50 years of innovation at MTU, up to and including a look at propulsion technologies of tomorrow. We give you an insight into bionic structures in engine construction and modular aircraft concepts, and present our customer Asiana Airlines.

I hope you enjoy reading this issue!



Reiner Winkler  
*Chief Executive Officer*



**COVER STORY: 1969**

The engine that started it all

MTU Aero Engines engineers had to overcome several challenges to get the Tornado engine performing as it should. A tricky task that laid the foundation for invaluable knowledge and the basis for the company's success.

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**COVER STORY: 1981**

A league of their own

Today, MTU low-pressure turbines have a huge range of applications: in bizjets, transport helicopters, and medium- and long-haul aircraft. The path to becoming a world-class manufacturer of low-pressure turbines began 45 years ago with an exhaust casing.

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**COVER STORY: 1987**

How the engine of the future was developed

The partners Pratt & Whitney, Fiat Avio and MTU Aero Engines began researching Geared Turbofan™ technology in the 1990s with the help of a demonstrator. Today, the innovative engine sets the industry standard.

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Blisks were used for the very first time in the Eurofighter EJ200 engine. Today, the rotor disks in the compressor with integrated blades are manufactured on a large scale using a technique specially developed by MTU Aero Engines.

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**COVER STORY: 2011****Printing a component, layer by layer**

With its use of additive manufacturing, MTU Aero Engines has become one of the first engine manufacturers to have implemented a process that manufactures lighter components using selective laser melting. It will also be used in the future to produce more complex components.

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**COVER STORY: 2050****Thrust for the future**

“Answering tomorrow’s challenges”: For MTU Aero Engines, this principle is both a motto and a responsibility. Never before has the company had such good answers ready as today.

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# The engine that started it all

*MTU Aero Engines had to overcome several challenges to get the Tornado engine performing as it should—and built up invaluable knowledge in the process.*

**Text:** Denis Dilba

## 1969



**Pooling power** — MTU, Rolls-Royce and Fiat (now Avio Aero) began developing the RB199 in 1969.



**Going the distance** — A total of 2,504 RB199 engines were manufactured, several of which are still in service.



**The Tornado** — It is still impossible to imagine European air defense without the Tornado.

“Without the RB199, there would be no MTU Aero Engines.” This one sentence underlines the importance the development of the Tornado engine had for MTU. But this alone does not do justice to this pioneering achievement. Because no other story illustrates quite as effectively what MTU had been about since day one: using high-caliber technical ingenuity to push the boundaries of what’s possible—in short, to innovate. Back at the start of RB199 development in 1969, this was known as engineering ingenuity, says engine developer Arthur Schäffler. This savvy was absolutely necessary in order to master the challenges MTU engineers faced back then with the new jet engine, notes 81-year-old Schäffler, who was part of RB199 development from day one and whose career would take him all the way to the role of technical director for Eurojet.

“The mission requirements for the Tornado could hardly have been any bigger,” remembers Schäffler. “On the one hand, the multirole fighter had to intercept enemy aircraft at Mach 2.2, on the other master operations at low altitude.” And of course the jet should be able to take off and land on short runways. In other words, the RB199 not only had to generate a great deal of thrust while being as lightweight as possible—and consume low amounts of kerosene and enable peak acceleration in a short timeframe—it also had to have a thrust reverser. The idea was to have a three-shaft engine with 12 compressor stages, with a compressor pressure ratio of 23:1 and a turbine inlet temperature of some 1,300 degrees Celsius. “Considering what was state of the art back then, this was a massive leap in both of these respects,” Schäffler says.

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### Grown-up challenge for the young MTU


Schäffler remembers how the Turbo-Union consortium, a joint venture between Rolls-Royce (40 percent), Fiat (20 percent) and MTU (40 percent) that was founded specifically to build the RB199, eagerly set about work. The division of labor meant that the MTU team, made up of engineers from MAN Turbo and Daimler-Benz, “landed a major deal considering what they knew at the time,” says Schäffler. “We were responsible not only for the medium- and high-pressure compressors, the medium-pressure turbine and thrust reverser, but also for the internal air and oil system for cooling and lubricating the highly stressed casing and channeling cooling air to the turbine blades. Such technological requirements were not the only uncharted territory for MTU. Up until that point, the Munich-based company and its predecessors had mainly manufactured licensed engine parts and had never had the responsibility for developing such major portions itself. “Being solely accountable for an assembly also meant we were under a fair amount of psychological pressure,” Schäffler says.

The modest performance of the first RB199 test run met with long faces among Schäffler and his colleagues. “The efficiency was considerably below par,” he says. While the medium-pressure compressor quickly attained “very satisfactory” performance, the high-pressure compressor ran into complex problems. These included the relatively thick rotor blades of the rear stages—which were made from heavy nickel alloys—expanding significantly slower than the casing under fast-changing operating conditions such as acceleration and deceleration. This meant that over long phases, the radial clearance became too large. The result was reduced performance parameters for the high-pressure compressor and an impermissible lowering for the aerodynamic stability threshold. “It was a long time before we found a design that successfully slowed the expansion of the casing,” Schäffler says. At least all the engine manufacturers were in the same boat at that stage, says the engineer. “The clearance problem was not well known—we just had to accept the long time it took to find a solution.”

### Failing the bird strike test

Just as surprising was the discovery that the surface of the blades for all rear stages of the high-pressure section was much too rough. “This meant that the system wasn’t achieving its full aerodynamic potential,” Schäffler says. Here too, it would be years before they succeeded in manufacturing the thumbnail-sized blades in a suitable quality. Another thing Schäffler remembers very well is how the blades had to be redesigned after the first bird strike test: “The bird passed through the low- and medium-pressure compressors without doing much damage before completely destroying the high-pressure compressor.” Compared to the other issues with the RB199, Schäffler says this was easy to fix: “When we made the blades for the high-pressure compressor’s first rotor stage, we simply extended the chord length by some 30 percent. The strengthened blades subsequently withstood the strike, as did the downstream stages,” Schäffler says. Step by step, MTU developed valuable knowledge in all areas.

“Even though the journey was sometimes arduous and caused us to curse regularly, the grasp of the overall system that we gained over this time proved extremely useful to MTU,” Schäffler says. Schäffler’s time also saw an innovative leap in engine control technology. In the fall of 1987, the analog regulator first used for the RB199 was replaced with a much more reliable, flexible and amenable digital control unit, the DECU 2000. The model was superseded in 1995 by the DECU 2020 featuring improved processors. “This control unit was in production until 2003 and successfully employed by the German and Italian air forces,” Schäffler says. Around 700 were made, “but I couldn’t tell you the exact number,” he laughs. But this is not the case when it comes to the number of RB199 engines built. “There were 2,504,” Schäffler says. “And many are still in service.” Schäffler says he is of course proud of the RB199, which despite all its challenges did ultimately become one of MTU’s major successes.

The 81-year-old, who until a few years ago still gave introductory courses to MTU employees on how jet engines work, says he was lucky to be employed at MTU. “It was the ideal life for an engineer.” 



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**Denis Dilba** holds a degree in mechatronics, is a graduate of the German School of Journalism, and founded the “Substanz” digital science magazine. He writes articles about a wide variety of technical and business themes.

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# A league of their own

*A journey that dates back 45 years: MTU Aero Engines is now a world-class manufacturer of low-pressure turbines—and its high-speed, high-end version for the Pratt & Whitney GTF™ engine is unmatched.*

**Text:** Dennis Dilba



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**Micrometer scale** \_\_\_\_\_ *Automatic measurement of a low-pressure turbine (LPT).*

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**Shorter but more efficient** \_\_\_\_\_ The low-pressure turbine (LPT) in Pratt & Whitney GTF™ engine is fully functional with just three stages. The LPT in the V2500 (right) required five.

What was MTU's first step on the path to becoming a leading manufacturer of low-pressure turbines? Surprisingly, it was the development of an exhaust casing. Exactly how this happened is something Ludwig Schweikl knows firsthand, because he and his colleagues were the ones who built it. "At that time, the early 1970s, corporate management made a strategic decision to get into the commercial engine business," says Schweikl, who had a long tenure as head of design at MTU. The experts already had experience with military engines and had developed and built the intermediate-pressure turbine for the RB199, the engine for the Tornado. Over the course of this production process, MTU came into contact with American engine manufacturer Pratt & Whitney. "Somehow this led to an invitation for the MTU development department to visit the Pratt headquarters in East Hartford," the engineer recalls. It would be a great way to get to know one another, said the Americans. Sounds good, responded the Germans. So, Schweikl soon found himself on a plane making its way to the US and was thus the first MTU developer to meet his counterparts at Pratt & Whitney.

"They were very skeptical as to whether or not we had anything to offer. At that time, Pratt & Whitney was the world's leading engine manufacturer and MTU was just a small company," the 82-year-old says. But he made a good impression, and MTU was asked to try its hand at the exhaust casing for a new version of what was then the classic medium-haul JT8-D. The collaboration worked smoothly, far exceeding Pratt & Whitney's expectations. MTU's skilled engineers impressed the American engine manufacturer—which then asked them to develop the low-pressure turbine for the JT10-D: a larger, more powerful follow-up to the JT8-D. It was an honor and an order that Schweikl and his developer team gratefully received. "This marked the beginning of the low-pressure turbine business for MTU," Schweikl says. Thus began a true development race, with one innovation topping the other—a race that continues to this day.

*"At that time, the early 1970s, corporate management made a strategic decision to get into the commercial engine business."*

**Ludwig Schweikl,**

*long tenure as head of design at MTU Aero Engines, Munich*

### Experts share the word about MTU's competence

The first low-pressure turbine for the JT10-D, soon renamed the PW2000, made a shining impression thanks to a special technical refinement. As the amount of thrust changes, rotors and engine casings expand and contract at different speeds. This can lead to greater clearances and in turn

to performance losses. To combat this problem, the engine incorporated the first solution for cooling the casing, called the active clearance control (ACC) system. This offset the difference in the thermal expansion of the components, thus reducing clearance and considerably improving the efficiency of the entire assembly. Pratt & Whitney contributed the idea and the patent, while MTU made it a reality. "Today it is standard in every engine," says Schweikl.

Word about MTU's expertise in low-pressure turbines spread throughout aviation circles. As a result, a short time later Schweikl and his team also took on the development of the low-pressure turbines for the V2500 program. A low-pressure turbine has a major influence on an engine's overall performance. With the V2500, which powers the A320 family and has become one of the most important programs in MTU's commercial portfolio, the engineers systematically applied what they learned with the PW2000. This meant they could significantly improve the efficiency of the low-pressure turbine for the V2500.

### Just three stages in the high-speed low-pressure turbine

Many more MTU low-pressure turbines followed: they are found in business jet engines, in the power turbines of turboshaft engines for heavy-lift helicopters, in turbofan engines for medium- and long-haul airliners, and even in the GP7000 for the Airbus A380 megaliner. MTU has numbered among the global elite in low-pressure turbine technology for a long time now. The Munich company's current masterpiece is the high-speed

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- 01** \_\_\_ Connecting the low-pressure turbine and drive shaft with the core engine.  
**02** \_\_\_ Assembly work on a V2500 low-pressure turbine.



- 03** \_\_\_ Milled from a single piece: Stage 1 of the LPT disk.  
**04** \_\_\_ MTU measuring technology in action on an LPT casing from the PW1000G engine family.

low-pressure turbine for the Geared Turbofan™ (GTF): optimizing the aerodynamics down to the smallest detail has achieved a higher degree of efficiency. At the same time, the high rotational speeds that result from the GTF's reduction gearbox mean the stages work harder. That's why the pressure turbine module in the A320neo engine needs just three stages. As a result, space, weight, maintenance costs, not to mention fuel consumption and therefore CO<sub>2</sub> emissions all decrease.

And as if this weren't impressive enough, the new turbine is also much quieter than conventional models. Its noise emis-

sions are at higher frequencies that are better absorbed by the atmosphere, to the point where the human ear can barely detect them. With this world-class low-pressure turbine, a key component without which the GTF would not exist, MTU today has moved into a league of its own. But even this exceptional turbine has room for improvement, through new materials, powerful computer simulations, and newly optimized aerodynamics. MTU engineers are currently working at it—and in doing so, they will write the next chapter in the extraordinary story of the low-pressure turbine's development. 



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**Smooth coordination**

*A PW1100G-JM on the test stand at MTU Maintenance Hannover.*



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# How the engine of the future was developed

*The first preliminary studies into a Geared Turbofan™ were begun by Pratt & Whitney, MTU Aero Engines and Fiat Avio in the 1990s. Today, the innovative technology sets standards and brings substantial reductions in fuel, CO<sub>2</sub> and noise.*

**Text:** Dennis Dilba

1969

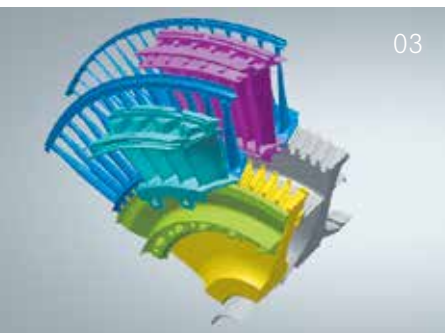
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01



03



04



02

- 01** — A predecessor of the later Pratt & Whitney GTF™ engine: the ATFI demonstrator. ATFI stands for Advanced Technology Fan Integrator.
- 02** — Preparing to run a stress test on the PW6000, which also helped pave the way for the Geared Turbofan™.

- 03** — Computer animation of sections from the high-speed low-pressure turbine (LPT) to be integrated into the Pratt & Whitney GTF™ engine.
- 04** — The instrumentation of the high-pressure compressor rotor calls for dexterous, sensitive fingers.

For decades, MTU has been working on ways to make aircraft engines consume less fuel, produce lower emissions and become quieter. The golden rule has always been that to fulfill the ambitious goals of tomorrow, you must push them through the development process the day before yesterday. This requires not only farsightedness and confidence in your own expertise, but also excellent partners and a good measure of courage. When this balance is right, you can achieve the goals of the future. A perfect example of this is the Pratt & Whitney Geared Turbofan (GTF)™ engine, into which virtually all innovations of the past decades have gone.

### From ADP to ATFI to GTF

Back in the 1990s, American manufacturer Pratt & Whitney began working with MTU and the former Fiat Avio on initial preliminary studies for a geared turbofan engine under the project name Advanced Ducted Propulsor (ADP). However, the project was not further pursued for commercial reasons. But over the years that followed, rising kerosene prices coupled with customer demand for quieter engines that produced lower emissions led to a re-eval-

uation of the geared turbofan concept's market potential. At the start of the 2000s, the investigations were resumed with the Advanced Technology Fan Integrator (ATFI). This demonstrator consisted of a propulsion system with a reduction gearbox between the fan and the low-pressure turbine and was tested based on a PW6000 core engine. In addition to the three ADP partners, Pratt & Whitney Canada were now also working on the project. And so engine manufacturer Pratt & Whitney laid the foundation for its patented Geared Turbofan™ program, which officially launched in 2008. At roughly the same time as the test phase of the ATFI, the MTU engineers developed a new high-pressure compressor as part of the Engine 3E project. For the layout and computation of the six-stage HDV12 compressor, a numerical 3D Navier-Stokes flow solver was used for the first time. As a result, the component achieved a high overall pressure ratio of almost 11.

The HDV12 was to form the basis for the high-pressure compressor of the PW6000 engine for the Airbus A318—and subsequently, like the ADP and ATFI demonstrators, to pave the way

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further for the Geared Turbofan™. Its core development started in 2005, when the partners decided to develop and test a demonstration engine. The initial tests of the overall system in 2007 immediately yielded very positive results with regard to the functionality of the critical components. However, it was also clear that the new engine overall had one big area of improvement left: further development would pay off only if it created a whole Geared Turbofan™ engine family. Convinced by the concept, Pratt & Whitney and MTU systematically invested further in the entire process chain so as to permit the creation of geared turbofans of different thrust classes. Just one year later, the Geared Turbofan™ took off for the first time on flight tests.

### Engineering courage pays off

With the two major MTU workshares, the high-speed low-pressure turbine and the first four stages of the eight-stage high-pressure compressor engineered in blisk design, the engine of the future already achieves a very high degree of efficiency today. The impressive result: fuel consumption and carbon dioxide emissions are reduced by 16 percent each, and the noise footprint by 75 percent. And as fewer compressor and turbine stages are needed, not only are the engines lighter, but maintenance costs decline as well, because fewer components are exposed to the hot gas. For the key GTF component, the high-speed low-pressure turbine, MTU won two German innovation awards. Germany's leading engine manufacturer is the only company in the world to have mastered this technology. The patience and perseverance was worth it: as well as representing a technological quantum leap, the Geared Turbofan™ concept has also been a major commercial success.

Today, Airbus offers the GTF for the A320neo and the A220 (formerly Bombardier C Series), Mitsubishi has it in their MRJ, and Embraer has it in the new E-Jets of the E-170 and E-190 families. Moreover, Irkut wants the GTF for the MC-21. At present, a total of 80 airlines worldwide have ordered more than 8,000 of the GTF engines. More new MTU innovations have gone into the current version, such as the first additively manufactured components and brush seals. In addition, MTU has looked after a third of the entire final assembly for the A320neo PW1100G-JM

*“What we’ve achieved of course makes us proud, but nobody at MTU should rest on these laurels.”*

**Dr. Jörg-Michael Henne,**

Senior Vice President Engineering and Technology at  
MTU Aero Engines, Munich


engine since the end of 2016. To this end, MTU invested some 20 million euros in a track-guided assembly line system, which was developed in-house and is unique worldwide. “What we’ve achieved of course makes us proud, but nobody at MTU should rest on these laurels,”

emphasizes Dr. Jörg-Michael Henne, Senior Vice President Engineering and Technology at MTU. Overall, the GTF has the potential to reduce fuel consumption and CO<sub>2</sub> emissions by up to 40 percent.

### Further development already being prepared

For instance, it would be possible to achieve even lower fan pressure ratios step by step over the coming years, which would further increase the bypass ratio—from the current 12:1 to as much as 20:1 by 2035. Moreover, MTU's engineers are working on further improving the core engine's thermal efficiency by increasing the pressure and temperature ratios. This will involve increasing the overall pressure ratio well beyond its current value of about 50:1, while dramatically reducing the amount of cooling air needed.

And for 2050 and beyond, MTU is already devising initial studies, concepts and ideas in collaboration with universities and other research institutes: “We need revolutionary approaches that must go beyond today's technologies, and above all else, we need new aircraft architectures,” says Dr. Stefan Weber, Senior Vice President Technology & Engineering Advanced Programs at MTU. Among the options under review for the engine are the use of highly efficient heat engines with extremely high pressures or the integration of recuperative elements to improve the thermodynamic cycle. Shielded propellers or fans distributed around the fuselage are also possibilities. In addition, there are technological solutions such as alternative fuels and steps toward turbo-electric flight, without which future targets cannot be met.

All improvements always have the same goal: improve efficiency and thereby minimize fuel consumption, emissions and noise. The engine of the day after tomorrow has long been in the starting blocks—and MTU is already taking responsibility today for moving aviation toward emissions-free flight. 



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**Blisk (blade integrated disk)** \_\_\_\_\_ *Integrated disk-blade solution for the Pratt & Whitney Geared Turbofan™ family.*



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# Symbiosis in action

*With the space-saving and lighter rotor disks in the compressor with integrated blades, engines consume less fuel. The blisk success story began in the Eurofighter EJ200 engine.*

**Text:** Dennis Dilba

Blades and disks from a single piece—so-called blade integrated disks, or blisks for short—have long been a fixture in aircraft engines. The high-tech components, which are used in compressors, not only save space and weigh less than conventional rotors with individual blades, but they also permit better blade aerodynamics. Furthermore, they reduce assembly work and thus costs. As a result, engines become more compact and lighter overall and consume less fuel, which in turn reduces CO<sub>2</sub> emissions and benefits the environment.

In 1995, when Arthur Schäffler first unveiled the new full-blisk low-pressure compressor to the four Eurofighter customers for their EJ200 jet engine, the response was less than enthusiastic. “Heated discussions broke out immediately,” recalls the then Technical Director of the EJ200 consortium Eurojet, thinking back to that meeting in London. The representatives from Spain,

Germany, Italy and the United Kingdom had some grounds for their skepticism. Although a first blisk had already been used in a helicopter engine back then, the blisks that MTU’s Schäffler was proposing had a much greater diameter than the helicopter component. “With the EJ200 blisks, we’d gone out to the very frontier of development technology,” says the engineer, who is now 81 years old. Driven there by necessity, the MTU engineers were forced to try the new technology in order to fulfill the service life requirements for the EJ200. The high rotational speeds of the rotors in the jet engine—and thus the centrifugal forces—were so great that fretting corrosion became a problem for the conventional individual blade technology. Fretting corrosion here refers to the formation of little pits on the surfaces of the blade root and rotor groove, which can lead to cracks and ultimately to loss of the blade.

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“The first 85 EJ200 engines that were delivered without blisks in the high-pressure compressor in stages 1 and 2 were thus limited to 400 flight hours—whereas the design had planned for 4,000 hours,” says Christian Köhler, who joined MTU in 1990 and is today the Chief Engineer of the EJ200 program. The blisks resolved the problem and fully convinced the customers of the integrated disk-blade solution. By the start of 2019, 558 jets had already been delivered with the EJ200 engines—and more are on order. MTU’s blisk experience was then further utilized in an experimental high-pressure compressor that was developed as part of the HDV12 technology program and which fit more or less exactly into the PW6000 engine for the A318. “This allowed us to show Pratt & Whitney our technological abilities,” Köhler says. With a few modifications, the high-pressure compressor is a standard component in the PW6000 today, and for blisk technology this represented the leap into commercial business.

*“Over the coming years, we’ll be manufacturing up to 6,000 blisks per year here. Without all the experience that we’ve built up over the years and our constant watchfulness and care, that would not be possible.”*

**Dr. Stephan Bock,**  
Director Engineering Advanced Programs  
MTU Aero Engines, Munich

### Special production process for blisks with large blades

In the classic method, the contours of the blades are milled out of a solid metal disk. However, the further forward you move in the engine—that is, where the disks get smaller and the blades bigger—the less economical the machining process becomes. “A lot of expensive material winds up in scrap, and

the milling takes a very long time,” Köhler explains. Measuring up to 20 centimeters in size, the blades of the first two EJ200 low-pressure compressor stages are therefore forged individually and only then joined to the disk in a linear friction welding process developed especially for this purpose. The experts at MTU subsequently developed a further technique for blisk manufacturing: “With precise electrochemical machining (PECM), we’re now able to manufacture blisks even from nickel alloys, which are difficult to weld and to machine,” says Köhler. In the technique, the blisk blank is dissolved out of the alloy using a liquid electrolyte, an electric current and a 3D molding tool.



**Blisk production on about 10,000 square meters** \_\_\_\_\_ In Munich, MTU operates one of the world’s biggest and most flexible manufacturing facilities for producing blisks for high- and medium-pressure compressors.

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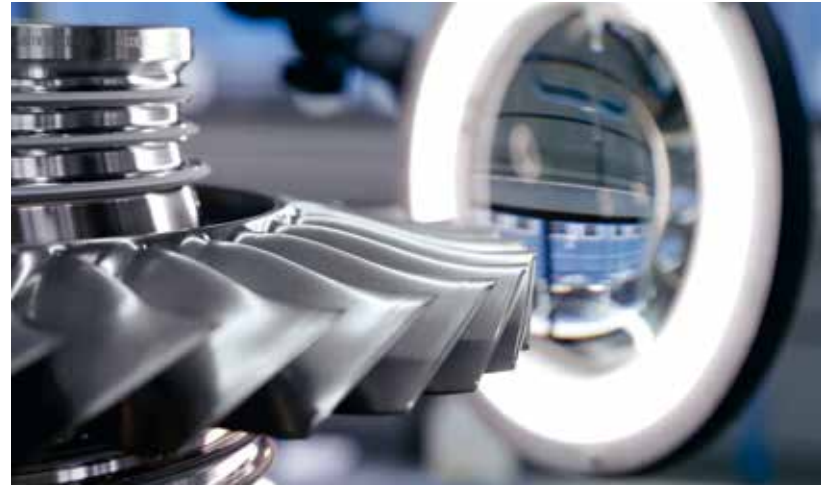
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One of the advantages of PECM over milling is that because they make no contact with the component during the process, the tools do not experience wear and tear. Moreover, due to the much higher reproduction precision of the chemical-electrical method, there is no need for further post-processing steps. Both these factors reduce costs. Using the innovative precision technique, MTU manufactures on behalf of Pratt & Whitney the fifth and sixth blisk stages of the Geared Turbofan™ (GTF) high-pressure compressor, which has eight stages in total and is laid out fully according to blisk design. “To manufacture the titanium blisks of the first four stages of the GTF high-pressure compressor, which were designed by MTU, we built a specially designed production facility at the Munich site,” says Dr. Stephan Bock, Director Engineering Advanced Programs. At this facility, large titanium blisk blades are joined individually to the disk by means of linear friction welding and then adjusted using adaptive milling; meanwhile, small and medium-sized titanium blisk blades are milled from a single piece.

### Up to 6,000 blisks a year

The center of excellence for manufacturing titanium compressor disks is a prime example of the implementation of Industry 4.0 thinking at MTU and the most state-of-the-art production facility of its kind in the world. It contains a high degree of automation, digitalization, connectivity, and self-controlling that is unique worldwide. The highly functional, energy-efficient new factory building also meets the latest in modern building standards. “Over the coming years, we’ll be manufacturing up to 6,000 blisks per year here,” says MTU expert Bock. “Without all the experience that we’ve built up over the years and our constant watchfulness and care, that would not be possible.” The processes have to be extremely stable: one manufacturing defect on a single blade can render the entire component unusable. However, Bock believes this is no time for MTU to rest on its laurels: “We’re already working on the blisks for the next GTF generation.” 🌐



**Turn on the light** \_\_\_\_\_ before visual inspection of a blisk. There’s no substitute for human senses and experience here.



**Snapshot** \_\_\_\_\_ Good to see how this blisk is milled out of a single workpiece.



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**Text:**  
**Denis Dilba** holds a degree in mechatronics, is a graduate of the German School of Journalism, and founded the “Substanz” digital science magazine. He writes articles about a wide variety of technical and business themes.

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# Printing a component, layer by layer

*With the borescope boss, MTU Aero Engines became one of the world's first engine manufacturers to have implemented industrial-scale additive production. It was the perfect strategic move: this new process is the future.*

**Text:** Dennis Dilba

The borescope boss is a small and seemingly insignificant component. Just about able to fit inside a person's fist, it has lateral extensions to the left and right, each with a hole. The middle of the boss has an opening with a silver-colored screw thread, and the rest of its surface has a grayish matte finish. Once screwed onto the turbine center frame, this accessory allows technicians to look inside the low-pressure turbine with an inspection camera—the borescope—and thus to check the condition of the blades.

Most people would simply have no idea what they were looking at if someone showed them the component. However, for Dr. Jürgen Kraus, Director Additive Manufacturing for MTU Aero Engines in Munich, the borescope boss holds a very special significance. “With it, we have made the leap to industrial-scale additive production,” says Kraus. While in the past these accessories were milled from a solid block, today they are elegantly printed through the use of selective laser melting.

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### 3D microwelding processes

This process is generally classified under the broader field of 3D printing, but from a strictly technological standpoint, it involves 3D microwelding processes. In this method, the 3D model of the component is “sliced” on a computer into individual layers measuring 20 to 40 micrometers thick. A powerful laser then melts material in powder form within a construction chamber exactly at the locations specified by the computer-generated component design data, joining it to the layer below. In this way, components are built up, layer by layer, with new layers continually being added. Experts such as Kraus, therefore, speak of additive manufacturing. Today, the low-pressure turbines in the A320neo’s Geared Turbofan™ PW1100G-JM are being outfitted with the borescope bosses. MTU is thereby one of the first companies in the aviation industry to have received regulatory approval for the use of this innovative technology in volume production of components, and one of the first to have implemented it.

### Starting with tools and blanks

MTU took the first step on this path very early on, starting work on the additive process as far back as the late 1990s. In the early years, the company focused on theoretical aspects, but quickly shifted to practical applications. “We began with the production of tools and master forms for precision casting, along with simple development parts,” Kraus recalls. In the second phase, the company produced fixture components to replace already existing parts, such as spray nozzles and grinding wheels used for manufacturing components. It was during this period that Geared Turbofan™ borescope bosses were developed. “These simple components, which are not critical to the immediate functioning of an engine, were ideal for exploring how additive manufacturing could work in volume production—thus paving the way for using it to manufacture components that are more complex and more critical,” explains Dr. Karl-Heinz Dusel, Senior Manager Additive Manufacturing Technology at MTU. For in addition to the manufacturing technology in and of itself, at that time the entire process chain also had to be rebuilt from scratch.



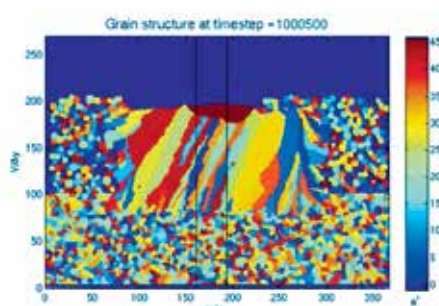
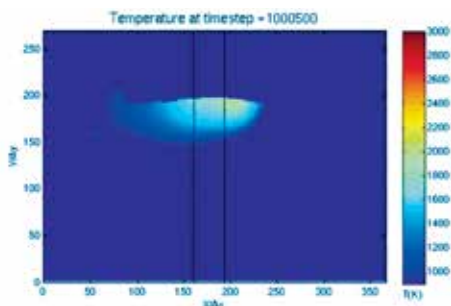
**Borescope bosses** \_\_\_\_\_ are small openings that admit a borescope so that the blades can be checked every now and again for wear and tear. MTU manufactures borescope bosses for the PW1100G-JM using an additive process.

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**Mixing test** — In additive manufacturing techniques, simulations can be used to test the homogeneity of the elements in a component's metal.

*“For the next generation of engines, we can envision using additive manufacturing for up to 15 percent of the components.”*

**Dr. Jürgen Kraus,**

Director Additive Manufacturing for MTU Aero Engines in Munich

Up to that point, MTU had only bought blanks, and had not manufactured them itself; as a result, Dusel and his colleagues were not able to fall back on already existing processes, procedures or structures for the manufacturing process or the securing of regulatory approval. “Simply working out the necessary norming system and calculating the material data took more than two years,” says Dusel. Moreover, it was necessary to develop and implement new methods for component testing and quality assurance. With the process now firmly established, MTU is working step by step to implement it with more complex components and other engine types. Current projects include, for example, new bionically designed and thus especially lightweight brackets for oil lines, and a stiffer, more cost-efficient seal carrier produced with additive manufacturing. This inner ring with integrated honeycombs will be installed in the high-pressure compressor in the future. The brackets, which play an equally critical role in the engine’s function, have a curved, filigree form.

### Bionically formed lightweight components

The new design has made it possible to cut the weight of the component by a third, without interfering with its strength or damping characteristics, according to Dusel. Hence, additive components help reduce engine weight, which reduces fuel consumption and therefore emissions. It will be a while before this point is reached, however. “Components such as these that are subject to intense

stresses must be validated in engine performance tests,” Kraus explained. While this work is being carried out, his team and external experts are already conducting feasibility studies on completely new components that could be utilized in the Next European Fighter Engine (NEFE), and in the coming generation of Geared Turbofans™. “For the next generation of engines, we can envision using additive manufacturing for up to 15 percent of the components,” says Kraus. It is already clear, he continues, that in the future, engine manufacturers will not be able to survive if they don’t implement the new process.

For that reason, starting at the beginning of last year, MTU has stepped up its commitment to additive manufacturing by establishing a separate department. “By clustering all activities from design and technology development to volume production in one organizational unit, we aim to maintain our lead and pull even further ahead,” says Lars Wagner, the MTU COO. Kraus already has an idea as to how all of that could work out: the next step is to develop and manufacture new lightweight components. It is necessary to come up with new designs, new components—which could conceivably include bearing housings, brackets and struts—and new materials. The advantages of the new process can be seen particularly in the manufacture of complex components. “The future lies with additive manufacturing—every optimized component makes an engine a bit more efficient,” Kraus says.



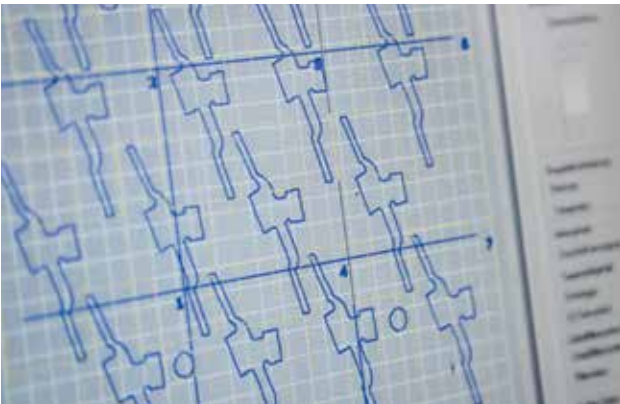
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**Layer by layer** \_\_\_\_\_ is how multiple borescope bosses “grow” on a substrate. After they have been removed from the base, then it’s time to machine them to near net shape.



**No rough edges** \_\_\_\_\_ Additive techniques make it possible to manufacture complex component contours that conventional methods, such as milling, can achieve only with a huge amount of time and materials.



**Selective laser melting (SLM)** \_\_\_\_\_ is used to build up the component’s layers—each measuring just 20 to 40 micrometers thick.



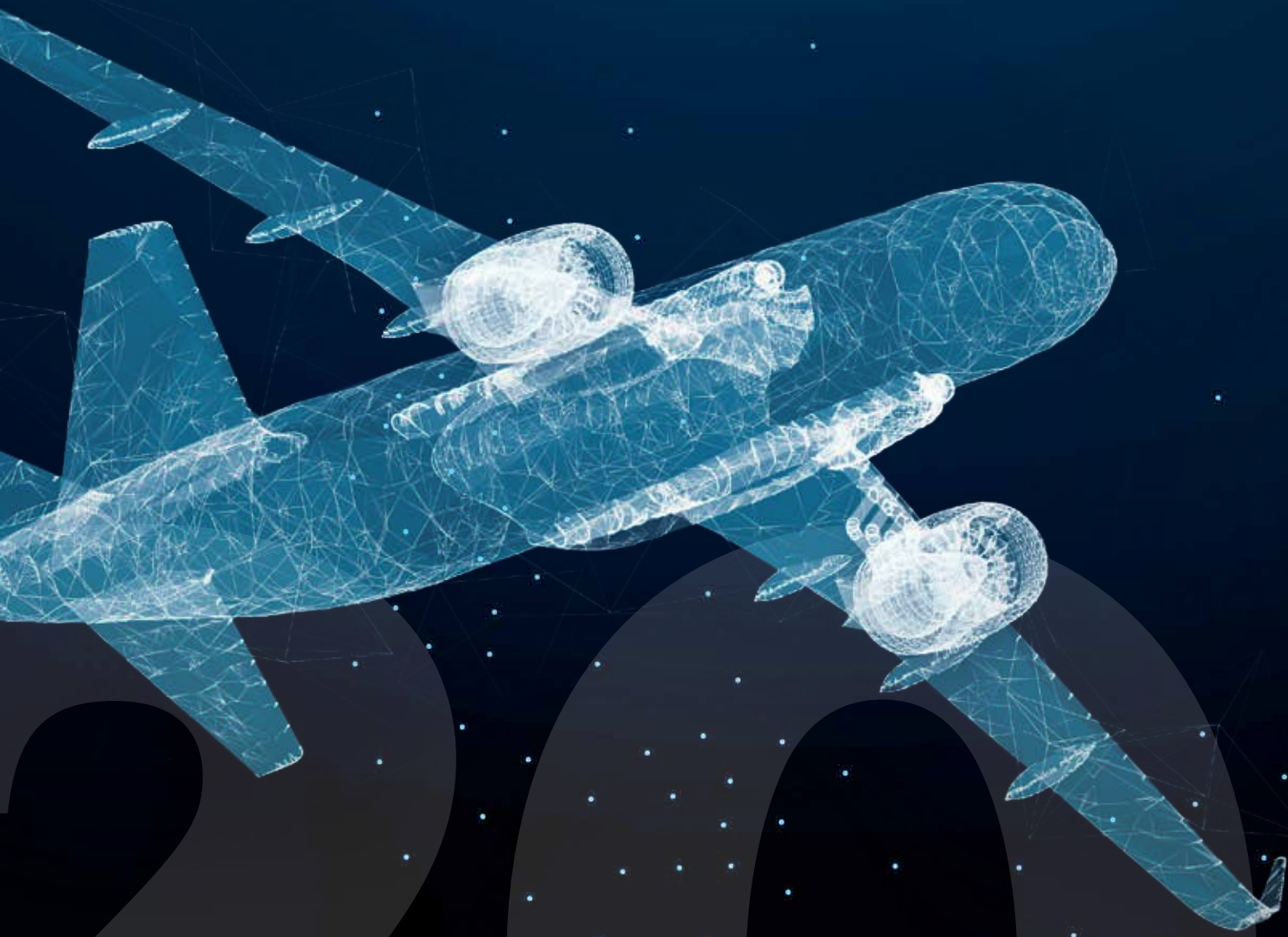
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# Thrust for the future

*“Answering tomorrow’s challenges”: For MTU Aero Engines, this principle is both a motto and a responsibility. Never before has the company had such good answers ready as today.*

**Text:** Martina Vollmuth

For decades, three letters in aviation have stood for innovative engine solutions: MTU. The engine experts in Munich have really made a name for themselves over the years, repeatedly coming up with valuable technological innovations. With their contributions to the Geared Turbofan™ (GTF) engine, they are impressively shaping developments in the industry of the present while preparing to shape the future like never before in the company’s history: MTU’s unique expertise means it is ideally placed to tackle the key missions of today and tomorrow: making commercial engines even more efficient and environmentally friendly and military engines even more powerful.

“Never has MTU had such a definitive technology roadmap as today,” explains COO Lars Wagner. “We’re conscious of our responsibility for sustainable, emissions-free flying. That’s why we’re already investing today in pioneering technologies for the aviation of tomorrow.” Wagner explains that, from 2030 onward, the commercial segment will be clearly oriented toward the next generation of the Geared Turbofan™, while in the military segment it is the NEFE (Next European Fighter Engine) that will determine the company’s direction. He continues: “In the commercial segment, we’re researching several evolutionary approaches that are already possible today thanks to sustainable

e-fuels. At the same time, we’re looking into alternative engine concepts ranging from hybrid-electric flight to fuel cells.”

## **Profile of commercial aviation in 2050**

However, MTU’s experts are not satisfied to leave it at that; they are casting their gazes further into the future. Part of a small band of visionaries worldwide, they are already working with partners from industry and research on ideas for the commercial engines that could fly from 2050 onwards. Wagner explains: “MTU is working out revolutionary engine concepts to achieve the ambitious goals of Flightpath 2050.” These new engine solutions have to go beyond today’s technology, with emissions-free flight the greater goal.

The MTU experts have several specific engine concepts in view, including the composite cycle and the STIG cycle engine. Such “revolutionary” solutions involve entirely new technology. By contrast, MTU characterizes the further development of the existing Geared Turbofan™ technology as “evolutionary”: the second GTF generation still offers considerable potential. Once it has been further optimized, it will dramatically reduce emissions and is due to be airborne by the mid-2030s.

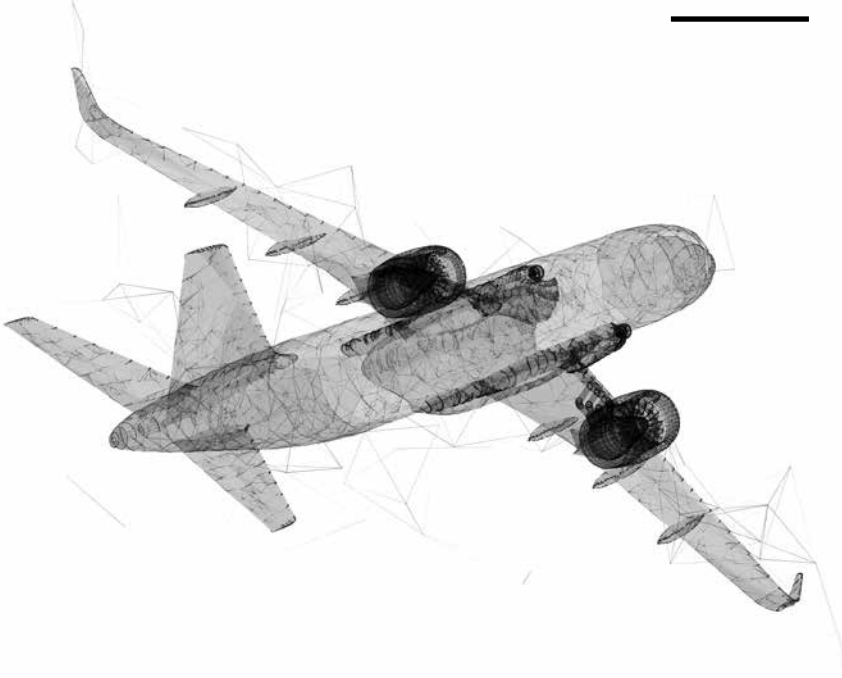
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*“Never has MTU had such a definitive technology roadmap as today.”*

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**Lars Wagner**

Chief Operating Officer  
MTU Aero Engines, Munich

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Then there will need to be a technological leap forward to develop technologies and concepts that will pave the way for largely emissions-free flight—this is the responsibility of the European aviation industry. Resourceful MTU developers have come up with two approaches and are combining the tried-and-tested gas turbine engine with brand new technologies: in the composite cycle approach, the conventional high-pressure compressor system is to be replaced by a piston compressor and engine. “This will allow us to significantly increase thermal efficiency,” says Dr. Stefan Weber, Senior Vice President Technology & Engineering Advanced Programs in Munich. The STIG cycle engine, meanwhile, integrates a steam power process into the gas turbine processes. This involves using a gas turbine with steam injection to feed the heat of the exhaust stream back into the process inside the engine. The wet combustion would substantially reduce both CO<sub>2</sub> and NO<sub>x</sub> pollutant emissions. “We’ll have to see which approach ultimately offers greater potential and is economically feasible,” Weber says. If this turns out to be the STIG cycle engine, it will not work in the current aircraft architecture, thus calling for a new configuration.

### **Sustainable, renewable fuels**

Work on these two MTU pilot concepts is being accompanied by other activities. “These measures alone won’t be enough for us to reach the ambitious goals for 2050,” says Weber. “They will get us a good part of the way there, but by no means will they let us achieve them completely. We need to close the remaining

gap through the development of sustainable fuels.” The idea is to shift away from consuming fossil fuels toward sustainable, renewable fuels. “We want to encourage their use,” Weber says. Promising approaches for producing synthetic fuels are offered by solar energy and by electricity—provided it is generated sustainably. The latter technology is already available today. One of the major advantages of synthetic fuels is that they don’t require any new infrastructure; they can simply be “dropped in” to existing petroleum-based infrastructure. To completely cut out NO<sub>x</sub> emissions as well, there’s no getting away from fuel cells—meaning flying with hydrogen. MTU has this technology in its sights, too.

### **E-flying**

One topic has been gaining more and more public attention recently: electric flying. This is because purely battery-driven aircraft fly completely emissions-free—provided the electricity they use has been generated sustainably. “Emissions-free” does not include noise, as this simply cannot be fully avoided when it comes to flight. Realistically, however, from today’s perspective there are large obstacles to overcome before we will see purely battery-powered passenger aircraft. Weber elaborates: “Electric propulsion systems and batteries reach performance levels today that permit their use in power gliders, sporting airplanes and other aircraft in that class.” But at present, transferring this technology into aircraft in the Airbus A320 class is impossible, as the battery capacity falls far short of what’s needed. “And we currently see no promising technological approaches opening up in the future.”

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**PROFILE OF COMMERCIAL AVIATION IN 2050**


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**Composite Cycle Engine** \_\_\_\_\_ Combining gas turbines and piston machines is an approach that dates back to the 1950s—however, today's commercial aircraft require a much higher level of performance. MTU has developed and patented a new concept for this combination.



**STIG Cycle Engine** \_\_\_\_\_ STIG (Steam Injected Gas turbine) refers to the integration of a steam process into the gas turbine. The idea is to use the energy from the exhaust to increase power output. It should also considerably reduce pollutant emissions in the process.

What does seem technically feasible from today's perspective are turbo-electric or hybrid-electric systems that integrate the turbomachinery and generator into the aircraft fuselage. The current for the electric motors could be generated by a gas turbine; in turn, the electric motors would power distributed fans on the wing. Whether there is truly potential to be tapped with this approach remains to be seen. Success ultimately hinges on technical progress in the field of batteries and electric motors. MTU has its finger on the pulse here, too, and is involved in various studies and initiatives: for example, it is collaborating with partners to investigate hybrid-electric or all-electric powertrains for air taxis or even 19-seater aircraft.

Weber is certain about one thing: "As a concept, the gas turbine engine will continue to hold sway. It's fit for the future and holds potential for further optimization." Using sustainable drop-in fuels with the existing infrastructure would make it possible to quickly put a significant dent in pollution emissions. There are two conceivable applications for the gas turbine in aircraft: either as an improved, greener main engine or else as the basis for low-emissions hybrid systems, insofar as their introduction is proven to be beneficial overall.

MTU has positioned itself clearly: it remains true to itself and its tradition, and is eyeing all possibilities for ensuring further progress in the skies. After all, as the experts know, the future of aviation begins today. 



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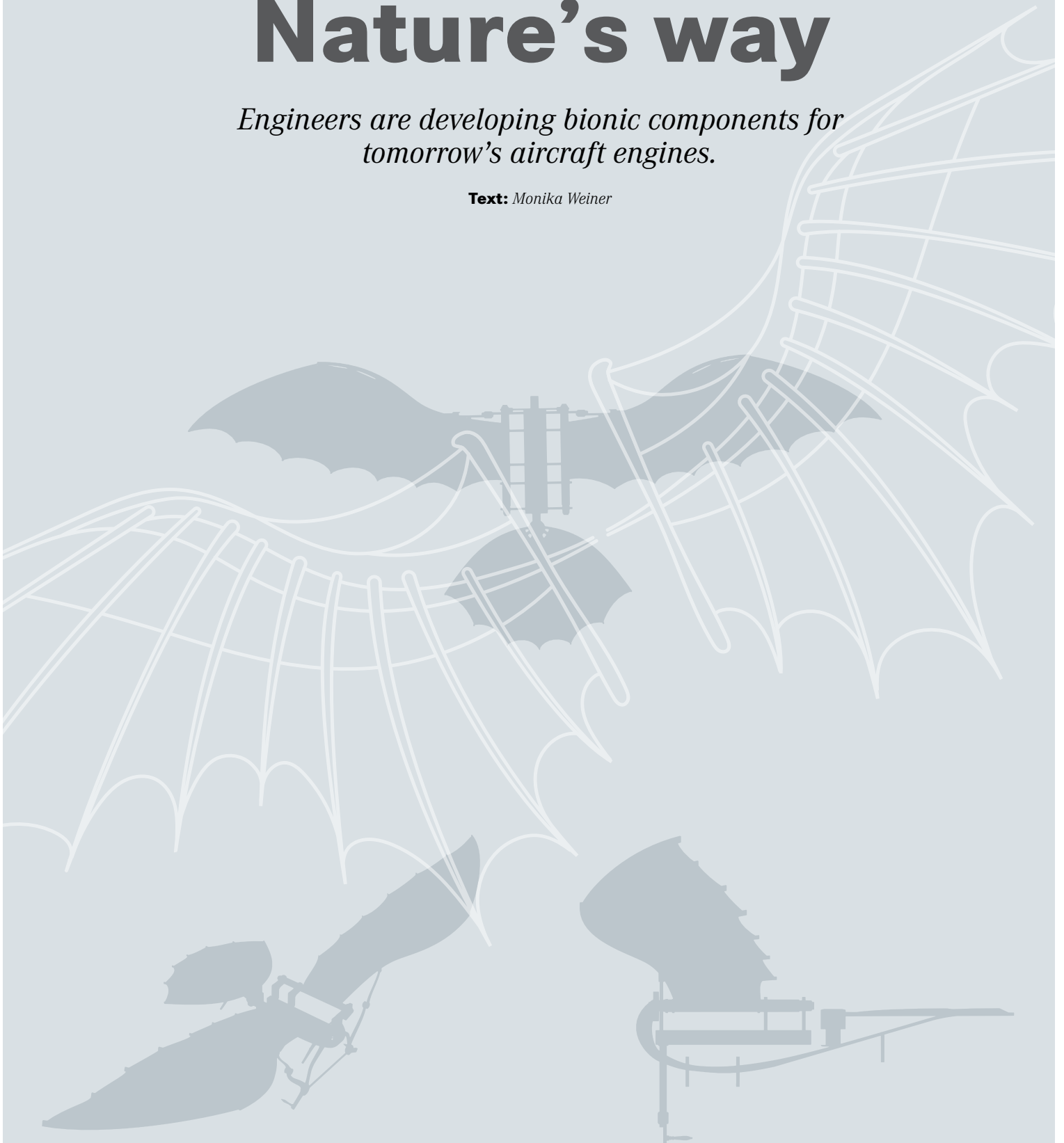


**Text:**  
**Martina Vollmuth** holds a degree in journalism and trained as a copy editor for daily newspapers. She is the official spokeswoman for technology at MTU.

# Nature's way

*Engineers are developing bionic components for tomorrow's aircraft engines.*

**Text:** *Monika Weiner*



Nature had several billion years to evolve and develop the perfect solutions for its needs. Wood, for example, gets its rigidity and strength from its cell walls. Bones have a lightweight structure and yet are incredibly strong. Reeds have different layers of cells that make them tough as well as flexible. And thanks to their structured surface, the leaves of the lotus flower can repel water and dirt, while shark scales have denticles that help reduce drag in the water.

Examples from nature such as these have been sparking creativity and inspiration for human inventions for years. Even Leonardo da Vinci studied the flight of birds prior to building his flying machines—even if his first attempts at flying failed because they relied on human strength alone to generate the necessary lift. But the concept of creating lift through propulsion is still found onboard all aircraft to this day. Following in da Vinci’s footsteps, engineers today also take inspiration and apply principles from nature when they develop materials and components.

**Huge innovation potential**

Bionics, a portmanteau of “biology” and “electronics,” has become a field of research in its own right. As the founder and CEO of German company die Bioniker GbR and a consultant at Altran Deutschland, Markus Hollermann is a firm believer in the huge innovation potential

that bionics offers. “Bionics isn’t about copying nature but about learning from it—applying its principles to electronic products and processes and developing new functionalities. Using examples from nature, we can create components for aviation applications that are lightweight, exceptionally strong and that absorb sound.”

Bionic structures can be used as a basis for lighter, quieter and more efficient engine designs—at least theoretically. For a long time, however, this appeared impossible to translate into practice. That’s because conventional components are forged or cast, which makes it difficult to integrate cavities or designs based on nature. But now, additive manufacturing processes are opening up a world of new opportunities for design engineers. A year ago, MTU Aero Engines formed its own bionic design team as part of its Center of Excellence for additive manufacturing.

Headed by Dr. Mark Welling, the team has now developed a bionic component: a bracket for oil lines. Given that the component is critical to safe engine operation, it must meet stringent requirements to obtain approval from the aviation authorities. Unlike the conventional, straight-edged brackets that are milled, this new bracket is curved and takes a shape not dissimilar to a bone. “The new design enabled us to

**FROM DEVELOPMENT TO MANUFACTURING**



**Additive manufacturing** — Numerical simulation is used to develop the bionic structure of a component, which is then reproduced in metal by means of additive manufacturing.

**BIONIC STRUCTURES REDUCE WEIGHT**

*Additively manufactured brackets for oil lines weigh half as much as those made using conventional milling.*



*produced by conventional milling*



*printed by SLM*



*produced by conventional milling*



*printed by SLM*

**Bionic brackets for oil lines**

*Additive manufacturing enables the components to be built with extreme precision based on examples from nature. They are not only lighter than conventional, milled brackets, but are stronger, too.*



**A bionic component is printed layer by layer**  
 Controlling an additive manufacturing machine.



**Material-conserving process** — Production of a bracket tray.



*“Nature is extremely economical; it doesn’t invest any more than what is required. If you look at bones, extra material is present only in places where it’s absolutely necessary for stability. We used a similar principle to optimize our brackets.”*

**Dr. Mark Welling**  
 Senior Manager Bionic Design,  
 MTU Aero Engines

cut the weight of the component in half, without interfering with the strength or damping characteristics,” says Welling. It’s no coincidence that the design resembles a bone: “Nature is extremely economical; it doesn’t invest any more than what is required. If you look at bones, extra material is present only in places where it’s absolutely necessary for stability. We used a similar principle to optimize our brackets—you could say that they’re the result of accelerated evolution.”

**Development by numerical simulation**

Numerical simulation begins with a hexahedral model, a finite element model that is subjected to specific loads and temperatures. A computer program then identifies which of the hexahedrons are critical for withstanding the stresses and which ones are not. The non-critical ones are removed one by one until only the essential structures remain. Next, the computer simulates dynamic stresses and their impact over thousands of takeoffs and landings. The model exposes any weak points where the hexahedral mesh needs to be modified.

In the next step, the design is optimized for additive manufacturing. Selective laser melting. In this process, thin layers of the high-temperature iron-nickel alloy Inconel 718 are applied to the substrate in powder form. A laser then melts the powder, fusing the layers together to create solid structures. In principle, this method is suitable

for producing any geometry, but it does require any support structures and overhangs to be removed or reworked afterwards. Optimizing the model minimizes the amount of work involved.


The CAD data from the simulation can now be used for additive manufacturing without further processing. For quality assurance purposes, MTU’s engineers developed their own method for identifying any structural weak points as early as possible. During the welding process, a sensor records the time it takes for the powder melted by the laser to resolidify and cool down. If this is unusually long, it’s a sign that the powder has not fused properly with the layer below.

Production of the blank for the bracket takes only a few hours. Before the bracket is mounted, it undergoes further quality inspections to ensure it is safe to use in the engine.

The new bionic brackets are now being installed in a test engine. Once they have passed endurance testing and demonstrated they meet the requirements for approval, they can be rolled out into large-scale production. “Then we’ll have another important milestone under our belt, paving the way for more developments of this kind in the future,” Welling says. “Our plan is to produce 15 to 30 percent of our engine components using additive technologies by 2030. That’s no mean feat, and we know we’ve still got some challeng-

es to overcome. But we're working through them systematically to find solutions.”

There is a long list of components that would be suitable for additive manufacturing. Among the potential candidates are a housing with integrated cooling, lightweight engine blades (see Ideation Challenge) or a redesigned variable guide vane actuator—a mechanism currently made up of many small parts that have to be assembled manually.

“Additive manufacturing can also help achieve the targets for reducing fuel consumption and emissions in aviation,” Welling says. “Following nature’s example, we can make aircraft engines lighter, quieter and more efficient.” 

*“Additive manufacturing can also help achieve the targets for reducing fuel consumption and emissions in aviation. Following nature’s example, we can make aircraft engines lighter, quieter and more efficient.”*

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**Dr. Mark Welling**

Senior Manager Bionic Design, MTU Aero Engines

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## Inside MTU — *Bionics Ideation Challenge*

Nature has its own perfect solutions—we just have to discover them. In 2017, MTU called on employees at all its locations worldwide to take part in the Ideation Challenge and contribute their ideas and answers to the questions: What can we learn from nature that can be applied to engine construction? And what’s the best way to combine bionic design with additive manufacturing?

A total of 67 people submitted entries online, ten of which were selected by a team of experts for the next round. The shortlisted contenders then had one last chance to pitch their ideas to a panel of managers. Finally, the panel selected three winners who were rewarded with the opportunity to put their ideas into practice.

“The aim of the competition was to spark a process of innovation,” says Dr. Patrick Holtsch, who helped organize the Ideation Challenge. “It’s clear from the results that MTU has a huge pool of ideas with great potential at its fingertips—which we can draw on in our development of tomorrow’s engines.”

### **Ideation Challenge: The winning ideas**

***The bionic borescope***  
borescope for on-site repairs based on the human hand. With its long, thin and flexible snake-like arm, the borescope can be inserted into the engine to inspect the components and smooth the surface of the blades, allowing repair work to be carried out for customers directly on site. The technology could help

avoid costly and time-consuming shop visits that require the engine to be disassembled.

### ***The bionic turbine blade***

inspired by the giant reed. With their hollow stems, these reeds are incredibly resilient and also capable of absorbing vibrations. This turbine blade has a similar design—its hard outer layer and inner honeycomb structure make it both lightweight and quiet.

### ***Housing with integrated cooling***

resembling the makeup of a bone. The cavities contain additional honeycomb structures that channel air directly to the areas that need to be cooled. The advantage is that the tubes conventionally used to supply cooling air to the housing are no longer required.



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**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.



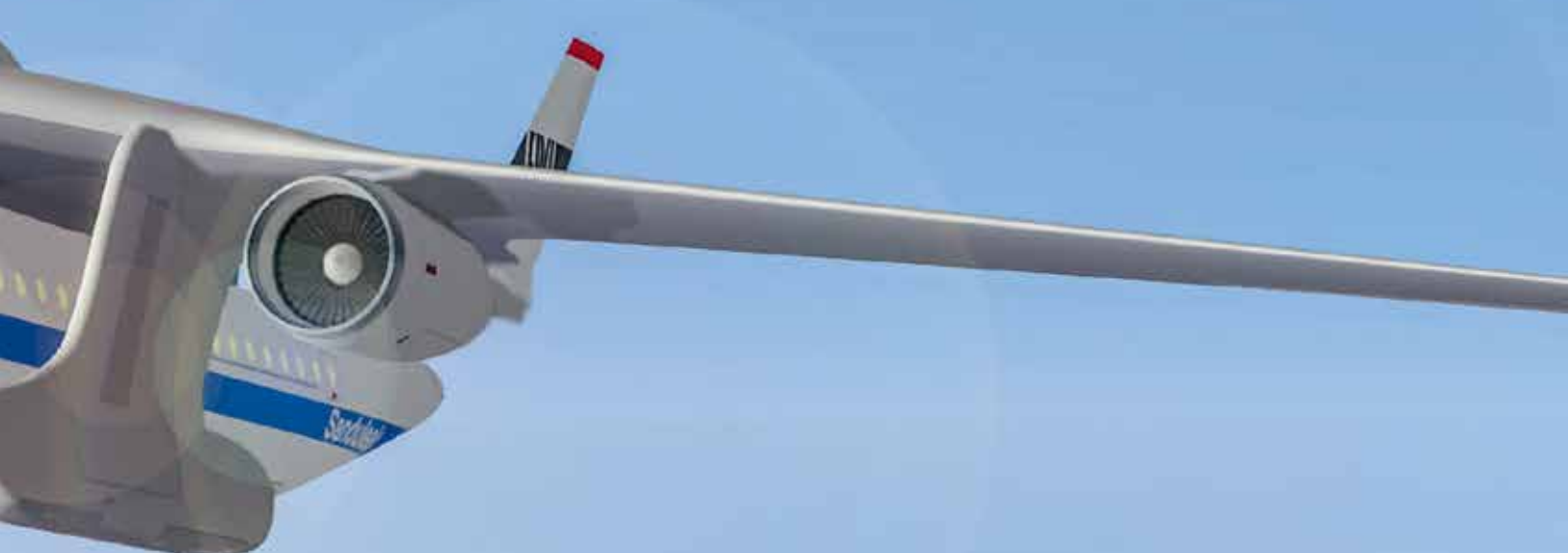
**Flying-wing aircraft with container capsules** — The idea behind the Clip-Air project comes from transport logistics. It aims to make aircraft more multipurpose and to decongest the airspace.



# Flexible aircraft

*Modular aircraft and cabins allow airlines to respond more quickly to different passenger needs and market situations, making air transport more efficient.*

**Text:** Denis Dilba



The transportation of goods in standardized containers, which were invented in 1956 by U.S. transport entrepreneur Malcom McLean, is considered one of the most important developments in logistics. Once loaded into the metal boxes, cargo can be carried over large distances on various modes of transport, including trucks, trains and ships. Grouping cargo in this way does away with time-consuming unloading and reloading and reduces warehousing and laytime costs in ports. This revolutionized goods transportation on land and at sea. Now, Claudio Leonardi from the Swiss Federal Institute of Technology Lausanne (EPFL) hopes to achieve a similar revolution in air cargo with his Clip-Air concept. The researcher has been working on this futuristic aircraft study since 2009.

## **Flying-wing aircraft with flexible-use container capsules**

Clip-Air consists of two elements: First, there is the flying part: a flying-wing aircraft. And then there are capsules that stack in a similar way to containers on a ship and simply dock to the flying module. Depending on the configuration selected, they can then serve as a cabin or a cargo hold. What makes Clip-Air ingenious is that the capsules can also be used as railcars. "This would effectively let us bring aircraft right into the centers of cities," says EPFL researcher Leonardi. Passengers would board their "flight" at the train station. The train would then bring the cabin modules to the airport, where they would be coupled to the flying-wing unit. There would be no need for passengers to transfer to the



**Versatile** — The Clip-Air concept is based on interchangeable modules of different sizes for carrying freight, passengers or fuel, depending on demand.

flight or board it separately; they could simply sit back and relax. This would make stress as people rush to their gate a thing of the past, and airports and airlines would also benefit from the time saved. Another advantage of the modular aircraft concept is that operators could respond flexibly to demand, adds Leonardi. “For example, you could attach only second-class or only first-class modules.” Depending on the bookings for a given flight connection, this would avoid flying with an empty first-class cabin, which is a waste of space and of fuel. It would also represent an innovation in rail transport, enabling freight and passenger modules to be transported at the same time.

The EPFL scientists have calculated that with a wingspan of 60 meters, the aircraft would have a range of up to 4,000 kilometers. Under the main wing structure, it could carry three modules measuring about 30 meters in length and four meters in diameter—each of which corresponds roughly to an Airbus A320 in size. This offers space to carry either three sets of 150 passengers or a large volume of cargo. Replacing one of the three cargo modules with an additional, mobile fuel tank would also increase the range of Clip-Air, says Leonardi, which is an added bonus. If and when the concept will become reality, however, is still very much an open question. Leonardi hopes, of course, that Clip-Air will take off one day, but he understands that the project is a long-term endeavor.

**Coupling poses a technical challenge**

Kay Plötner, Head of Economics and Transportation at the Bauhaus Luftfahrt research institute, doubts whether such a modular aircraft concept will ever get off the ground. And the scientist knows the subject matter well: In 2013, collaborating with de-



**Travel in comfort** — Clip-Air’s passenger modules can be transferred straight from the airfield to the train station while passengers sit back and relax.

sign students from the University of Glasgow, he and his Bauhaus Luftfahrt colleagues also developed a modular aircraft study that combined rail and air transport.

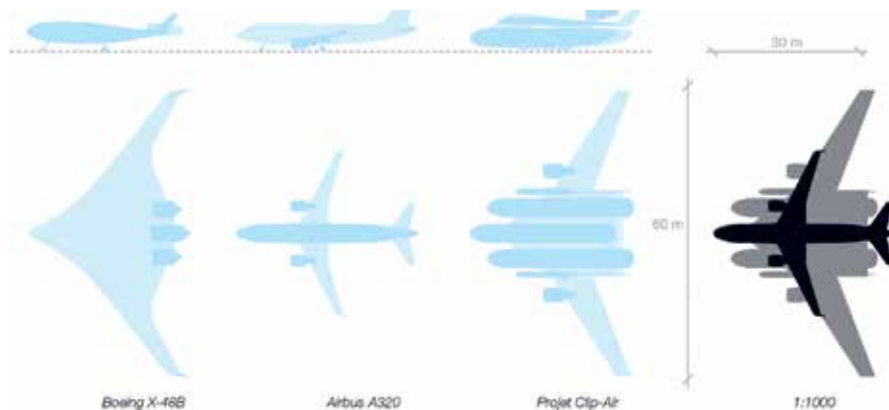
“Where such systems often fall down is that the aircraft themselves become too heavy and inefficient,” says Plötner. The coupling mechanism for the modules has to be designed in such a way as to be secure. As the forces are concentrated on a few points, a more solid design is required, which ultimately adds more weight. Another complication is that the complexity at airports would increase unless the infrastructure undergoes significant overhaul. “This means you’d have to make very costly alterations to airports and in some cases to train stations as well.” These problems also apply to the current Link & Fly concept from the French technology consulting company Akka Technologies, which involves coupling just one train module with a flying module.

The Bauhaus Luftfahrt expert reckons that the modular Transpose concept from the Airbus research unit A3 based in Silicon Valley has a somewhat greater chance of success. At the start of 2017, the team led by project director Jason Chua presented a concept for modular aircraft cabins.

**Adaptable cells**

These mobile modules are designed to be switched in and out at airports within a matter of minutes, which would allow airlines to adapt their aircraft to the individual needs of passengers on certain routes in the future. According to A3, between ten and 14 of these cabin compartments would fit inside an A330. Chua’s idea is to have modules containing facilities like kids’ play areas and childcare for families, flying conference rooms, gyms and cafés.

## CLIP-AIR AIRCRAFT COMPARED TO CONVENTIONAL COMMERCIAL AIRCRAFT

**Flexible aircraft** \_\_\_\_\_


The individual modules are docked under the main wing structure of a flying-wing aircraft. It can fit up to three modules—each of which corresponds roughly to the size of an Airbus A320.

“This added value for customers should, of course, be an incentive for them to pay a little extra,” says Plötner. Something similar existed once in the past: special modules were designed for the lower deck of the Airbus A340-600. These modules housed the restrooms for economy class, the main kitchen and a relaxation room for flight attendants—albeit at the expense of the usable cargo space. Moreover, they were permanently installed and not exchangeable, as they are in the A3 concept. “Theoretically, the Airbus idea would be feasible,” says Plötner.

**Aircraft from a pool**

Whether the demand is there and the modular cabins guarantee higher or at least the same revenue, however, is something that Plötner and other experts are doubtful about. In addition, the airlines would have to carry out new weight calculations for each new configuration of the cabin. Chua is confident nonetheless that a Transpose prototype will take off in just a few years’ time. A3 is already in contact with the Federal Aviation Administration regarding approval, he adds. Plötner and his colleagues are more optimistic about an idea that also takes into account the upcoming individualization trend in air transport, but does not rely on modular concepts: “My response to the demand for flexibility in the future is to have a large pool of aircraft with different configurations

available at an airport, so the airline can simply decide based on their booking situation which one they want to use,” says the expert. “We call this an aircraft sharing model.” In this scenario, the aircraft would no longer belong to the airlines, but to a large leasing company, for example.

“We believe this model would involve relatively little alteration to the transport system—you wouldn’t have to make any major changes to the jets or the airports,” says Plötner. The only radical thing about this is the way it changes planning, operations and crew scheduling for the aircraft serving in the network. If all airlines worldwide agreed to take part and, for example, all Boeing 737 aircraft and Airbus A320 jets were combined in one sharing pool, the Bauhaus Luftfahrt researchers calculate that between 20 and 25 percent fewer aircraft would be required. “This would leave transport capacity unchanged but open the door to lower operating costs,” says Plötner. In addition, the global aircraft sharing model largely avoids the costly transition to modular hardware. “Wherever possible, we use things that can be changed via software: light, digital labels and displays.” So, in the same way you install an app on a smartphone, in the future you might be able to switch a leased aircraft from Lufthansa to easyJet with the simple tap of a button. 



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**Text:**  
**Denis Dilba** holds a degree in mechatronics, is a graduate of the German School of Journalism, and founded the “Substanz” digital science magazine. He writes articles about a wide variety of technical and business themes.



# ASIANA AIRLINES

**Large fleet** — Asiana Airlines operates a fleet of 83 aircraft in total, including 55 Airbus A320 family jets powered by V2500 engines.



# South Korea's number two airline

*Asiana Airlines might not be a household name on the international stage yet, but it is a five-star alternative for intercontinental routes.*

**Text:** *Andreas Spaeth*



**Cheju Island** \_\_\_\_\_ The highlight of the South Korean island, a popular Asiana destination, is the Seongsan Ilchulbong volcanic tuff cone on the eastern seaboard.

**THE MOST FLOWN ROUTE IN THE WORLD: SEOUL – CHEJU**



**Cheju** \_\_\_\_\_ With its fine sandy beaches and impressive sights such as this hareubang sculpture, the largest island off South Korea is a popular destination for vacationers.

Which is the world’s busiest air route? An ideal question on any TV quiz show. There’s a good chance that no contestant would know the answer or even come up with the correct guess. That’s because, in terms of passenger traffic, the world’s most popular route is actually a domestic route in South Korea: from Gimpo, Seoul’s domestic airport, to the popular resort island of Cheju—about an hour’s flight from the capital. According to statistics from travel data provider OAG, almost 14 million passengers make this short hop every year, about double as many who fly the most popular domestic routes within Japan. Located at the southern tip of the Korean Peninsula in East Asia, South Korea is tiny compared to neighboring China to the west and Japan to the east. Even though South Korea is slightly smaller than Iceland in size, it is home to some 51 million inhabitants.

According to analysts at the Centre for Aviation (CAPA), South Korea has a thriving domestic aviation market that served 65 million passengers in 2017. This is largely attributable to the country’s topography as the many mountains and stretches of water restrict overland travel,

although there are competitive high-speed trains that run on trunk routes. As the country’s flag carrier and largest airline, Korean Air has long dominated the domestic market. But when the Kumho Asiana Group—a multi-industry conglomerate typical of Korea—launched Asiana Airlines in 1988, a second player arrived on the scene. The full-service airline currently generates roughly one-third of its business within its home country where it serves ten destinations, but Asiana has also grown into a well-respected, mid-size global carrier. It launched its first international services back in 1991, initially within the Asia-Pacific region and to Los Angeles. Shortly after, it added Vienna and Brussels to its route map as its first European destinations.

With its fleet of 83 aircraft, Asiana is relatively small compared to some other East Asian carriers. Its approach to growth is conservative, with a focus on long-haul services. Asiana currently flies to 51 cities in the Asia-Pacific region, plus to six destinations in North America and eight in Europe. Air transport rating organization Skytrax awarded the carrier five stars—the highest possible ranking—for its outstanding passenger



**Approaching to land** \_\_\_\_\_ An Asiana Airlines A320 over the Port of Ulsan in the southeast of the country.

service. A member of Star Alliance since 2003, Asiana offers a number of popular intercontinental routes via Incheon as appealing alternatives for Europeans who want to fly via Asiana's world-class hub en route to Australia, for example, or for American passengers who can reach 23 destinations in China with just one stopover. And for passengers flying in the other direction as well, of course.

According to CAPA, the average length of an Asiana flight is three hours 20 minutes, an indication that the airline's main business comes from flights within central Asia. Seoul to Tokyo is by far Asiana's busiest market and one that it actually serves on two totally separate routes, each with about the same number of passengers: One operates from Gimpo, Seoul's domestic airport, to Haneda Airport—which mostly handles Tokyo's domestic flights. The other runs from Incheon, South Korea's international hub, to Tokyo International Airport in Narita. These connections rank fourth and fifth in Asiana's international network, while routes from Incheon to Shanghai, to Kansai (in Japan) and to Los Angeles occupy the top three spots.

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#### SOUTH KOREA

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Administrative language: Korean  
 Capital: Seoul  
 System of government: republic  
 Area: 100,363 km<sup>2</sup>  
 Population: 51.4 million  
 GDP: USD 1,530 bn (2017)

Source: [www.auswaertiges-amt.de](http://www.auswaertiges-amt.de)  
 As of October 2018

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**Country of superlatives** \_\_\_\_\_ Occupying the southern tip of the Korean peninsula, South Korea is only about half the size of England but is one of the world's strongest economies. It boasts the fastest internet connections, the busiest flight route and one of the best airports in the world, as ranked by Skytrax in 2018: Incheon International Airport, Asiana's hub in Seoul.

## ASIANA AIRLINES

“Our A320 family aircraft form the backbone of our regional business, so ensuring their reliable operation is essential to our success”

**E-Bae Kim**  
*Executive Vice President  
Corporate Support at Asiana*

### Flagship A380

In 2014, Asiana introduced the flagship Airbus A380 to its fleet and now operates six of the 495-seat aircraft on routes to six international destinations. It deploys its A380s on two daily flights to Los Angeles as well as on services to Bangkok, Hong Kong, New York, Sydney and Frankfurt, the Star Alliance hub. Asiana welcomed its first A350-900 to the fleet in 2017. Now it operates six of the jets, with 15 more on order along with nine A350-1000 jets. Delivery of these new widebodies, which is expected to be completed by 2025, is set to modernize the fleet, bringing down its average age of currently 11 years.

On regional routes, Asiana and its subsidiaries also operate 55 Airbus A320 family jets powered

by V2500 engines. This is where MTU Maintenance Hannover comes in, supporting Asiana’s V2500 fleet to ensure smooth operations. In 2018, the partners signed a new contract covering maintenance for 40 percent of the airline’s V2500s and Engine Trend Monitoring for Asiana’s whole V2500 inventory. “We signed our first maintenance contract with MTU back in 2011 for CF6 engines and we’ve been extremely happy with their outstanding service and expertise ever since,” says E-Bae Kim, Executive Vice President, Corporate Support at Asiana. “In 2018, we embarked on another long-term journey with MTU for our V2500 engines. Our A320 family aircraft form the backbone of our regional business, so ensuring their reliable operation is essential to our success.”



#### Flagship aircraft

*Asiana operates six Airbus A380 aircraft on routes to destinations all over the world.*





#### Popular travel destination

In 2017, South Korea welcomed over 13 million tourists.

*„We know we can count on MTU to provide the best level of service for our commercial operations and that our successful partnership will continue to grow.“*

#### E-Bae Kim

Executive Vice President, Corporate Support at Asiana

#### Customer proximity is key

One important advantage MTU offers in South Korea is the presence of a local representative. “We recognize that close customer proximity is extremely important here, which is why I moved out to Seoul in 2017,” says Wolfgang Neumann, Director Sales, Far East Asia at MTU Maintenance. “This way, I have direct contact with Asiana and other local customers on a daily basis. Before, when I was flying in from Germany for just a few days at a time, I always had a fixed agenda. Now I’m flexible and my customers can reach me at practically any time—and that really makes a

difference.” This setup also helps MTU get to grips with how a South Korean company ticks—something that’s not always easy for Westerners. “My impression from the time I’ve spent here in Seoul is that Asiana is quite a lean organization and somewhat less hierarchical than its competitors,” says Neumann. And this proximity is something the customer appreciates too: “We know we can count on MTU to provide the best level of service for our commercial operations and that our successful partnership will continue to grow,” says E-Bae Kim. “And I’m very proud to be part of it.”



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Text:

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

# Bright outlook for new long-haul bizjets

*The Gulfstream G500 and G600 are hot new arrivals on the large-cabin business jet scene—the market segment with the strongest growth and the highest revenue.*

**Text:** *Andreas Spaeth*

**Flying with class** — With their larger tanks and more efficient engines, two newcomers—the Gulfstream G500 and G600—are taking the business jet market by storm.



Finally, the bruised business aviation market is starting to show long-awaited signs of recovery. At the start of the global financial crisis in 2008, annual business jet deliveries were peaking at around 1,300. These were big numbers at the time considering that business jets serve a niche market segment. In the wake of the recession, however, annual deliveries slumped, falling by around 50 percent to a level they would remain at for many years to come. After almost a decade of stagnating production volumes, the market greatly welcomes any stimulation it can get.

Now more optimistic, analysts are confident that 2019 will be the year when things start to pick up in the business aviation sector. After all, new aircraft models are sparking keen interest from an exacting clientele with cash to burn—in a segment where single aircraft are available for approximately 30 million U.S. dollars but where it's usual to pay somewhere in the region of 40–75 million for a brand-new private jet for long-haul routes. Analysts believe that four newcomers to the bizjet market will drive up sales in 2019 by more than ten percent compared to the previous year.

**THE GULFSTREAM SISTERS**



**Gulfstream G500** — Like the G600, the smaller G500 can carry 19 passengers but has a shorter range of 9,630 kilometers.



**Gulfstream G600** — The G600 and the G500 both reach speeds of Mach 0,9, making them the fastest jets in their category.

**PW800**



**PW800** — The PW800 is part of the PurePower® engine family from Pratt & Whitney. It offers double-digit percentage reductions in fuel consumption, pollution and noise emissions as well as operating costs. MTU Aero Engines holds a 15 percent work share in the program.



**Years of experience** — To date, MTU Aero Engines has delivered some 7,000 modules for the Pratt & Whitney Canada PW300 and PW500 business jet engines.

**More range, more luxury and more space**

“There’s a significant, almost endless desire for more range, more luxury and more space among business-jet buyers,” says David Tyerman from Cormark Securities in Toronto. “We saw that with the G650, and the Bombardier Global 7000 takes it yet another step further. Every time a manufacturer comes out with a product that’s more capable, there seems to be a market that we didn’t know existed.” Bombardier has now extended the baseline range of its Global 7000 to 13,500 kilometers, meaning the ultralong-range aircraft (now known as the Bombardier Global 7500) can whisk up to 19 passengers nonstop from New York to Hong Kong, or from Singapore to Munich, in sublime comfort.

Three rival companies dominate the long-haul business jet market: Bombardier (Canada), Gulfstream (U.S.) and Dassault (France). Gulfstream previously laid claim to the furthest reach with its G650ER, which offers an operating range of just over 12,000 kilometers. Now the jet has been ousted from the top spot by the even further-flying Bombardier Global 8000, which can cover a distance of

14,600 kilometers without stopping to refuel. However, it is the G500 and G600, two newcomers from Gulfstream, that are really shaking up the market.

**Higher efficiency engines boost the market**

Even to the untrained eye, the exterior of a Gulfstream jet is easily distinguishable from other manufacturers’ models by its distinctive oval windows. But the differences that make the difference aren’t apparent at first glance. Two key ways to increase the range of business jets is to give them larger tanks and more efficient engines. The smaller G500 and the stretched, longer-reach variant, the G600—with a range of approximately 12,000 kilometers—are both powered by the Pratt & Whitney Canada’s new PW800 engines. Munich-based MTU Aero Engines holds a 15 percent work share in this engine program, with responsibility for the low-pressure turbine and various stages of the high-pressure compressor.

When it comes to engines for business jets, MTU has years of experience under its belt. “We focus on the medium- and large-cabin jets,” explains Wolfgang Mattig from MTU in Munich, where he



**PW500** — MTU Aero Engines joined this commercial engine program for midsize business jets in 1993 with a workshare of 25 percent.



**Promising market** — MTU Aero Engines plans to triple its revenue in the business jet sector in the next ten years.

is responsible for programs delivered in partnership with Pratt & Whitney Canada. MTU holds stakes of between 15 and 25 percent in the slightly smaller PW300 and PW500 business jet engines: “The fleet powered by these engines is growing fast. We’ve already delivered around 7,000 modules to our partners in Canada,” Mattig says. French manufacturer Dassault’s popular Falcon 7X and its successor, the Falcon 8X, are powered by the PW307A and the PW307D respectively and MTU has a workshare in both.


The PW800 is a recent addition to MTU’s business jet portfolio. “With our stake in this new Pratt & Whitney Canada engine program, we’re looking to tap into the opportunities this segment offers,” Mattig says. The PW800 has the same core engine as the models that power the A320neo, A220, Embraer E2 and Mitsubishi MRJ

passenger aircraft. It’s also set to become the propulsion system for another important business jet: the new Dassault Falcon 6X, which is scheduled to make its maiden flight in 2021 and will form the basis for a brand new category of aircraft.

#### **Mach 0.98 and maximum headroom of 1.98 meters**

The newcomers on the business jet scene have clearly made quite an impression on Mattig. Both models have the PW800 as their exclusive powerplant: “As clean-sheet designs, the G500 and G600 aircraft reach speeds of Mach 0.90, outperforming all other jets in their class. When it comes to the tallest and widest cabin, the Falcon 6X—with its maximum headroom of 1.98 meters—has the edge. These impressive features are sure to cause a stir among business jet customers, almost 65 percent of which are based in

North America; another 13 percent are in Europe and 12 percent in South America.

MTU is optimistic about the potential this sector holds. “The market for large-cabin business jets looks very promising,” Mattig says, “and we expect our bizjet sales to triple in the next ten years.” Analysts at Aviation Week are also expecting an uptick in the market: according to a recent forecast, 792 business jets are slated for delivery worldwide in 2019, with this number growing to 917 in 2028. What’s also noteworthy about this forecast is that for the same period it anticipates deliveries of ultralong-range business jets (such as the G500 and G600 or the Dassault Falcon family) to generate the highest revenue of any aircraft category at almost 105 billion U.S. dollars, trailed by large-cabin jets at around 30 billion U.S. dollars. 



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Text:

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

1969

January

February

March

April

May

June



**Jumbo jet** — Until 2005, the Boeing 747 was the world's largest passenger aircraft.



**Queen of the skies** — Despite its speed and sleek shape, the Concorde did not manage to make supersonic passenger flights into a sustainable business.



**Droop nose** — Both the Concorde and the Tupolev Tu-144 featured a nose cone that pilots could lower to improve visibility on the ground.

# 1969

## “One small step for a man...”

*The year 1969 marked the history of aerospace like virtually no other with the moon landing, the foundations of world-class aviation groups, the start of the jumbo jet age and supersonic passenger travel.*

**Text:** Denis Dilba

A selection of the key events in aviation history from 1969

### February

The ancestor of the jumbo jet, Boeing's "RA001" 747 prototype, takes off from the U.S. company's airport in Everett near Seattle. With a wingspan of 60 meters and distinctive cockpit hump, this 70-meter giant is still powered exclusively by Pratt & Whitney JT9D engines. From 1973 onwards, the jumbo would be equipped with the popular CF6-50 engine. Today, the CF6 series—for which MTU has been a risk and revenue sharing partner since 1971—remains one of the world's most successful engine families.

### March

Concorde takes off from Toulouse-Blagnac on its first test flight. Over the next few months, the supersonic passenger aircraft developed by the French and British aviation industries together would fly below the speed of sound; only in October would it first break the sound barrier. Concorde entered commercial service in 1976. However, supersonic passenger flight did not turn out to be big business, so much so that the two operating airlines Air France and British Airways retired the Concorde in late October 2003 after one of the jets crashed. Thanks to its slimline design and a top speed of up to 2,400 km/h, this aircraft still reigns as the queen of the skies.

### May

At the Paris Air Show in Le Bourget, French transport minister Jean Chamant and German economic minister Karl Schiller sign the contract to build what would become the Airbus A300. A year after the contract signing, the Airbus Industrie consortium was founded. This marked the beginning of the end for the United States' uncontested supremacy in the passenger aircraft market.

### June

Following its maiden flight on New Year's Eve 1968, the Tupolev Tu-144 becomes the first commercial supersonic aircraft to break the sound barrier in June 1969. However, the technically underdeveloped

July

August

September

October

November

December

# mtu MÜNCHEN

**Groundbreaking** — Founded 50 years ago, MTU München became MTU Aero Engines in the year 2000.



**Vertical takeoff aircraft** — To this date, the Do 31 remains the world's only transport aircraft to achieve vertical takeoff and landing. In the picture: the prototype outside the Dornier museum in Friedrichshafen.



**Short but sweet** — The Trident 3B flew for only 17 years. Competition from Boeing with its quieter and more efficient aircraft was simply too tough.

jet would enjoy just as little success as its West-European counterpart: the Tu-144 transported just 3,284 passengers on 55 flights. The development program was halted in 1983. Of the 16 aircraft produced, today only 5 are available to the public, including at the Technik Museum Sinsheim in Germany.

## July

On July 11, MTU Motoren- und Turbinen-Union München GmbH MAN Maybach Mercedes-Benz was founded, known as MTU München for short. Basis for the foundation is a contract between Daimler-Benz and MAN that defined the consolidation of the two companies' turbo aircraft engine and high-speed diesel engine activities; in addition to MTU München (aircraft engines), MTU Friedrichshafen (diesel engines) was also founded.

On July 21 at 3:56 a.m. CET, U.S. astronaut Neil Armstrong became the first man on the moon. He was followed by Buzz Aldrin. Some 600 million TV view-

ers experience the event via live broadcast. Michael Collins, the third astronaut on the Apollo 11 mission, stayed on board the Columbia mothership, which could not orbit the moon independently. On July 24, Apollo 11 returned to Earth.

## August

The Brazilian government founds Empresa Brasileira de Aeronáutica, better known as Embraer. After its privatization in 1994, the aviation group rises to become the fourth largest aircraft manufacturer behind Airbus, Boeing and Bombardier Aerospace.

## September

Made by J. Wagner Helicoptertechnik, Friedrichshafen-Fischbach, the FJ-Sky-Trac is the first helicopter developed in Germany since the Second World War and receives type approval from the German Federal Aviation Office.

## October

The German government ends the development program for the Dornier Do 31 vertical takeoff aircraft: due to a new NATO doctrine and a shift in German Armed Forces requirements, the concept is declared to have no future for military applications. The Do 31 is nevertheless a technical masterpiece and marks a milestone in aviation history. Today it remains the only jet-powered transport aircraft to achieve vertical takeoff and landing.

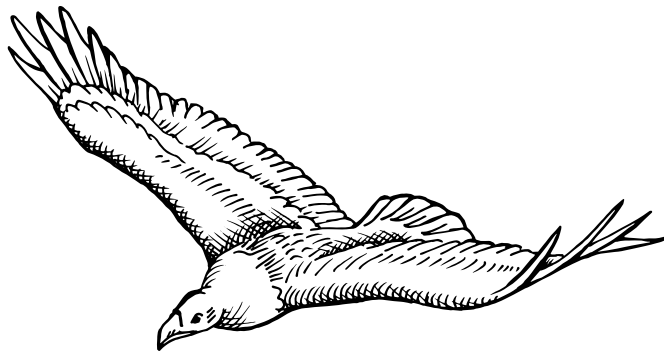
## December

Trident 3B, made by British manufacturer Hawker Siddeley, takes off for the first time. Originally a three-engine aircraft, this Trident model was equipped with a fourth engine on its tail assembly to provide extra thrust during takeoff. This exotic aircraft was developed specially for British European Airways (BEA) and offered space for 180 passengers. Louder and consuming more kerosene than its rival, the Boeing 737, the 3B was retired by BEA in 1986. ✈️

# Fat ones

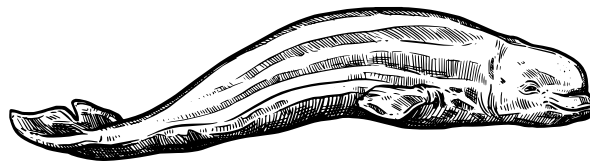
*Given how they are shaped like pregnant fish or oversized whales, it's hard to believe that these transport planes can take off at all.*

**Text:** Isabel Henrich / Monika Weiner



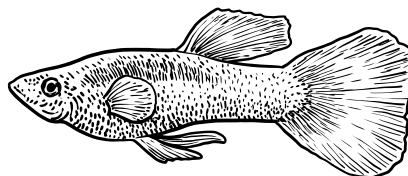
## **Kings of the skies** —

*A wingspan of 88.4 m makes the AN-225 the largest aircraft in service worldwide. A wingspan of 3.2 m makes the Andean condor one of the world's biggest birds.*



## **Giant flying whale** —

*The face painted on the Airbus transport plane is supposed to resemble a smiling beluga whale. The plane's characteristic shape is reminiscent of the curvature of the beluga whale's head.*



## **Pregnant airplane** —

*The Super Guppy is shaped like a fish that is only a few centimeters long: the guppy. Engineers christened the first model of this aircraft "Pregnant Guppy" because it reminded them of the fat abdomen of the female fish during pregnancy.*



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**THE THREE LARGEST TRANSPORT AIRCRAFT IN COMPARISON:**


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**Antonov AN-225 Mrija**


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Predecessor model:	Antonov AN-124
Height:	18.2 m
Length:	88.4 m
(Wing)span:	84.0 m
Max. payload:	250 metric tons
Quantity:	1
Maiden flight:	Dec 21, 1988

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**Beluga XL**


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Predecessor model:	Beluga ST
Height:	18.9 m
Length:	63.1 m
(Wing)span:	60.3 m
Max. payload:	53 metric tons
Quantity:	1 (a total of 5 are planned)
Maiden flight:	Jul 19, 2018

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**Super Guppy Turbine**


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Predecessor model:	Pregnant Guppy, Super Guppy
Height:	14.8 m
Length:	46.8 m
(Wing)span:	47.6 m
Max. payload:	24,5 metric tons
Quantity:	4
Maiden flight:	Aug 24, 1970

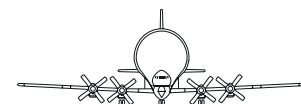
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**Antonov AN-225 Mriya** —  
 With a cargo volume of 1,220 m<sup>3</sup>,  
 the Mriya was developed to transport  
 the Soviet spaceplane Buran.



**Beluga XL** —  
 The second unit was completed in  
 March 2019. It is set to take to the skies for  
 the first time in the second quarter of 2019.

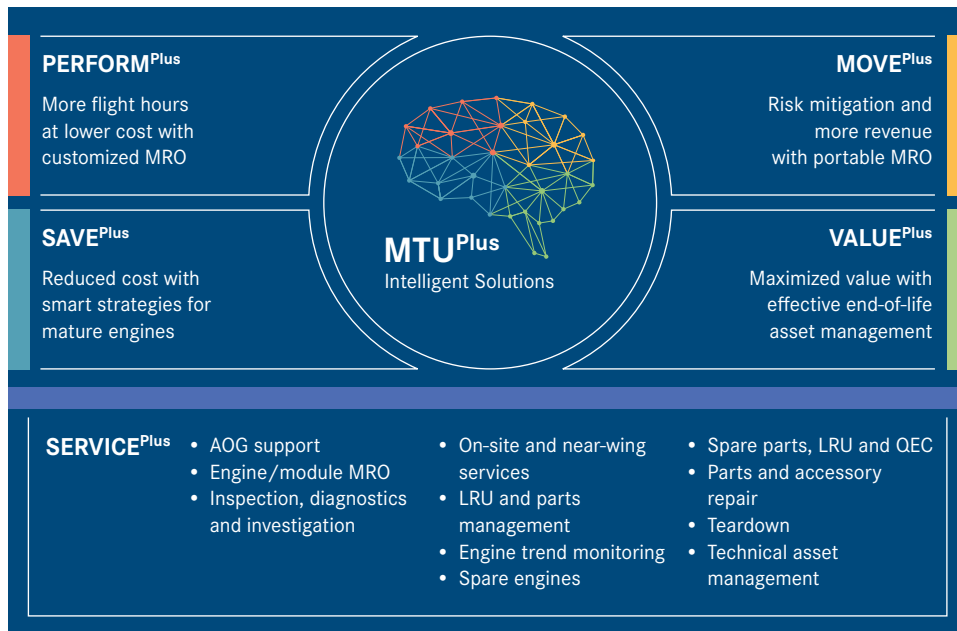


**Super Guppy Turbine** —  
 The widebody cargo aircraft was mainly  
 used for the transport of space construction  
 parts and Airbus aircraft parts.

---

# MTU<sup>Plus</sup> Intelligent Solutions

*MRO solutions tailored to customer needs*



MTU Maintenance ranks among the top five service providers worldwide, with 40 years of experience and having completed over 18,000 shop visits. With **PERFORM<sup>Plus</sup>**, MTU Maintenance offers operators of newer engines more flight hours at lower cost. This is achieved with intelligent fleet management, predictive maintenance with engine trend monitoring, high-tech repairs, on-site services and spare engine support. For engines approaching the end of their life cycle, MTU has developed **SAVE<sup>Plus</sup>** smart strategies that are tailored to the remaining flight periods and help to keep costs down. Towards the end of aircraft life, asset owners are looking to get the best possible value from their engines. With **VALUE<sup>Plus</sup>**, MTU Maintenance offers its customers effective end-of-life asset management, always finding the right solution—whatever the engine type or parts. And its **MOVE<sup>Plus</sup>** solution supports customers with a portable MRO solution across the lifecycle, enabling fast remarketability of assets through easy transfers and predictable costs with simplified MRO. In addition to these integrated service solutions, MTU customers can enjoy a range of tailored offerings with **SERVICE<sup>Plus</sup>**.

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