

Best connections

Concepts for coping with the rise in air traffic



MARKET

The paint job
Aircraft paintwork

MARKET

Saving fuel is in
Sustainability in aviation

TECHNOLOGY

The next wave
Technological advances
in turbine and compressor



Quiet in the city — With its low-noise PW1500G engines, the Bombardier CS100 can take off from London City Airport and fly non-stop to New York in exclusively business class seating.

Dear readers,

As a way of tackling the transport problems of the future, the billionaire space entrepreneur Elon Musk has proposed a tube transport system called “Hyperloop.” This envisions using solar energy to convey passengers and cargo through a tube at over 1,200 kilometers per hour in transport capsules on air cushions. In May of this year, he presented a prototype of the propulsion system.

In my view, high-speed transport solutions such as this can solve only a few specific transport problems here and there. In the long term, the real challenge will lie in conveying constantly increasing volumes of passengers and cargo between rapidly growing metropolises and to ever more sparsely populated regions outside the megacities. For long-distance passenger travel, in particular, there will be only one really suitable means of transport until the middle of the century at least: the airplane.

This throws up new questions, which are being addressed by the aero engine industry. Current predictions state that the number of aircraft worldwide is set to triple by 2050, which will also increase the environmental impact of aviation. This is why we are working urgently with our partners to develop quieter, more efficient, and less polluting engine concepts, so that we can meet the ambitious climate protection goals the international aviation industry has set for itself.

A milestone on this road is the Geared Turbofan™ technology in the PW1000G engine programs from Pratt & Whitney, in which MTU Aero Engines has a stake. The first aircraft with Geared Turbofans entered regular service this year. In addition to reducing fuel consumption and pollutant emissions, the new aircraft outperform their predecessor models in one area above all: they are much quieter, which enables them to use airports closer to cities. For example, the Bombardier CS100 is small and quiet enough to take off from London City Airport, and is capable of flying straight to New York without having to stop over for refueling in Ireland, as smaller aircraft generally had to do before now. These two factors together can shave several hours off the journey time.

In this edition of **AEROREPORT**, you will find an insight into aviation trends, reports on aircraft paintwork and on an unusual customer, an interview with an innovation researcher, and information about the latest developments in technology, which have one goal above all others: to achieve growth that has less of a negative impact on the environment, the climate and people’s lives.

I hope you enjoy the issue.



Yours sincerely,

A handwritten signature in blue ink that reads "Michael Schreyögg". The signature is fluid and cursive.

Michael Schreyögg

Member of the Executive Board, Chief Program Officer



COVER STORY

Best connections

To cope with the global rise in air traffic between urban centers, we are going to need quieter aircraft and more efficient airports. Big data applications are among the solutions helping to get passengers and luggage to their destinations quicker than ever.

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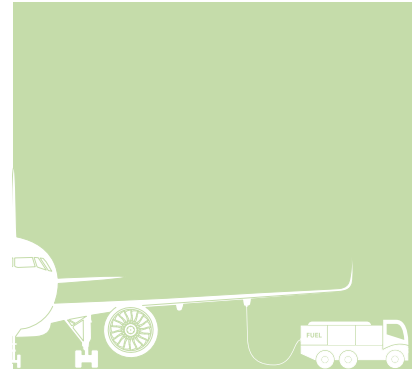


MARKET

The paint job

Paint is important—and not just for the external appearance of an aircraft. Paintwork has many functions, which include protecting aircraft against corrosion and lengthening their service lives. In the future, it will even improve environmental performance.

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MARKET

Saving fuel is in

Aviation can already point to huge progress in its environmental performance. Over the past 50 years, CO₂ emissions have been reduced by 70 percent per passenger kilometer. However, because the transport sector continues to grow, there are numerous initiatives designed to make the increasing aviation traffic more environmentally friendly.

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**PARTNERS****Back home safe**

Each year, the professionals of Tyrol Air Ambulance service fly more than 3,000 patients back home using up to six specially equipped aircraft—a logistical, aeronautical and technical feat that draws on 40 years of experience.

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**EXPERTISE****“We also have to rethink our behavior”**

Innovations in aviation primarily target the reduction of fuel consumption and emissions. But that might not be enough, says Prof. Marion A. Weissenberger-Eibl from the Fraunhofer Institute for Systems and Innovation Research ISI.

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**TECHNOLOGY****The next wave**

By the end of the decade, the Airbus A320neo will have an even more fuel-efficient engine. To make this possible, two key components of the geared turbofan are currently undergoing tests at MTU Aero Engines.

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

Cooperation with Embraer

In the future, **MTU Maintenance Lease Services B.V.** will be cooperating with **Embraer Aviation International SAS.**



The collaboration comprises the supply of replacement engines and associated leasing services for operators of Embraer E-Jets in Europe, Africa and the Middle East. Through its constantly growing pool of replacement engines, MTU Maintenance Lease Services enables its customers to guarantee the availability of replacement engines for their customers, thereby helping them optimize their deployment readiness and cost competitiveness. Thanks to the cooperation with Embraer, MTU Maintenance Lease Services is further expanding its client roster and strengthening its position as a leading independent maintenance service provider for the **CF34-10E** engine.

T408 released for production

Certain situations can cause even hard-nosed military officers to wax lyrical. Shortly before the summer vacation, one such situation arose at General Electric (GE) in Lynn, Massachusetts—and it drew effusive words from Brigadier General Kurt Stein from the U.S. Marine Corps: “Many thanks to everyone involved in this program, including the engineers and our colleagues from manufacturing, assembly and testing.” He was talking about get-

ting approval for series production of the **T408**, the engine for the **CH-53K King Stallion heavy-lift cargo helicopter.**

Those scheduled to soon fly with the CH-53K also have plenty to look forward to. It can transport external payloads of 27,000 lbs.—nearly three times that of its predecessor model. There is no doubt what the decisive factor is: three T408 engines per CH-53K, each with 7,332 shaft

horse power, supply the necessary power.

MTU is also delighted about the engine approval. In its role as developer and manufacturer of the power turbine, the company has taken responsibility for a complete assembly on a U.S. military engine program for the first time. In addition, it is receiving licenses for the maintenance, final assembly and testing of the T408 models for a future European heavy-duty transport helicopter.

Aigner opens PW1100G-JM assembly

One of the biggest milestones in the company’s history has been reached: MTU Aero Engines has completed final assembly on the first **PurePower® PW1100G-JM** production engine and delivered it to Airbus. The final assembly line, which MTU developed for the **A320neo engine**, was officially opened by Ilse Aigner, Bavarian Minister of Economic Affairs and Media, Energy and Technology. On account of the high production rate, preassembled components and modules are fitted together at six assembly stations, which together resemble a conveyor belt system. In this way, several engines in various states of assembly can be processed side by side. Once the PW1100G-JM line has fully ramped up at the end of 2018, some 100 employees will be working there in 6-day multi-shift operation. In August,

the U.S. Federal Aviation Administration (FAA) had already approved the assembly line and the testing. Now the official opening is the final decisive stage for the production ramp-up of the pioneering engine program at MTU Aero Engines.



MTU CEO Reiner Winkler, Minister Ilse Aigner and MTU COO Dr. Rainer Martens (from left).

Wolfgang Heilmann Prize awarded

Christian Lieber has received this year's Wolfgang Heilmann Prize for his master's thesis entitled "Simulation of an engine bearing chamber using smoothed particle hydrodynamics." The Karlsruhe Institute of Technology (KIT) graduate further developed this numerical method for simulating the **complex two-phase flow processes in the bearing chamber**. This makes it possible to design the engine component more quickly and with greater precision. MTU established the **Wolfgang Heilmann Prize** in 1990; it is awarded annually for outstanding work by new academic talent at KIT who are carrying out research in the field of aircraft engines.



Wolfgang Heilmann Prize _____ Dr. Cornelia Hillenherms, Vice-President of the German Society for Aeronautics and Astronautics (DGLR), award winner Christian Lieber, and Heinz Knittel, technology coordinator at MTU Aero Engines (from left).

Royal service for Royal Jordanian

Since the 1980s, MTU Maintenance has maintained engines for **Royal Jordanian Airlines**. Meanwhile, the carrier is also a regular engine leasing customer. and in the recent past, there have been some important additions to this relationship: at the end of April, a renewed and exclusive five-year agreement came into effect for maintenance of the **V2500 fleet**. The service package now also includes **MTU^{plus} Engine Trend Monitoring**. This system is based on a sensor-based functionality designed to rec-

ognize technical problems long before they can disrupt flight operations or result in expensive repairs. Also in April, a new maintenance contract entered force for the **CF34-10E engines** in Royal Jordanian's Embraer 195 and 175 E-Jets. The third of these engines is currently in the shop at MTU Maintenance Berlin-Brandenburg. At the end of September, a further new contract was signed for maintenance of the **CF6-80 engines** for the Airbus A310 cargo aircraft.

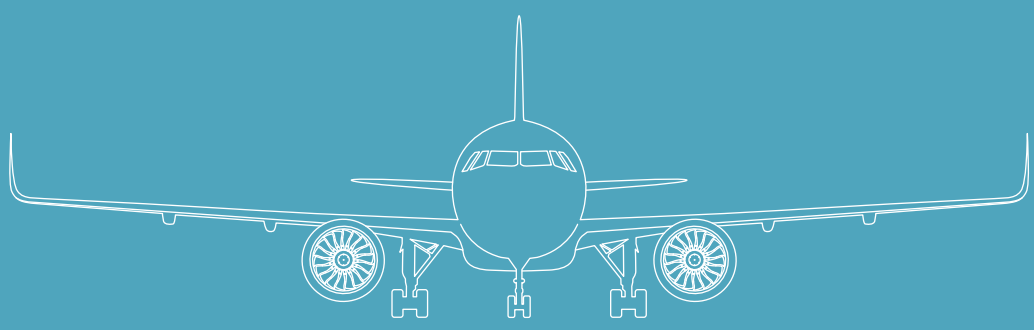
Exclusive contract with Sky Regional Airlines

For the next ten years, **MTU Maintenance** will have exclusive responsibility for maintaining CF34-8E engines for the Canadian operator **Sky Regional Airlines**. As part of a **Total Engine Care (TEC[®]) package**, MTU Maintenance will look after all services relating to the maintenance of the engines including on-site repairs and the supply of replacement engines. The services will be coordinated or performed by MTU Maintenance



Berlin-Brandenburg, which is specialized in the maintenance of engines in the **CF34 family**. The orders resulting from the agreement will be worth some 250 million U.S. dollars in total. Since 2003, MTU Maintenance has carried out almost 900 shop visits for engines in this family (CF34-1, -3, -8C, -8E, -10E). In 2015,

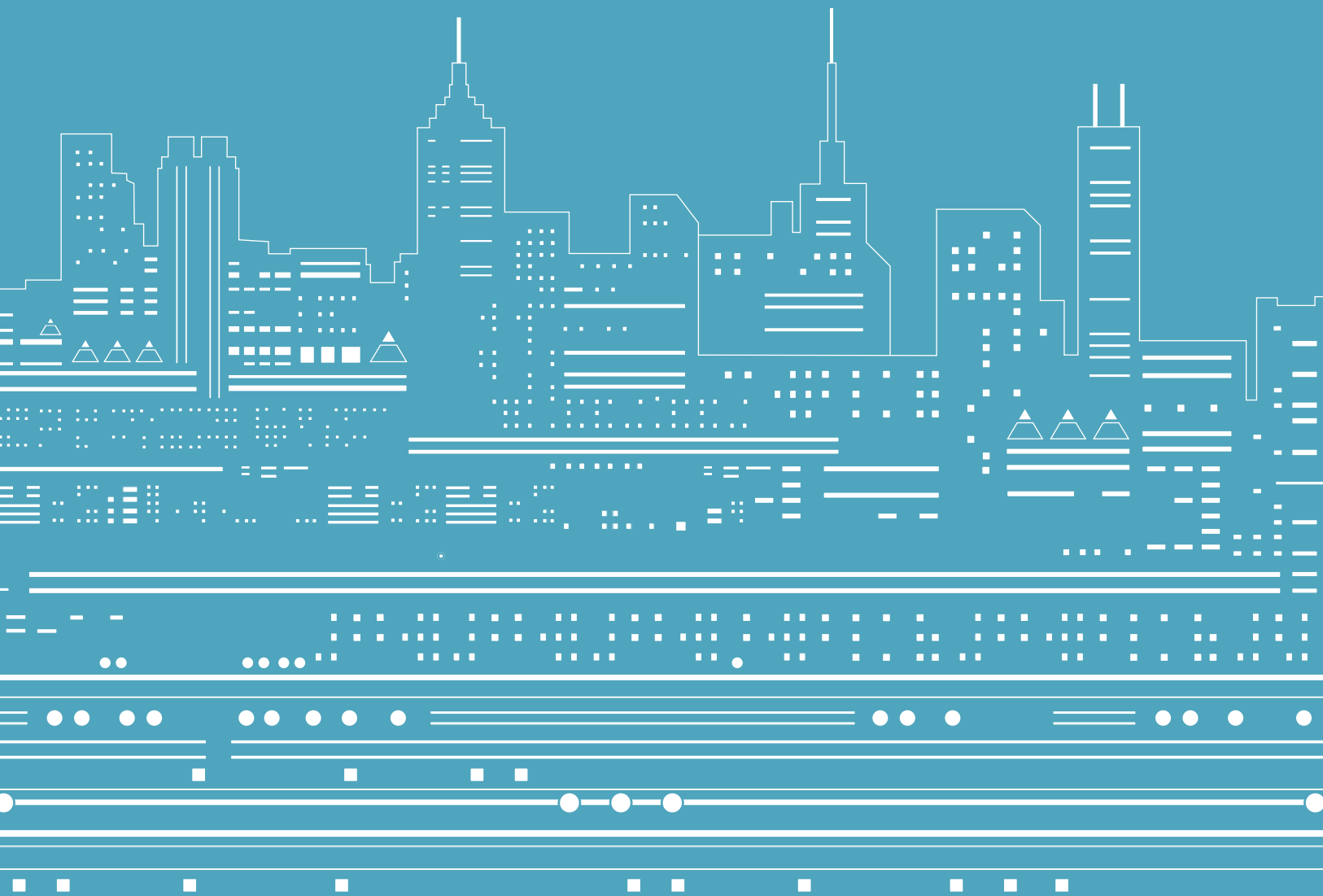
the company was the number two maintenance service provider for all CF34 engines worldwide.



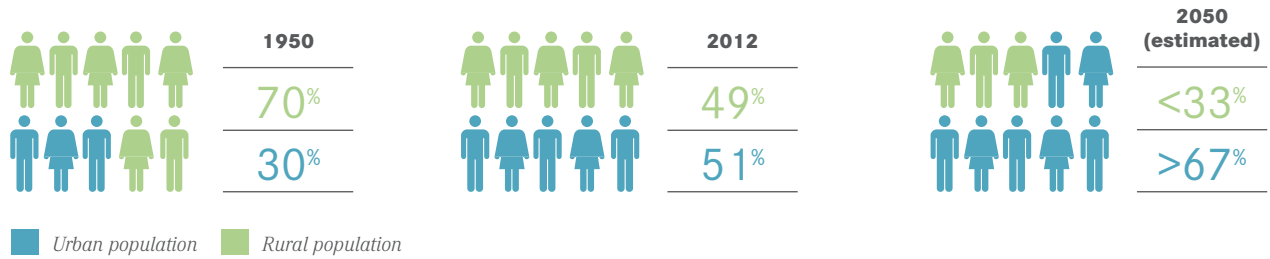
Best connections

To cope with the global rise in air traffic between urban centers, we are going to need quieter aircraft and more efficient airports. Big data applications are among the solutions helping to get passengers and luggage to their destinations quicker than ever.

Text: Denis Dilba



DISTRIBUTION OF WORLD POPULATION: URBAN / RURAL



Source: UN

It is a well known fact that we can expect air traffic to grow rapidly over the coming years—though the sector disagrees slightly on exactly what that yearly growth will be. At this year’s International Airshow in Farnborough in the UK, for instance, Airbus and Boeing were talking about a global growth rate of 4.5 percent per year up to 2035, while the International Air Transport Association (IATA) puts the increase at a somewhat more modest 3.8 percent

per year. Still, we are long past quibbling about how large exactly the increase in air traffic will be—today, the important questions are where that growth will take place, what impact it will have and how we can keep pace with the soaring demand for mobility.

According to the current forecasts of the United Nations, the bulk of global population growth—and thus potential passenger

THE CENTAIRSTATION CONCEPT FROM BAUHAUS LUFTFAHRT



In collaboration with 12 students from Glasgow School of Art, 25 scientists from Bauhaus Luftfahrt have developed a dovetailing airport and aircraft concept: “CentAirStation” and “CityBird.” Their mission: new, inner-city airports and new aircraft, which will operate between these inner-city airports and conventional ones, will help meet the requirements of air travel in 2040 and beyond.

Source: Bauhaus Luftfahrt e. V., June 2016

The conditions:

- 1 Urbanization will continue to 2040 and beyond, also leading to marked growth in megacities.
- 2 These megacities must have efficient connections to air transport.
- 3 Global air travel is set to grow at around 4.7 percent per year, tripling the amount of flights by 2040.
- 4 One aim of the European Commission’s “Flightphath 2050” is for 90 percent of all travelers to be able to reach their destination within four hours, door to door.

“Our vision is that passengers should be able to take off no more than 15 minutes after arriving on the train, and be able to exit the building within 10 minutes of landing.”

Kay Plötner,
Bauhaus Luftfahrt e. V.

increases—will take place in cities. Back in 1950, just 30 percent of the population lived in urban areas, a figure that now surpasses 50 percent and which experts expect to exceed two thirds of the population after 2050. While urbanization has reached an advanced stage in the countries of the West, it is just taking off in Asia, Latin America and Africa. In China and India in particular, cities have boomed, bringing with them an affluent and consumer-oriented middle class. As income increases, these people can afford to fly more. If population growth remains on or near its current course until 2050, we must be prepared for a three- to fourfold increase in air traffic.

Infrastructure on the ground

“The question is how infrastructure can keep pace with mobility needs in such rapidly expanding cities,” says Kay Plötner from the Bauhaus Luftfahrt think tank in Munich. The aerospace engineer is one of those involved in a concept that could provide an elegant solution to the problem: new, smaller-sized airports located directly in city centers and offering direct links to each other and other already existing airports. Plötner and his colleagues have called the study, which they presented at the 2016 Berlin Airshow, “CentAirStation.”

The idea is to build four-storey buildings over existing underground and municipal railway lines, providing a place for aircraft to take off and land. You could think of it as a sort of aircraft carrier, just on land, says Plötner. The flight deck is 650 meters long and 90 meters wide, while the floor

below is used for boarding and clearance. One floor below that, there is security and luggage drop-off as well as restaurants and shops accessible from the trains arriving at ground level. “Our vision is that passengers should be able to take off no more than 15 minutes after arriving on the train, and be able to exit the building within 10 minutes of landing,” says Bauhaus researcher Plötner.

It should be noted that the CentAirStations are designed to work only with a new type of aircraft, the “CityBird.” Plötner explains that this would be a short-haul aircraft with around 60 seats and a range of 2,700 kilometers. Engines with a high bypass ratio are to combine modern turbo components with piston technology, allowing for particularly low NOx emissions. MTU Aero Engines is one of those who has worked on the pioneering composite cycle engine concept. In addition, a catapult launch is to boost the drive power needed for takeoff, making operations even quieter. However, the CityBird is also designed to be able to land and take off from traditional airports—ultimately, the idea is to complement existing airports, not replace them, says Plötner.

Four hours door to door

Bauhaus’s idea could play an important role in fulfilling one of the European Commission’s ambitious targets for “Flightpath 2050”: that, by mid-century, 90 percent of all journeys in Europe should take no longer than four hours door to door. Florian Rudolph, a researcher at the German Aerospace Center DLR’s Institute of Air Transport

AUTOMATED BAGGAGE TRANSPORT

61.3%

fewer **baggage items lost** since 2007

18

billion U.S. dollars

estimated amount **airlines have saved** worldwide since 2007 thanks to improved baggage transport

33.3%

increase in passengers worldwide since 2007

62%

of **airports** want to automate bag drops

70%

of airlines want to automate bag drops

66%

of airlines plan to offer customers baggage tracking using **data transfers in real time** via apps for mobile devices

97%

of passengers travel with **mobile devices** (laptops, tablets and smartphones)

Source: SITA, *Baggage Report 2015* and *Air Transport IT Review 2016*

DEVELOPMENT OF DIGITALIZATION IN PASSENGER AIR TRAVEL WITHIN ONE YEAR



2015

2016

78%

99%

of airlines offering **online check-in**



2015

2016

50%

78%

of airlines offering **check-in via mobile devices** (tablets, smartphones)



2015

2016

45%

75%

of airlines offering **mobile boarding cards**

Source: SITA, *Baggage Report 2015 and Air Transport IT Review 2016*



Digitalization in passenger sector — Three out of four airlines worldwide already issue electronic boarding cards on mobile devices—only one year ago, fewer than half provided this service.

and Airport Research, illustrates just how difficult that is in today's world: "If I want to fly from Braunschweig to Paris via Hannover and be sure of catching my flight, I have to factor in a buffer for any bus and train delays and set off from home three hours before my flight," says Rudolph. When you add in the flight time, the four-hour target is long surpassed.

In the DLR Optimode research project, Rudolph and his colleagues have examined how buses, trains and airlines can be better coordinated so that travelers can be sure of catching their flights without having to plan in buffer time. "If airlines, bus and train companies know that air passengers are sitting in a bus or train on their way to the airport, they can calculate alternative routes, put on extra connections or arrange speedy boarding in the event of any delay," says Rudolph.

"Passengers would be kept informed about these developments via a live app. Should the delay prove too great, the system would calculate a new connection and get the passenger to their destination by another route," says Rudolph.

It all sounds quite simple, but it is a real challenge in practice. Currently, airlines only know for sure that a passenger is actually going to fly when they board on the day of their flight. So that transportation operators can react flexibly, travelers would have to be prepared to share details about their location with bus and train companies as well as with the airline. The experts at the DLR envisage that this will happen automatically, for instance by scanning a bus or train ticket and comparing it against GPS coordinates relayed by a smartphone. When the passenger enters the airport, they

“The digital transformation presents aviation with enormous opportunities. It makes flying safer, more comfortable and more efficient, as well as making the manufacture of aircraft and aircraft components cheaper and more flexible.”

Bernhard Rohleder,
Bitkom

confirm that they have arrived with a barcode scan. Still, even though the first Optimode prototype has received exceedingly positive feedback, the researchers are clear that their project is a venture into the unknown. “Until now, individual operators have focused on optimizing their own systems,” says Rudolph. “The challenge now is to convince them to move away from their individual priorities for the benefit of transportation as a whole.”

Big data is transforming aviation

What Optimode has already shown is that raw data will have just as big an impact on aviation as urbanization. Airlines will be able to make use of passenger information to optimize the service they provide, offering a passenger’s favorite hotel with their flight booking, for instance, or directly noting in-flight food preferences. Not only that, but check-in will be a much smoother process as well: suitcases marked with radio chips will be able

to be deposited well before the airport—automatically locating the relevant passenger later on in the journey. Industry experts anticipate that waiting at baggage reclaim will be the exception rather than the rule within the next decade.

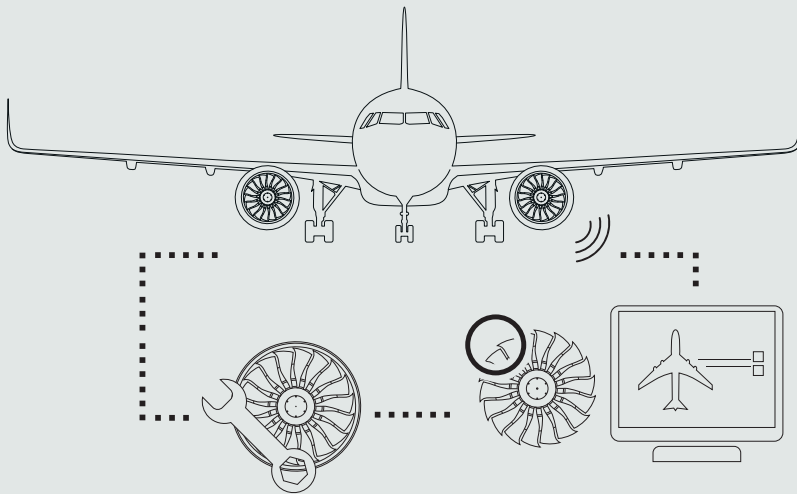
“The digital transformation presents aviation with enormous opportunities. It makes flying safer, more comfortable and more efficient, as well as making the manufacture of aircraft and aircraft components cheaper and more flexible,” says Bernhard Rohleder, CEO of Germany’s digital association Bitkom. Dr. Friedhelm Kappei, Senior Manager Central and Performance Engineering at MTU Maintenance Hannover, knows the potential of big data analysis first hand through the MTU^{Plus} Engine Trend Monitoring software, which monitors engine parameters such as engine speed, temperature and pressure both at takeoff and during flight. When the aircraft lands, these data are relayed to MTU.

Data as a raw material in the aviation industry

“The flow of data does more for global growth than the flow of goods.” This was the conclusion of a study published by international consultants McKinsey in early 2016. According to the study, global data traffic has increased by a factor of 45 in the past 10 years and is set to increase further a by a factor of 9 by the end of the decade.

The potency of data flows is driven by technical improvements to hardware, as the trade publication “Aviation Week” pointed out with regard to the industry: “Advances in digital connectivity systems promise a wide range of applications and services that will help enhance airlines’ operational efficiency and safety.” The magazine gave examples of how data flows are being used in the industry, including minimizing flight delays with the help of weather data—supplied by aircraft and weather observation stations, this data can be gathered in a central computer and sent as regular updates to the various players involved.

Inside MTU — Engine Trend Monitoring



“We can also help avoid expensive repairs by identifying early on if a small component needs to be replaced, thus preventing any more significant damage.”

Dr. Friedhelm Kappei,
MTU Maintenance Hannover

MTU’s Engine Trend Monitoring software records flight data such as engine speed and pressure. After landing, these data are relayed to MTU Maintenance. “We analyze the data and check if there are any discrepancies that suggest damage to the engine,” explains Dr. Friedhelm Kappei,

Senior Manager Central and Performance Engineering. The advantage, says the MTU expert, is that this allows MTU customers to better plan when a specific aircraft has to be grounded for engine maintenance. “We can also help avoid expensive repairs by identifying early on if a small compo-

nent needs to be replaced, thus preventing any more significant damage.” Kappei expects that, in time, these engine data will be relayed in real time—something which is not yet viable mainly due to the high data transfer rates required.

Work on the Engine Trend Monitoring solution began around 15 years ago, and as much as 30 years ago in the case of the geared turbofan technology that is just now going into regular service in the latest generation of engines, says MTU market expert Dr. Marc Le Dilosquer. “It goes to show that we have to start work on changes in the aviation sector today in order to be able to reap the fruit in the future.” He does not anticipate a revolution of air travel given the current situation, but rather a steady evolution. This is in part due to the fact that the expensive infrastructure is largely in place and must continue to be used where possible.

As to whether it makes sense to expand an existing airport, this can now be evaluated using an adapted piece of DLR software that was originally used to predict the development of stars’ luminosity.

More flying, less noise


All those involved know that changes in aviation can be implemented only with the acceptance of the public. “Above all, it’s a case of making aircraft so quiet that they make no or minimal disturbance,” says Roland Gerhards, CEO at the ZAL Center of



“Above all, it’s a case of making aircraft so quiet that they make no or minimal disturbance.”

Roland Gerhards,
Center of Applied Aeronautical Research (ZAL)

Applied Aeronautical Research in Hamburg. While electric flying has the potential to reduce noise in the long term, fuel cells and small electric motors in the landing gear are prime candidates for significantly reducing noise in the short term, says Gerhards. “This would allow aircraft to coast their way silently to takeoff.” Both topics are currently being researched at the ZAL and could be ready for implementation within the next five to ten years.

Noise reduction also is an issue for aero engine manufacturers: The new generation of geared turbofan engines not only reduce fuel consumption and harmful emissions, but also reduce the noise footprint by up to 75 percent. This cuts the noise levels around an airport to a quarter of their present levels. As a result, it is possible to operate more aircraft without creating too much noise in the surrounding area, opening up room for future growth. 



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



More on this topic: www.aeroreport.de



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.



Decorative protection _____ Up to six layers of paint, each less than one millimeter thick, are applied to an aircraft in order to protect the outer shell from environmental influences such as cold and UV radiation.

The paint job

Paint is important—and not just for the external appearance of an aircraft. Paintwork has many functions, which include protecting aircraft against corrosion and lengthening their service lives. In the future, it will even improve environmental performance.

Text: Monika Weiner

Aircraft manufacturers are keen to reduce weight whenever they can. There are good reasons for this wrestling over every gram: the lighter the aircraft, the less fuel it consumes, the more passengers it can accommodate and the better its carbon footprint. Consequently, engine manufacturers are constantly optimizing their designs: fuselage parts are increasingly being made from expensive, carbon-fiber-reinforced plastics; for the interior design, solid metals are being replaced by fiber-reinforced composites. And then the painters come along and spray almost a ton of paint on an Airbus A380. Is that really necessary?

“Absolutely,” explains Maike Timm, production manager for aircraft painting services at Lufthansa Technik. “Without the protective layer of paint, the aircraft components would get damaged very quickly—whether they are made from metal or plastic, it makes no difference.” In everyday flight service, the surfaces are exposed to huge strains: ice crystals, dust particles, ash and grains of sand pelt into the materials at speeds of 1,000

kilometers an hour. On top of this, there is UV radiation and temperature swings of -55 to +100 degrees Celsius. Unless the surfaces are sealed, de-icing agents, kerosene and lubrication oil residues cause metals to quickly corrode and destroy the material compounds of fiber-reinforced plastics. For cost reasons, the first passenger aircraft took to the skies unpainted—there was a war on in Europe. But the aluminum alloys were soon tarnished and had to be frequently repolished. Today not even the Junkers Ju 52 flies without a protective paint layer—even if it is not apparent at first sight. The outer shell sports a coat of metallic paint.

Protection coat by coat

Without paint, nothing works in aviation. However, the cans of paint you find in your local home improvement center are not up to the job—aircraft paint has to be extremely thin, scratchproof, dirt-resistant and environmentally friendly. Summing up the situation, Timm says: “Thanks to new developments, we can now



Detailed work on aircraft wing _____ *Painting at Airbus paint shop in Toulouse.*



Perfect fit _____ *A Lufthansa Technik employee working on a window band on D-AIRX, an Airbus A321-131, which was painted in early 1950s style to celebrate 50 years of Lufthansa in 2013.*



Top coat _____ *The aircraft gains color with the third coat of paint—as here at Airbus.*

Colorful planes



Gold for Olympians — Delicate work as colored films are applied to the “Plane of Champions,” a Boeing 747-8 specially designed by Lufthansa for the German 2016 Olympic team.

After the 2016 Olympic Games in Rio, the German Olympic team flew home in a “Plane of Champions,” a Lufthansa Boeing 747-8 specially designed for the event. However, the aircraft was

not repainted for the occasion, just covered with adhesive colored films. The aircraft underneath still has the classic white design.

In principle, aircraft can be painted in any color. However, white has the advantage that it does not heat up. Although a black airplane could use a thinner coat of paint because dark colors provide better coverage, it would also absorb much more sunlight. The interior would then have to be constantly cooled.

Even colorful and complex designs can be used. That said, multi-colored paintwork is expensive, because every color has to be applied in a separate operation, and parts that are meant to become or remain a different color have to be masked off by hand. To minimize the amount of work this entails, engineers are currently developing robots that can apply the various colored paints directly to the aircraft.

“Without the protective layer of paint, the aircraft components would get damaged very quickly—whether they are made from metal or plastic, it makes no difference.”

Maik Timm,
Lufthansa Technik

work very economically. Almost a ton of paint for the Airbus A380 may sound like a lot, but it’s spread over a surface of nearly 4,000 square meters. The four to five coats of paint that must be applied have a combined thickness of only a fraction of a millimeter.”

Decades of experience are contained within these layered systems. In the simplest case, two different components are required: painters first apply an anti-corrosion primer to the cleaned and sanded surfaces; then the paint itself can be sprayed onto

the primer. At this stage, there are also one-coat and two-coat systems available. The paint manufacturer AkzoNobel has developed a two-coat system composed of a base coat and a clear coat. “The base coat/clear coat system has various advantages,” explains Thomas Böttcher, sales manager for aircraft paints at AkzoNobel Aerospace Coatings. “The clear coat protects against UV radiation and increases the gloss and paint retention. In addition, the surfaces are so smooth that the aircraft is less susceptible to dirt and has to be washed on average only half as often. And, lasting six to eight years, the lifetimes of the two-coat paintwork are significantly longer than most other paint systems, which last an average of only five years.”

Further intermediate layers allow additional functions to be integrated, such as selective paint removability. This function is created by means of a thin separating layer applied to the anti-corrosion primer. If the aircraft needs a new paintjob after a few years, the old paint can be chemically stripped along the separating layer, leaving the anti-corrosion coating beneath intact. “In this way, it is possible to cut the times needed for removing old paint and applying new paint by ten percent,” emphasizes Böttcher.



Paint from a gun _____ Among other techniques, Airbus uses electrostatic paint spraying systems, which generate less spray mist. Here the fuselage the first A350XWB for Finnair is painted in Toulouse.

Using surfaces to save fuel

In the future, paints will even help save fuel—for example, by having ultra-smooth surfaces over which the wind glides with scarcely any resistance. Engineers at Lufthansa Technik are currently experimenting with polishing agents containing nanoparticles that smooth out all surface irregularities.

Another approach involves providing the surfaces with a structure that reduces drag. This is how sharks move so easily through the water: microscopically thin grooves in their scales running parallel to the direction of the current reduce resistance. Researchers in the EU's Clean Sky project have explored how this riblet effect can be used for aviation. Engineers at the Fraunhofer Institute for Manufacturing Technology and Advanced

Materials IFAM developed a technique by means of which fine grooves can be applied to an aircraft. The simultaneous stamp hardening method makes it possible to imprint microstructures using a paint-coated silicon film that bears a negative of the riblet structure. By means of simultaneous UV irradiation, the paint sets, and then the silicon film can be taken off. "The paint offers several advantages," explains Fraunhofer researcher Dr. Volkmar Stenzel. "It's UV-resistant, it's good at withstanding mechanical strains, it doesn't create any additional weight and it can be applied easily to non-flat surfaces."

As part of the Clean Sky project, Lufthansa Technik and Airbus engineers tested the resistance of 10x10 centimeter microstructured areas of paint under real conditions in standard flight

“For example, work is being conducted into special resins that make paints dirt-, water- and ice-repellent. Such paints would dramatically reduce the times and costs needed to clean and de-ice aircraft.”

Dr. Volkmar Stenzel,
Fraunhofer IFAM

operation. Currently the researchers are looking for solutions to apply the required structures in a fully automated process, and are investigating whether the cost is worth it. According to projections, it can save around one percent of the fuel used in aviation—with an annual kerosene consumption of some 300 million tons in civil aviation, it certainly is worth it.


Reduced drag is just one of many expectations the aviation industry has for the aircraft paints of tomorrow. “The trend is toward the integration of extra functions,” reports Fraunhofer expert Stenzel. “For example, work is being conducted into special resins that make paints dirt-, water- and ice-repellent. Such paints would dramatically reduce the times and costs needed to clean and de-ice aircraft.” 

Table of paint layers

Layer	Name	Function	Thickness	Future developments
Bottom coat	Primer	Corrosion prevention	25 micrometers	Replacing primers that contain chromates with chromate-free alternatives
Intermediate coat	Adhesion promoter	Smoothing and bonding	25 micrometers	
Optional coat between intermediate and top coat	Separating layer	Allows the layers above it to be stripped	10 micrometers	
Top coat	Top-coat paint	Color and protection against mechanical and environmental influences	50-130 micrometers	Integration of dirt- and water-repellent properties; trend toward ever smoother, more dirt-resistant surfaces; extremely fast-drying paints that set under UV light
Alternative to top coat: two-coat system	Base coat	Color	25-75 micrometers	Fast-setting, reduced frictional resistance, dirt/icing prevention, longer durability
	Clear coat	Protection against UV radiation and mechanical influences	25-45 micrometers	



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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.

Saving fuel is in

Sustainability in aviation: an overview

Text: *Silke Hansen*

It is not as if the industry has only just woken up to the issue. Aviation can already point to huge progress in its environmental performance. Over the past 50 years, CO₂ emissions have been reduced by 70 percent per passenger kilometer. In 2015, the average fuel consumption of German airlines was only 3.6 liters per 100 passenger kilometer across all aircraft types and routes, according to calculations by the German Aviation Association (BDL). However, because the transport sector continues to grow, there are numerous initiatives designed to make the increasing aviation traffic more environmentally friendly.

From generation to generation, airplanes and aircraft engines have become increasingly efficient. Less kerosene consumption means less CO₂. There is a direct relationship between fuel consumption and emissions of this greenhouse gas. Through numerous measures, the industry is working on curtailing kerosene consumption and therefore greenhouse gas emissions.

Growth without additional emissions

Today, aviation has committed itself to ambitious goals, both at European and international levels—and incidentally, it

is the only transport sector to do so. In several stages, greenhouse gases are to be reduced by 75 percent per passenger kilometer by 2050 compared to the year 2000 according to the European aviation research organization ACARE's Strategic Research and Innovation Agenda (SRIA). The International Air Transport Association (IATA) is pursuing the goal of carbon neutral growth from 2020.

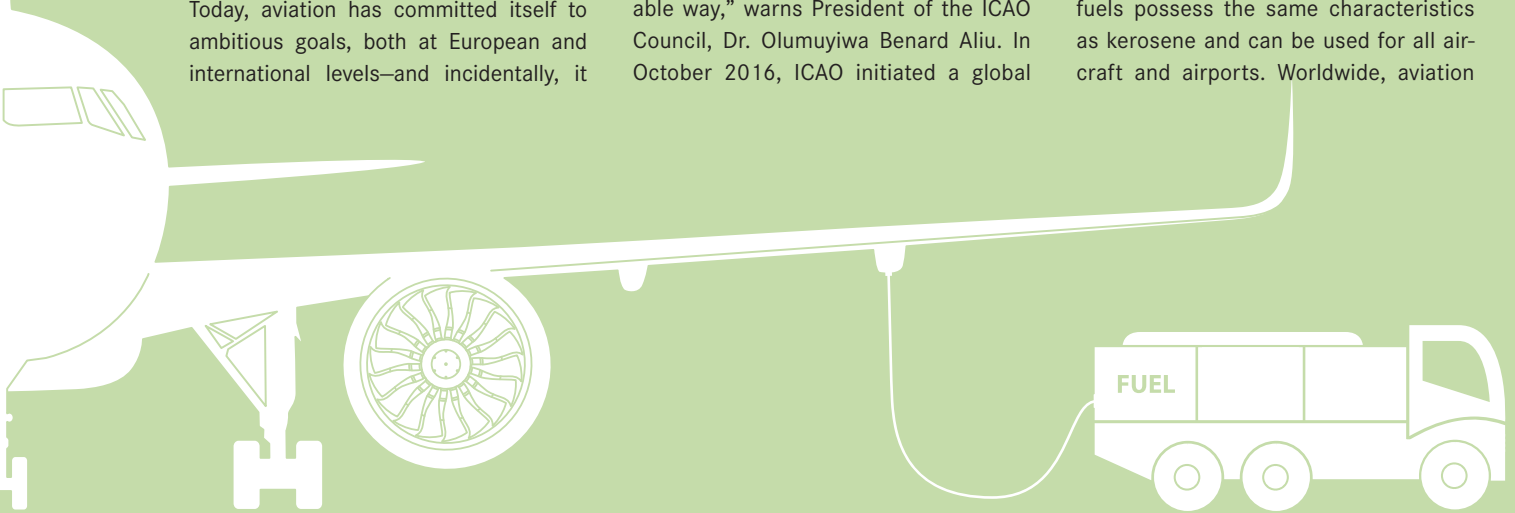
The International Civil Aviation Organization ICAO, the UN's aviation agency, is also targeting aircraft CO₂ emissions and wants to put an internationally valid CO₂ standard in place. According to this standard, new aircraft from 2020 on should observe the specified CO₂ limits, and models that are already in production should meet the limits by 2023. From 2028, no aircraft that does not comply with the standard should be allowed to take off. "Although aviation is currently responsible for less than two percent of annual CO₂ emissions, we have to structure the expected doubling of worldwide passenger traffic from 2030 in a responsible and sustainable way," warns President of the ICAO Council, Dr. Olumuyiwa Benard Aliu. In October 2016, ICAO initiated a global

climate agreement designed to systematically compensate for growth-related CO₂ emissions resulting from air travel from 2020.


Aviation does not affect the climate through CO₂ emissions alone, even if their impact is the strongest. The combustion of kerosene produces airborne pollutants such as nitric oxides, for which ICAO thresholds have long been in place. Another contributor to global warming is the creation of contrails and cirrus clouds at high altitudes. Minimizing this problem is a job for air traffic management experts, who should develop new flight routes that mean aircraft can fly lower.

Alternative fuels

Sustainable fuels are an alternative to kerosene. However, the requirements of these fuels as regards energy density, safety and operating characteristics are much higher than for road transport. At the moment, several second-generation biofuels are authorized for standard flight operations. These so-called drop-in fuels possess the same characteristics as kerosene and can be used for all aircraft and airports. Worldwide, aviation



requires almost 500,000 tons of kerosene every day. The large-scale production of biofuels must not negatively impact food production or biodiversity. For this reason, specialists are carrying out research into synthetic fuels manufactured through process engineering solutions such as using solar energy in the desert to produce aviation fuel out of water and CO₂. Not all methods are cost-effective yet. According to the Aviation Initiative for Renewable Energy in Germany, alternative aviation fuels cannot currently be produced at competitive costs.

As a long-term approach, the industry is intensively discussing another possibility: electric flying. “In our estimation, current technology is still several decades away from an electric-powered A320,” says Dr. Jörg Sieber, who is responsible for innovation management at MTU Aero Engines. Electric flying would require much more powerful batteries and electric motors than are available today. “Short-range regional aircraft are conceivable perhaps in 30 years’ time. For medium- and long-haul flights, suitable battery concepts are currently lacking.” In view of this, MTU has chosen to invest in hybrid systems comprising a gas turbine with a generator and electrically powered fans. But how sustainable is electric flying? No oil is burned up in the aircraft’s engine of course, avoiding the emission of harmful exhaust gases, but the electricity powering the aircraft has to be produced, and must not come from the burning of fossil fuels. 

Inside MTU — Corporate Responsibility

How sustainable is an individual organization? What can it contribute to climate protection? What is particularly important to it? Answers to these questions are provided by sustainability reports, which many big companies now compile. This includes MTU, which publishes annual information about its sustainability objectives and standards as defined by the internationally valid guidelines of the Global Reporting Initiative (GRI). In this way, the individual reports can be compared against each other. For the year 2017, this elective measure will become mandatory—at least in Europe. Then a new law will come into force that requires listed companies with more than 500 employees to publish information on sustainability topics. A major focus for MTU is the Clean Air Engine (Claire) agenda, which seeks to reduce the CO₂ emissions of aircraft engines by 40 percent by 2050 (see also page 45). But that is not all by any means: MTU also shows responsibility toward employees, suppliers and society.

Read more at www.mtu.de

> [Company](#)

> [Corporate Responsibility](#)

Facts & Figures — Sustainability in the aviation industry

Worldwide, the aviation industry is working for a greener future: over 400 organizations in 65 countries have initiated projects designed to reduce greenhouse gases—including aircraft manufacturers, airlines, engine specialists and airport operators. Here is a small selection:

First “bioport” in continuous operation: Oslo Airport mixes biofuels into its fuel hydrant system. Amsterdam and Brisbane plan to follow suit.

Innovative aircraft tractor: Lufthansa’s new TaxiBot brings aircraft from gate to runway with engines stopped.

Green revolution: the Geared Turbofan developed by Pratt & Whitney and MTU reduces CO₂ emissions by 16 percent in the first generation alone.

New technologies: as part of the EU research programs LEMCOTEC, E-BREAK and ENOVAL, the engine industry is developing technologies for new engines designed to reduce fuel consumption by up to 26 percent from 2025 (compared to the year 2000).



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Text:

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



Greenland — Greenland is the largest island in the world, measuring 2,670 kilometers from north to south. 82 percent of its surface is covered in ice.

Helicopter or dog sled

Air Greenland, the world's northernmost airline, connects Greenland to the world and supplies remote Arctic villages.

Text: *Andreas Spaeth*

air greenland

Savissivik lies at the end of the world, its northern end to be precise. The small village, at last count, had just 66 inhabitants, holding out 800 kilometres north of the polar circle on 76°N latitude. A dozen wooden houses as well as a community center with running water, that's about it. Other than that, there is just a non-descript prefab church, where a part-time priest celebrates mass on Sundays, if he doesn't oversleep, that is. The people here live on fishing—by boat or kayak in the short summer, but up to nine months a year just through holes in the ice—and on state aid. At least there is a heliport, as during winter, helicopters provide the only connection to the outside world, besides dog sleds. And winter has its grip on Savissivik during most of the

year, temperatures of minus 35°C to minus 40°C during months of continuous darkness are normal early in the year.

Twice weekly, on Wednesdays and Fridays, a shiny red Bell 212 lands inbound from Qanaaq, almost 200 kilometers to the north, the only bigger settlement in a 300-kilometer radius. “We bring fresh fruit and vegetables, milk, medicine and mail, but also fly people to see the doctor,” says Toke Brødsgaard, a helicopter pilot with Air Greenland. He also takes regular passengers—but despite being subsidised, the fares are so high that most villagers can't afford them. The flight, making a stopover at the US-run Thule Air Base, costs the equivalent of about 150 euros one way.



01



02



03

- 01** ____ *In front of a giant iceberg, the Bell 212 looks almost like a toy helicopter.*
- 02** ____ *Remote idyll: nowhere in Greenland can be reached by road.*
- 03** ____ *With the Bell 212, Air Greenland regularly serves even tiny settlements.*



Sublime beauty _____ a since decommissioned Dash-7 flies over a fjord in Greenland.

*“We bring fresh fruit and vegetables, milk, medicine and mail,
but also fly people to see the doctor.”*

Toke Brødsgaard,
Helicopter pilot with Air Greenland

Airlifting in the arctic winter

Greenland, measuring almost 2.2 million square kilometres, is the world’s biggest island and politically belongs to Denmark. Geographically it’s a part of North America. The biggest north-south distance is 2,670 kilometers. Almost 82 percent of the surface is covered by the huge permanent shield of the inland ice cap, up to 3,000 meters thick. Only the west coast has some ice-free areas. This is also where most of the 55,000 inhabitants of Greenland live, about the same number as the population in cities like Rosenheim in Germany or New Brunswick/New Jersey in the United States. There are no roads between any two settlements in Greenland—but Air Greenland serves 13 airports around the country with their Dash-8-200 turboprop aircraft and helicopters, as well as nine permanently operating heliports plus 39 further landing sites.

Supply flight routes go to over 100 settlements, some home to just 40 inhabitants who simply couldn’t exist without support from the air, especially during the harsh arctic winter.

Most Greenlanders, local Inuit or expat Danes, live along the west coast. As means of transport during winter there are just dog sleds, sometimes cars can drive on the frozen-over sea. In summer, coastal steamers are the most important mode of transport. Only the aircraft and helicopters of Air Greenland run the whole year round. In winter, the helicopters are the only lifeline for many villages. Supplies are often flown by five-seat Airbus Helicopters AS 350B3 rotorcraft, of which the world’s northernmost airline runs five. On most passenger flights, the eight Bell 212 helicopters are deployed, offering up to 13 seats.



01



02

Between 1965 and 2012, up to eight Sikorsky S-61N large passenger helicopters plied scheduled routes, then the biggest civil fleet worldwide. The S-61 can take up to 25 passengers or carry up to 2.5 tons of payload. Two of the 1965-vintage veterans are still in active use today, mostly for emergencies or special missions such as the annual dog sled race in Disko Bay in western Greenland. For this event, up to five sleds plus mushers and a maximum of 76 dogs are taken on at the same time. A further S-61, built in 1979, was acquired only recently and totally rebuilt with modern equipment for search and rescue missions above water and ice. “Today, operating an S-61 is seven times more expensive than a fixed-wing aircraft,” says Toke Brødsgaard, and the helicopters are more prone to be affected by bad weather than the Dash-8 fleet.

Harsh flying conditions all year round

Weather is a determining factor of living in Greenland. For a long time, Air Greenland used to be colloquially called “Imaqaa Airways,” or “Maybe Air,” because it was so unreliable. “But that was many years ago,” insists Jakob Petersen, a flight dispatcher, working in Air Greenland’s operations control center in the cap-

ital, Nuuk. “Then we had many more helicopters, and they were much more restricted in their actions when weather was bad.” But wind remains a big problem, and especially so at the capital’s airport, of all places. Nuuk, the only city deserving this description, is home to about a quarter of the population, with almost half of all Air Greenland customers flying to and from Nuuk. In total, the airline carried 395,000 passengers in 2015, more than six times as many as Greenland has inhabitants. “Our maximum wind limit for takeoff is 40 knots, and 35 for landings—but the day before yesterday, it blew here at 50 knots,” reports Petersen. A dozen flights were cancelled.


“Weather problems can affect you during all seasons in Greenland, fog and storms even during summer; snow, blizzards and ice in the winter, and Nuuk unfortunately is on top of the affected destinations,” according to Petersen. Toke Brødsgaard formerly flew S-61s himself and recalls: “About 30 percent of our helicopter flights were affected by weather on average. Spring and fall are the most difficult times; during winter things are more stable,” says the helicopter pilot. Mostly the weather only turns bad during a flight, forcing the pilots to turn around or land at an



- 01** ____ Air Greenland's only jet, an A330, lands at Thule Air Base.
- 02** ____ Kangerlussuaq Airport lies in the middle of the North Atlantic route.
- 03** ____ Colorful houses are typical for settlements in Greenland.
- 04** ____ The bright red Bell 212 helicopters are highly visible even in adverse weather.

alternate heliport. To avoid collisions with terrain, the required minimum altitude is 500 feet (about 150 metres). "Most of our pilots are Swedes or Norwegians, a few are from Greenland," says Brødsgaard. "This way passengers feel safer than with Danes, who are rarely experienced mountain fliers."

The Kangerlussuaq hub

No matter if one flies to or from or within Greenland, most flights touch Kangerlussuaq. Here, just above the polar circle, is the location of Greenland's biggest airport, the former US Air Base, closed in 1992, better known under its Danish name Søndre Strømfjord, three-letter code SFJ. Only from here does Air Greenland flies its sole jet, an Airbus A330-200, to Copenhagen, even twice daily during the summer peak. That could be changing: "Currently there is a discussion about an expansion of airports such as Nuuk, enabling them to take direct jet flights from Copenhagen," says Air Greenland's CEO Michael Højgaard. But whether that will ever happen is uncertain. Until it does, even far-away Arctic outposts like Savissivik are only connected to the world by Air Greenland, and mostly via Kangerlussuaq. 



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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.

Back home safe

Each year, the professionals of Tyrol Air Ambulance service fly more than 3,000 patients back home using up to six specially equipped aircraft—a logistical, aeronautical and technical feat that draws on 40 years of experience.

Text: Philipp Bruhns

In the winter, when ambulances start queuing up again on the runway of the Kranebitten airport in Innsbruck, it doesn't mean that a disaster has occurred. Instead, it is simply the beginning of boarding for one of aviation's most unusual scheduled services, the "plaster bomber." Operated by Tyrol Air Ambulance (TAA) several times a week, the service brings injured skiers back home from the Alps quickly, comfortably and with all the medical care they need.

Most stops are in the Benelux region, but Scandinavia is also a regular destination. Year round, the transports also make several stops around the Mediterranean to pick up beach vacationers and take them back to northern and central Europe.

In its standard passenger version, as used by TAA parent company Welcome Air, the Dornier 328 turboprop aircraft seats 31 passengers. When used as an

air ambulance, its capacity depends on how much space the patients on a particular trip require. The seating is individually configured by the maintenance team prior to each flight, and includes both stretcher berths and normal aircraft seats with leg rests. Composition of the crew and the medical facilities on board also vary according to the individual requirement. If required, the Dornier can even be used as a flying intensive care unit with six beds.



The success of the TAA transports lies in their superlative medical standards and a great deal of planning expertise, explains TAA CEO Manfred Helldoppler: “We offer the insurance companies who most often bear the transport costs a unique and affordable product. This regularly puts us at the forefront of the competition even in ratings within the sector.”

Ready for takeoff within two hours

What’s more, Tyrol Air Ambulance’s service extends well beyond the “plaster bomber.” Ever since its foundation in 1976, it has also offered ambulance flights using a growing fleet of specially modified business jets. In order to transport one or two patients, often when intensive medical care is involved or a pickup far from the big tourist destinations, TAA deploys three Gulfstream 100 aircraft and a Cessna Citation Bravo. Patients and their relatives can reach the Medical Assistance team 365 days a year, 24 hours a day. First, the team get a comprehensive medical picture, coordinating the exchange of information between

caregivers on location, relatives and the insurer’s medical service. If transportation home gets the go-ahead, the flight is ready for takeoff within two hours. In that time, the TAA specialists on the ground must scramble the jet, crew and medical team, obtain all the necessary diplomatic and landing clearances and wrap up all the associated ground operations. In the case of unusually long journeys, this can occasionally take slightly longer due to the approvals involved.

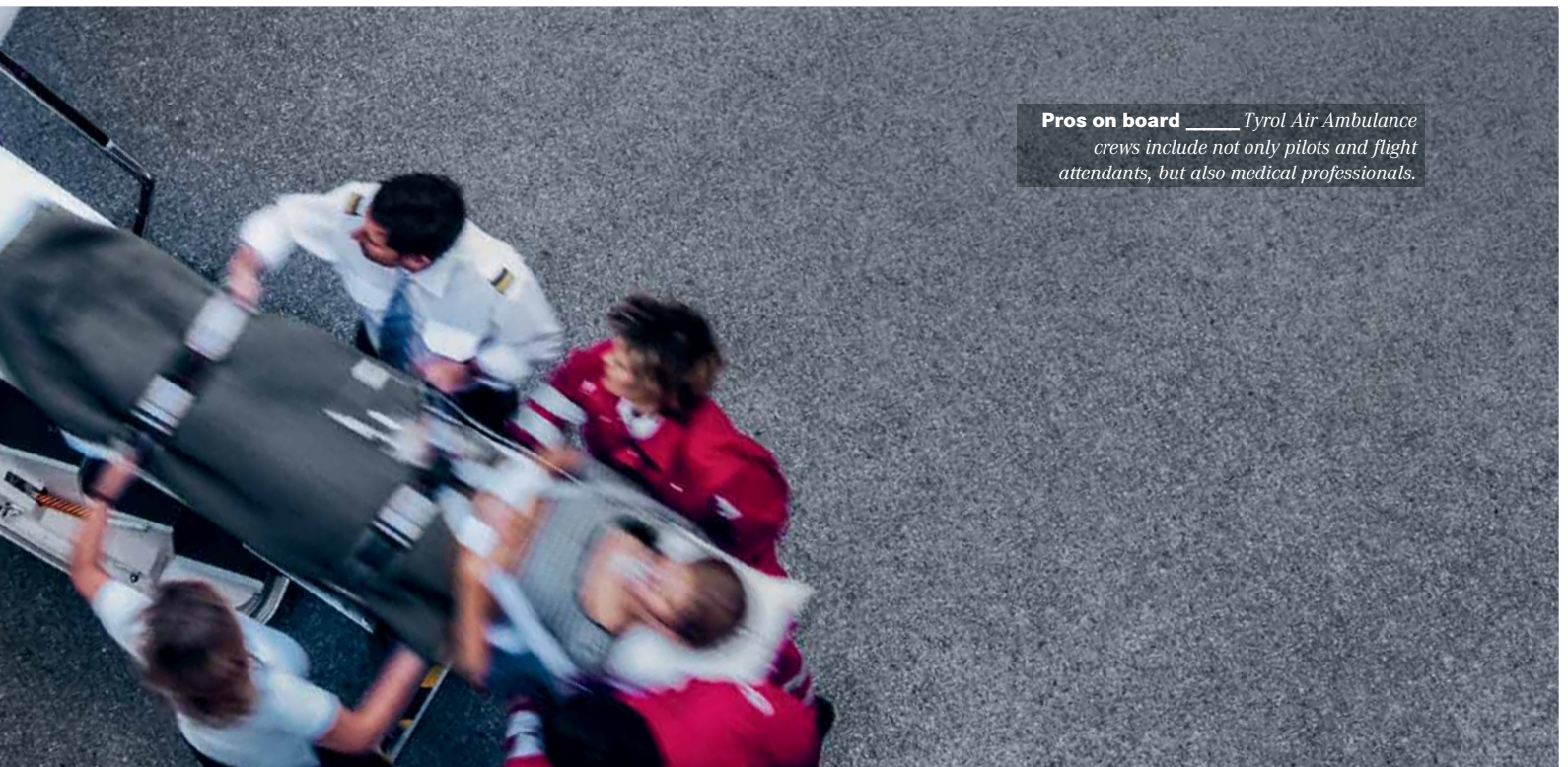
And yet, in spite of all the careful preparation by experienced medics and dispatchers, none of these flights can be said to be routine given the intensive care needs of severely injured patients. It can well happen that a patient’s condition deteriorates before the flight to the extent that they first have to be stabilized where they are. Only experienced emergency specialists familiar with the specific symptoms are allowed on board as doctors since, once the aircraft is in the air, they must take full responsibility for making the right decision. There are also particular

challenges for the crew in the cockpit, for instance when the patient is suspected of having a severe tracheal injury and must be flown at low altitude.

“For us, no two missions are the same, even when it’s meant to be a routine transport,” says CEO Helldoppler as he describes the particular challenges faced by his airline. “Ensuring that everything runs smoothly requires a lot of experience and great flexibility from the whole team—both on the ground and in the air.” He says that the work is unusually varied and fulfilling, which is why “so many of our roughly 100 full-time employees and the experienced medical professionals in our 70-strong pool of doctors and nurses have been with us for such a long time.”

Almost 100 percent availability

Doing an important job in the wings is the technology and maintenance team, whose task goes beyond turning business jets and regional aircraft into flying intensive care units. Maintenance also brings with it its own demands, as TAA Director




Pros on board _____ *Tyrol Air Ambulance crews include not only pilots and flight attendants, but also medical professionals.*

“Ensuring that everything runs smoothly requires a lot of experience and great flexibility from the whole team—both on the ground and in the air.”

Manfred Helldoppler,
Tyrol Air Ambulance

Technical Operations, Johan Schot, explains. “At first glance it no doubt seems strange that an operator of our size undertakes nearly all of the maintenance work on the aircraft itself. However, we’re not a normal airline. The on-board equipment alone sets our aircraft apart from traditional regional and business aircraft.” The team works on short notice and has to guarantee almost 100 percent availability of the whole fleet. “On top of that, our jets amass many times the flight hours that is normal for aircraft of this type.”

There are, then, high demands when it comes to flexibility and service capability, and the same is expected of engine repair and maintenance. For 15 years now, TAA has entrusted the maintenance of the Pratt & Whitney Canada engines of its Dornier 328 and Cessna Citation Bravo aircraft to the Customer Service Centre Europe (CSC). “By doing this, we gain access to an extremely extensive global OEM service network and lease engines at short notice, together with quickly deployable mobile repair teams—which is a lot like our own setup,” says Schot as he describes the advantages of the long-standing collaboration. 



Inside MTU — *Help for the helpers*

Innsbruck’s Tyrol Air Ambulance is a customer of the Pratt & Whitney Canada (P&WC) Customer Service Centre Europe (CSC), a joint venture between MTU Maintenance Berlin-Brandenburg and P&WC targeting all aftermarket services in the Europe Middle East and Africa (EMEA) region. It is headquartered at Ludwigsfelde. A variety of engine models overseen by the CSC, including the PW530A engines of TAA’s Cessna Citation Bravo, is maintained there. “Individually tailored service packages are one of the CSC’s great strengths,” says its General Manager Carsten Behrens. “As a market leader in the region for the care of Pratt & Whitney Canada engines—the applications of which range from helicopters to turboprops and jets—we have worked with a great many operators in the air ambulance and air rescue sector for many years, and have thus come to know the challenges of their demanding missions.”



Tyrol Air Ambulance — Within a few hours, the cabins of TAA aircraft can be converted into flying intensive care units. The fleet includes a Gulfstream 100, a Dornier Do328 with turboprop engines and a Cessna Citation Bravo with jet engines by Pratt & Whitney Canada. The aircraft are frequently used in the Alps, from where vacationers who have had accidents are flown to their northern European home countries.



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Text:

Dr. Philipp Bruhns has been working in corporate communications for over 15 years, and has been self-employed since 2008. Based in Denmark, Bruhns has a doctoral degree in psycholinguistics and as an author specializes in maintenance topics and health and social issues.





“We also have to rethink our behavior”

Innovations in aviation primarily target the reduction of fuel consumption and emissions. But that might not be enough, says Prof. Marion A. Weissenberger-Eibl from the Fraunhofer Institute for Systems and Innovation Research (ISI).

Text: Eleonore Fähling



Univ.-Prof. Dr. oec. Marion A. Weissenberger-Eibl —
Dipl.-Kffr. (Univ.), Dipl.-Ing. (FH), Director of the Fraunhofer Institute for Systems and Innovation Research (ISI) and Chair of Innovation and Technology Management at Karlsruhe Institute of Technology (KIT).

Since 2013, Prof. Dr. Marion A. Weissenberger-Eibl has been Chair of Innovation and Technology Management at the Karlsruhe Institute of Technology (KIT), an institution devoted in particular to carrying out scientific investigations with practical relevance for its area of research. In addition, she has headed the Fraunhofer Institute for Systems and Innovation Research (ISI) since 2007, and lectured in innovation and technology management at the University of Kassel from 2003 to 2012.

Having obtained primary degrees in business management and clothing engineering, she obtained a PhD (2000) and a professorship (2003) at the TUM School of Management at the Technical University of Munich. Alongside her scientific work, she is also a member of the Supervisory Board of MTU Aero Engines AG.

“There is an urgent requirement for concepts that make carbon offsetting and the reduction of greenhouse gas emissions actually possible.”

Professor Weissenberger-Eibl, the flight from Munich to Hannover takes scarcely an hour. However, you also have to factor in several hours for traveling to and from the airport and for check-in, boarding and disembarking. If you go by train, it takes roughly the same time to get from one city center to another. In that case, what’s so good about flying?

Prof. Marion A. Weissenberger-Eibl: For people like me who travel a lot, flying makes sense whenever you can actually save time or when there is no real alternative. I’m talking about international and transcontinental flights. For me, flying is a fascinating phenomenon and has become an integral part of our globalized society, connecting people and cultures. For domestic flights, however, you should ask yourself if flying is really the best alternative. At Fraunhofer ISI, for example, we record our environmental footprint in a sustainability report that also covers our travel activities.

How can and must the air transport system develop in the future?

Weissenberger-Eibl: Even if aviation currently accounts for “only” two percent of worldwide transport emissions according to the United Nations’ ICAO civil aviation agency, concepts are urgently required that make carbon offsetting and the reduction of greenhouse gas emissions actually possible. With global aviation emissions projected to triple by 2050, it is absolutely vital to find solutions as quickly as possible. One possibility would be climate-neutral biofuel. In addition, projects that seek to increase energy efficiency should be further pursued and expanded, such as work on engine concepts that promise significant fuel savings or indeed the further development of flying wings.

For this to happen, what players are needed? What innovations? What must change?

Weissenberger-Eibl: Naturally, the first people to come to mind here are the legislators and regulators, such as the Federal Aviation Administration (FAA) in the United States, but also biofuel manufacturers and suppliers as well as engine and aircraft manufacturers.

However, you have to be realistic and appreciate that genuinely revolutionary technical innovations still have to be developed first in most cases. And it is precisely this situation that underscores the importance of non-technical and organizational measures. Although emissions trading can play a supporting role here, it’s not enough to minimize emissions. We also have to fundamentally question and rethink our behavior—and that goes for all of us. At Fraunhofer ISI, we’re trying to minimize business trips wherever possible and sensible, such as by using phone or video conferences instead.

How do innovations actually arise?

Weissenberger-Eibl: Innovations are born out of a need; they develop out of a functioning technological development system and also out of application niches. They can be triggered by governments or society through means such as funding programs and investments in promising technologies. In other words, it’s mostly a case of technologies for which there is a demand, or else it arises from research and development in profit-oriented companies.

Consequently, most innovations are demand-driven, while interaction with users also plays a decisive role—something we’ve been talking about for several years now under the guise of open innovation.

GLOSSARY

Carbon offsetting Compensating for carbon emissions produced by the burning of fossil fuels, e.g. by buying certificates whose proceeds fund climate protection projects such as reforestation.

Open innovation Opening up the innovation process within an organization to the outside world in order to increase innovation potential.

Frugal innovations These are all about developing lean, fast and low-cost solutions, e.g. by concentrating on the bare essentials, by using existing or bought-on components, and by simplifying distribution channels.

What stands in the way of innovations?

Weissenberger-Eibl: Innovations are frequently impeded by regulations that exclude new technologies. Under certain circumstances, another aspect can be the high development costs or the major expenditure required to change structures within companies. However, the Innovation Indicator 2015, which Fraunhofer ISI compiled together with the Centre for European Economic Research on behalf of the Federation of German Industries (BDI) and the German National Academy of Science and Engineering (acatech), also identified other obstacles to innovations, for instance, that the basic conditions for research in Germany are still in need of improvement. More investment, the continuation of research pacts, a resulting increase in planning certainty for universities and research institutes, and better coordination of federal and state governments in the field of third-level education are also having positive effects throughout the German innovation system.

“There is a shortage of graduates specializing in the STEM disciplines – science, technology, engineering and mathematics. We need them to successfully design and shape the energy transition, digitalization and new mobility concepts.”

Prof. Marion A. Weissenberger-Eibl,

*Fraunhofer Institute for Systems
and Innovation Research (ISI)*

What should an innovation-promoting educational culture look like?

Weissenberger-Eibl: Education is one of the main pillars of our innovation system. It forms the basis for science and business and makes a decisive contribution to Germany’s competitiveness. In international comparisons of innovation capability, Germany holds its own, but unfortunately it’s not at the very top of the table. In the abovementioned Innovation Indicator, Germany ranked fifth in the overall indicator and ranked seventh in the Education sub-indicator. For years, education was one of the biggest weaknesses in the German innovation system. And even though some things have improved here, there is still some way to go, especially in the STEM (science, technology, engineering and mathematics) subjects. In these areas, there is a lack of graduates—and we need them to successfully design and shape the energy transition, digitalization and new mobility concepts. Although I’m glad to see that there’s currently a positive development in this sub-indicator, substantial work still needs to be done in the education system.

Which areas of the aviation industry need innovation most urgently?

Weissenberger-Eibl: In my opinion, it’s vital that we continue working on changing the environmental impacts of aviation. Further innovations are needed both to reduce greenhouse gas emissions and with respect to noise problems. The European aviation advisory council ACARE, for example, has committed the aviation industry to ambitious targets and published them in a Strategic Research and Innovation Agenda (SRIA) (see also article “Saving fuel is in” on page 22).

How quickly do we need these innovations?

Weissenberger-Eibl: As quickly as possible—both from an environmental and an economic point of view. If not apparent beforehand, the Paris Climate Conference emphatically demonstrated that “business as usual” is not an option for international climate politics and the efforts to tackle climate change. At Paris, Fraunhofer ISI presented a study, carried out as part of the DecarbEE project, which revealed that by implementing suitable energy efficiency and decarbonization measures, the fast growing economies of the European Union and the USA, China, India, Brazil and Mexico could save some 2.8 billion dollars by 2030. This clearly shows that increased environmental and climate protection can also offer and release big economic potential.

In relation to the aviation industry, a stronger focus on energy efficiency targets can help get the sector fit and ready for the future and maintain its international competitiveness. The German Aviation Association (BDL) publishes an annual Energy Efficiency Report, and the 2015 edition shows that the aviation industry has recognized the need for action: for example, thanks to more efficient aircraft and engines, German airlines have reduced fuel consumption per passenger and 100 kilometers by 42 percent since 1990. However, these efforts must be redoubled and with a greater emphasis on opportunities.

What political, economic and social background conditions are also required?

Weissenberger-Eibl: First of all, politics—supported by research—has to recognize important stimuli and incentives for innovation and then promote this innovation, which will go on to have economic and social consequences. Let’s take as an example a topic that is very important for the aviation industry: the security of supply of raw materials. Our Raw Materials for Emerging Technologies 2016 study, which we carried out on behalf of the German Mineral Resources Agency (DERA), shows that new technologies will cause the demand for economically strategic raw materials to climb dramatically in the future. This plays a hugely important role for the strongly import-dependent German economy in particular.

For instance, sharply rising demand for superalloys in the aerospace industry over the coming years could affect the markets for special and minor metals, which would have consequences for the industry as regards technology costs. So that Germany does not fall behind internationally, politicians must act early to secure the supply of economically strategic raw materials for the sector. And politicians must also consider the fact that the implementation and market penetration of new technologies




The Fraunhofer Institute for Systems and Innovation Research (ISI) analyzes the genesis and effects of innovations and carries out systematic, interdisciplinary research into the short- and long-term developments of innovation processes as well as the social effects of new technologies and services. Its clients come from the spheres of business, politics and science. Some 230 people are employed at the institute's headquarters at Karlsruhe in southern Germany.

depends on acceptance among the general population. Fraunhofer ISI takes these aspects into account in its research—for example, through studies that investigate the social acceptance of innovative energy technologies such as wind power generation on the mainland.

Getting back to the air transport system: in your view, which innovation has caused the most lasting change to the industry over the past few decades? Or is this innovation yet to arrive?

Weissenberger-Eibl: The most serious change in the industry in recent times has no doubt been the rise of low-cost carriers, whose strategies and cost models threw the established airlines into a panic. From a purely market-based perspective, these developments can perhaps be viewed as a good thing, but from a sustainability point of view they are not very innovative. For such cases, innovation researchers have the expression “frugal innovations,” which are stripped back to the core aspects of products or services and achieve big market success in this way.

In the case of air transport, the budget airlines triggered a lasting trend, in that flights were reduced to their transport utility and not so much what they can offer in terms of luxury and a

pleasant experience. Let's take as an example the dropping of entertainment services or free in-flight meals. This has made flying more affordable for many people, but it has also caused aviation to lose some of its aura of being special and unusual. Some companies in the industry are now consciously bucking this trend in order to position themselves in contrast to the low-cost carriers. However, all this has tended to push aspects such as sustainability and climate protection even further into the background over the past few years. In order to be ready and equipped for the future and international competition, companies in the aviation industry should integrate these factors even more comprehensively into their overall strategy. 



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Text:
Eleonore Fähling is MTU's Editor in Chief for AEROREPORT and has been in charge of the MTU employee magazine since 1999.



Series precision

Developed by MTU Aero Engines, the precise electrochemical machining (PECM) technique for integrally bladed compressor rotors (blisks) enters series production for the A320neo's PW1100G-JM engine.

Text: Denis Dilba

High-tech behind bullet-proof glass — Instead of milling the blades of nickel blisks in a single piece, the PECM method uses electricity and an aqueous sodium nitrate solution, which acts as an electrolyte, to dissolve the metallic material in a targeted manner.

In 2015, things got really serious for “Set 1” when the first two ECM/PECM series production systems at MTU Aero Engines’ Munich site had to show what they could do. The electrochemical duo was tasked with manufacturing the compliance hardware for the PurePower® PW1100G-JM Geared Turbofan™, the engine for the A320neo: the fifth and the sixth high-pressure compressor stages. These are blisks with a diameter of around 450 millimeters and blades with extremely complicated geometries. The sample components were rigorously tested by client Pratt & Whitney with regard to strength and geometry—and they passed. Series production commenced in September 2015, and since then two further systems have come on stream; a third pair is under construction and another two are in planning.

MTU has been working on the cutting-edge PECM technology for some time now. This development was set in motion by the realization that the blisk design was gaining more and more acceptance—including

growing popularity in the area of high-pressure compressors. Blisks have one major advantage over their counterparts with individually inserted blades: with integral components, the blade angle can be set such that the respective stage works more efficiently. As a result, the individual stages can each compress air more effectively. Thanks to the integral design, the edge load on the rotor disks is reduced, which saves weight. In addition, the elimination of leaks enhances the efficiency in the compressor. “Both these things together reduce fuel consumption—and therefore the engine’s CO₂ emissions as well,” explains MTU engineer Thomas Frank, who heads rotor production operations and is responsible for nickel blisks.

New method for new geometries and materials

From a technical point of view, however, the fuel consumption advantages and emissions reductions are not granted automatically. Temperatures of around 650 degrees Celsius prevail in stages 5 and 6 in the high-pressure compressor. Tita-

um is the material usually used to build compressors, but the lightweight metal ceases to have the requisite strength at these temperatures. For the PW1100G-JM, high-temperature-resistant nickel alloys are used instead, but these alloys cannot be processed cost effectively using conventional milling techniques because of the high level of tool wear. A further difficulty is the extremely complex 3D geometry of the blades, which stretches the ECM technique previously used with success for larger blisks to its limits. An even more precise method had to be developed—PECM.

As with the ECM method, PECM also involves using an electrolyte and electrical current to carefully and precisely dissolve a metallic material. The material to be processed acts as an anode (positive pole) and the three-dimensional, metallic tool acts as a cathode (negative pole). The big advantage PECM has over conventional machining techniques is that the tool does not touch the component, which means it does not incur process-related wear. An aqueous sodium nitrate solution is used as



Precision work — A finished high-pressure compressor blisk is removed from the machine. The component is already machined to net shape, because PECM is much more exact than conventional electrochemical ablation.



01

01 ____ *The electrically conducting sodium nitrate solution also acts as a cooling agent and carries away the ablated metal.*


02 ____ *Controlling the PECM process. Because the component is not touched, the tools are subject to scarcely any wear.*



02

an electrolyte, which flows between the anode and cathode. This liquid has three functions: it establishes an electrically conductive connection; it carries away the removed material and the hydrogen created by the process; and it cools the process. Compared to the ECM technique, the PECM method achieves higher accuracies by employing extremely small working gaps in the micrometer range between workpiece and electrodes.

In contrast to conventional, single-axis processes, the workpiece is processed simultaneously with two electrodes which travel toward each other. This was not easy to master. Moreover, the electrolyte solution also had to be improved. Consequently, MTU decided to develop and build the mass production systems itself. “We’d already built up special know-how to the extent that we couldn’t find the same quality among external suppliers anymore,” explains Martin Bußmann, project manager for industrialization of the new method. “And, naturally enough, we also wanted to keep our edge in the knowledge we had acquired.”

MTU also plans to exploit the advantages of the PECM process for other components or manufacturing steps in the future. After all, in principle, the technique is suitable for many applications, such as for edge rounding or for manufacturing individual rotor blades and guide vanes. “The blade geometries for high-pressure compressors are becoming even more complex, and the materials are becoming ever more heat-resistant. This is pushing conventional machining technology more and more to the limits of its technical possibilities and cost effectiveness,” says production manager Frank. “PECM offers a future-proof alternative.” 



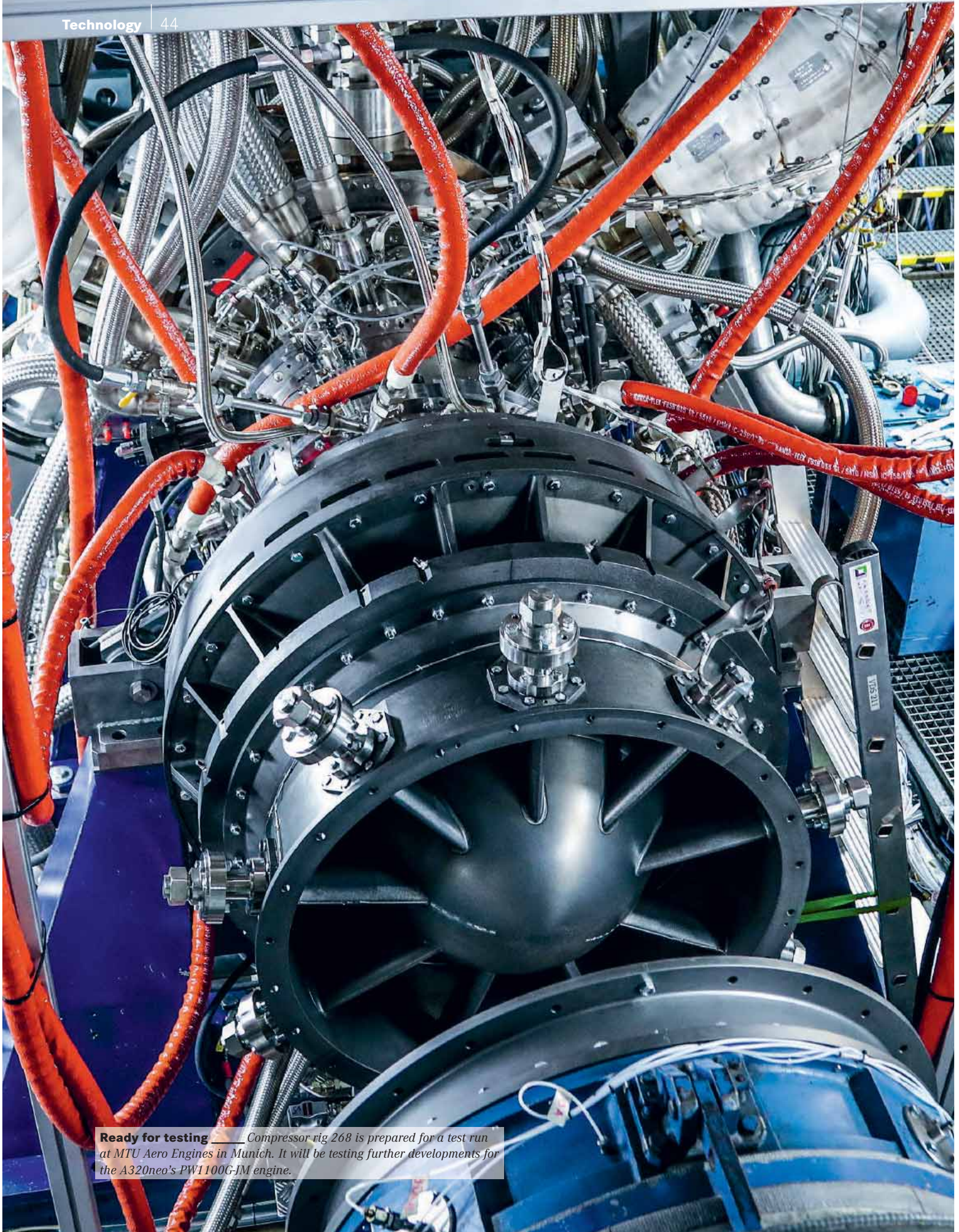
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Text:
Denis Dilba holds a degree in mechatronics, is a graduate of the German School of Journalism, and founded the “Substanz” digital science magazine. He writes articles about a wide variety of technical and business themes.



Ready for testing — Compressor rig 268 is prepared for a test run at MTU Aero Engines in Munich. It will be testing further developments for the A320neo's PW1100G-JM engine.

The next wave

By the end of the decade, the Airbus A320neo is set to have an even more fuel-efficient engine. To make this possible, two key components of the Geared Turbofan™ are currently undergoing tests at MTU Aero Engines.

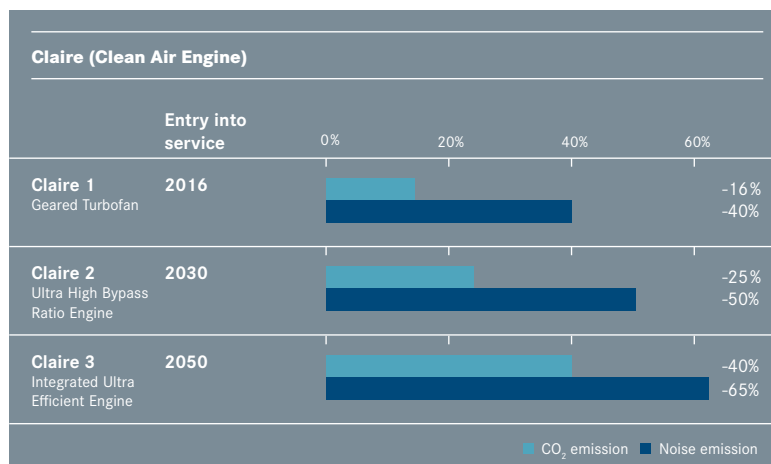
Text: Patrick Hoeveler

High-tech guessing game: Behind all the cables, hoses and supporting structures, it's hard to make out the latest offspring of the partnership between MTU Aero Engines and Pratt & Whitney. The core module of the next generation in the geared turbofan family is being tested on a rig at the German engine-maker's Munich location. Some 1,300 measurement points have been wired up on the high-pressure compressor to record the widest possible number of parameters. Such rig tests involve a lot of time and effort, but the engineers consider them indispensable and even plan to test two different engine components this year—with the support of the aeronautics research program funded by the German Federal Ministry for Economic Affairs and Energy. "Rig tests are an essential element in our technology process. We use them to verify the performance of innovative products under the relevant operating conditions. This helps us prepare the way for the next wave of new technologies," says Dr. Stefan Weber, Senior Vice President Technology and Engineering

Advanced Programs at MTU. It is part of the company's research policy to carry out such tests on its two key products, the compressor and the low-pressure turbine, at four-to-five-year intervals.

In this particular case, the focus lies on enhancements to the PW1100G-JM Geared Turbofan™. To maintain the technological lead established by the Airbus A320neo engine, which only recently entered service, efforts must be made to further reduce its fuel consumption. This will be achieved by improving the performance of the high-pressure compressor, developed in collaboration with Pratt & Whitney, and that of MTU's high-speed low-pressure turbine. This is not an easy task, given that both components already have an extremely high degree of fuel conversion efficiency. "We will have to work hard on a number of issues that, in the end, will enable the progress needed," says Dr. Gerhard Kahl, project manager in charge of compressor rig 268. Because the compressor components have to match the dimensions of the original engine, the number of stages has not been increased. Attention has therefore been focused on optimizing the blade profile and reducing parasitic losses. In engineering parlance, parasitic losses are unwanted phenomena that interrupt the flow of air, such as leakages or gaps between rotating and static parts. In their search for potential improvements, the engineers make use of increasingly sophisticated design tools. But the joint MTU and Pratt & Whitney development team also has to make sure that this doesn't affect the compressor's operating stability. For this reason, the rig tests not only include analyzing aerodynamic factors but also record data concerning temperature, gap widths, vibrations and many other parameters.

Claire _____
MTU's technology agenda shows which efficiency improvements future engines must achieve by 2050 compared to the V2500.



In production _____
Some of the technologies tested in compressor rig 260 are already in service inside geared turbofan engines.




When the compressor is mounted on the test rig, it is powered by an array of electric motors with a combined output of 16 megawatts—the equivalent of 18 Formula One racing cars. After passing through the compressor, the air is throttled down to atmospheric pressure and evacuated via an exhaust chamber. “MTU has accumulated many decades of experience in engine assembly and testing. This gives us a head start in our current activities,” says Kahl. By the end of the year, the exhaustive compressor testing schedule will have racked up 140 hours.

Background _____ Rig

Rig is a common English word with many meanings. In a musical context, e.g., it refers to the set of instruments utilized by a guitar player, including amplifier, pedalboard, cables and guitar pick or plectrum.

In an engineering context, a rig is an apparatus used to conduct tests that mimic the conditions under which a real-life engine is required to operate.

The rig testing is already finished for enhancements to the low-pressure turbine originally developed for the geared turbofan under the sole responsibility of MTU. These tests, totaling 100 hours, were carried out on the high-altitude test rig at the University of Stuttgart, where MTU traditionally tests its turbines. In this case too, the designers verified the efficacy of the improvements to the engine’s aerodynamic performance. “Without changing the dimensions, we redesigned the blades and further reduced the aerodynamic losses occurring in the peripheral areas of the turbine,” says Dr. Irene Raab, project manager in charge of turbine rig 456. A detailed analysis of the results is now in progress. The next stage, scheduled for next year, involves testing the complete second-generation geared turbofan. After that, the even more fuel-efficient GTF will be required to undergo the usual certification procedures, some of which will probably be carried out in Munich. And that’s not all: Like their colleagues in the compressor department, the turbine team also has developed more innovations than can be implemented under the present program. They could also benefit future engine generations. 



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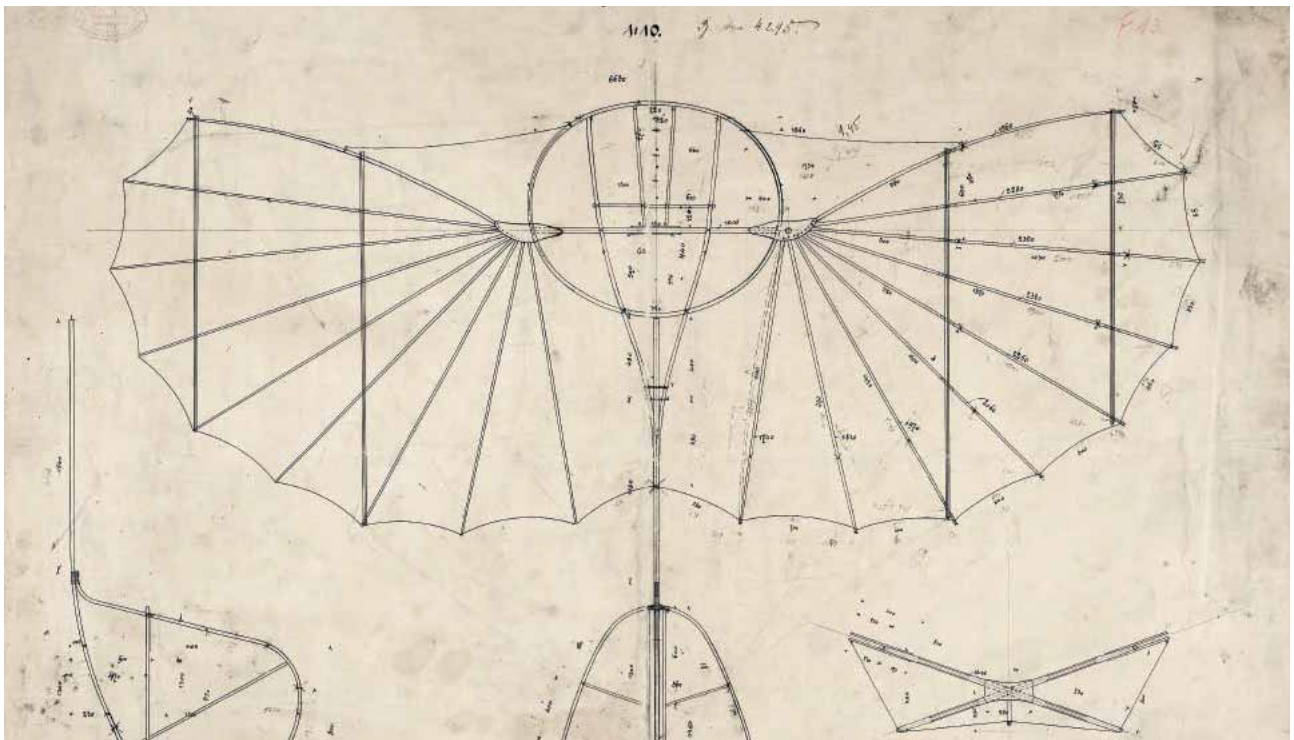
Text:
Patrick Hoeverler is a journalist with more than 15 years’ experience in the field of aeronautics and aerospace reporting.



Summary _____ Rigs contribute to the success of an engine. Currently, one of the most successful programs is the A320neo's PW1100G-JM engine—seen here on the way to the test bed.

Like a bird

DLR celebrates 125 years of human flight by reconstructing the Otto Lilienthal glider



“Normalsegelapparat” — One of the treasures in the archive of the Deutsches Museum in Munich is this original workshop drawing by Otto Lilienthal.

“Free, unrestricted human flight would have a profound effect on us all. National borders would lose their meaning,” aviation pioneer Otto Lilienthal (1848-1896) once said of his vision. His legacy encompasses not only the first successful, controlled and repeatable flights in an aircraft, following the heavier-than-air principle, but also the first batch production of an aircraft. The glider that Lilienthal designed and subsequently built at his machine works in Berlin has at least nine recorded sales.

What’s more, he was also the first person to systematically investigate and describe aerodynamic principles. His revolutionary book, “Der Vogelflug als Grundlage der Fliegekunst” (Bird flight as the basis of aviation) was published in 1881 with a circulation of just 1,000 copies. It would go on to assist others in their own development of aircraft—including the Wright brothers, who noted: “His most important finding was that a convex wing provided more lift than a flat one.”

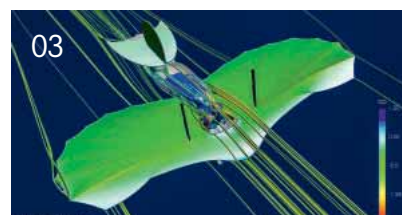
It was already known that birds had curved wings, but Lilienthal was the first to exactly measure this phenomenon and transfer it to aircraft design. He began testing in the spring of 1891, and is estimated to have completed more than two thousand successful flights before he died on one of his flight tests in 1896.

Now, to mark 125 years since Lilienthal undertook his very first flights, the German Aerospace Center (DLR) has reconstructed Lilienthal’s glider according to

his own drawings and tested it in the wind tunnel. One of the goals of the testing was to prove that Lilienthal built an aircraft that was stable in all three axes, since the design relied not only on the curved wings but also on elevators and rudders.

In this respect, Lilienthal's glider was ahead even of the Wright brothers' flying machine, says Professor Andreas

Dillmann, head of the reconstruction project and of the DLR Institute of Aerodynamics and Flow Technology: "The Wright flying machine proved instable at any flight speed in wind tunnel testing at NASA." In contrast, the flight characteristics of the Lilienthal glider are comparable with those of training gliders of the 1920s and 30s—decades after Lilienthal.



01 ___ *Reconstruction in the DLR Institute of Aerodynamics and Flow Technology in Göttingen according to Lilienthal's drawings and using the materials the way he did.*

02 ___ *Simulation of wind tunnel testing on the Lilienthal glider.*

03 ___ *Flow measurement in the wind tunnel.*

A host of round numbers

2016 is a year of anniversaries for MTU Aero Engines

15 years in April since the foundation of MTU Maintenance Zhuhai.

20 years in September since the foundation of the Engine Alliance, the joint venture for the development and production of the GP7000 engine for the A380.

20 years in November since the foundation of ASSB (Airfoil Services Sdn. Bhd.), the joint venture between MTU and Lufthansa Technik for blade repairs near to Kuala Lumpur.

25 years in July since the foundation of MTU Maintenance Berlin-Brandenburg.

35 years in November since delivery of the first overhauled engine at MTU Maintenance Hannover.

2,000 in November: the 2,000th shop visit for MTU Maintenance Zhuhai – a V2500 from China Southern Airlines.

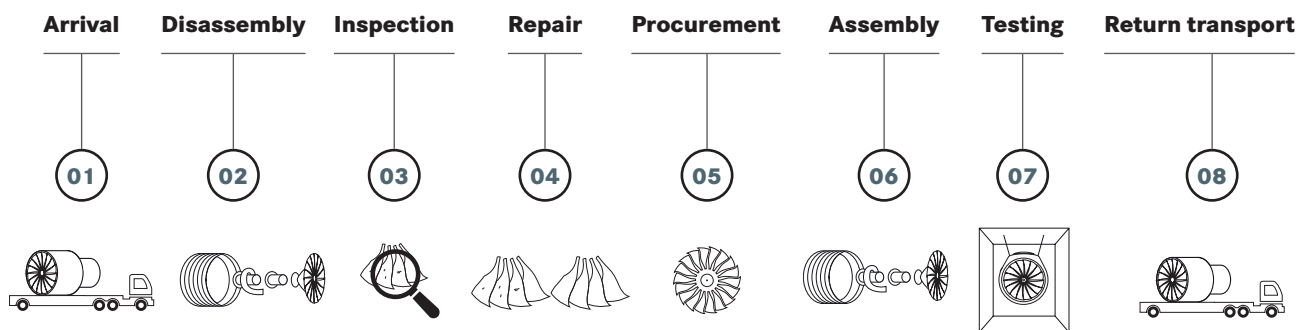
Through the shop in eight steps

GE90: a typical shop visit

When a GE90 arrives at MTU Maintenance in Hannover, speed is of the essence. The engine's size means it cannot be transported by air fully assembled, and it goes straight from the ramp to the disassembly department. "Depending on the agreed scope of work, we can dismantle the engine right down to the last screw," says account manager Nils Hoffman. The parts are then inspected for damage. Most of the time spent working on the engine goes

on making repairs and procuring replacement parts. The engine is then carefully reassembled, tested and returned to the customer in the space of some 85 calendar days. "Factors that influence the length of the shop visit include the scope of the work agreed and the availability of key replacement parts. The trick is reconciling the many and sometimes contrary factors at play—such as what the customer wants and availability," says Hoffmann.

THE EIGHT STATIONS OF ENGINE MAINTENANCE



- 01 Arrival at MTU Maintenance.** The size of the GE90 means it cannot be transported by air fully assembled. Before it arrives, the account managers arrange with the customer the extent of work to be done and plan the overhaul. That way, they can order any replacement parts that take longer to procure.
- 02 Disassembly of the engine,** even down to the last screw depending on the scope of work agreed.
- 03 Inspection of individual parts** for damage using non-destructive test processes such as X-rays, ultrasound or turbulence testing. The decision is then made which parts can be repaired and which must be replaced.
- 04 Repair of parts.** Examples of repair processes:

 - Adaptive high-speed milling
 - High-speed grinding
 - Laser carving
- 05 Procurement of spare parts:**

 - New parts from OEM
 - Mint-condition used parts from specialist retailer
- 06 Assembly:** the engine is put back together.
- 07 Test run on the test bed,** during which certain values indicating overhaul has enhanced performance must be recorded.
- 08 Return transport to the customer.**

Superbrain for pilots

The Eurofighter HEA helmet

“It looks like something out of Star Wars; it performs like something out of Star Wars.” This is how the British manufacturer BAE Systems describes the multifunctional HEA helmet, which weighs less than two kilograms. The helmet lets Eurofighter pilots keep track of their flight data and gives them a view of the sky around them, while also allowing them to steer the sighting mechanism through voice recognition and control. HEA stands for head equipment assembly.



Superbrain — BAE Systems Chief Test Pilot Mark Bowman with the Eurofighter HEA helmet.

- 01 LED clusters on the helmet surface:** two sensors on the front side consoles in the aircraft’s cockpit and one on the ejection seat record the pilot’s head movements via the infrared beams of the LEDs. In this way, the system calculates the pilot’s exact line of vision at every moment, ensuring that the correct image is displayed in the visor (see 3) and that the sighting mechanism works without any delay.
- 02 Fold-down sun shield:** can be placed over the actual visor.
- 03 Visor with integrated head-up display:** data on flight movements in the aircraft’s surroundings are captured by radar in the aircraft systems and projected onto the visor using a semi-translucent projection mirror. Other information that can be seen directly in the visor includes: a display of the pursuit of an aircraft per voice command (see 6) and flight data such as altitude, speed and angle of attack.
- 04 Binocular display:** the projected images overlap by 40 degrees, so that both eyes see the same picture. This is less tiring on the eyes than looking at a monocular image.
- 05 The helmet’s polystyrene lining:** customized to each pilot using an additively manufactured 3D model of their head.
- 06 Oxygen mask with microphone** for voice recognition and control (DVI, Direct Voice Input) and voice radio for external communication.

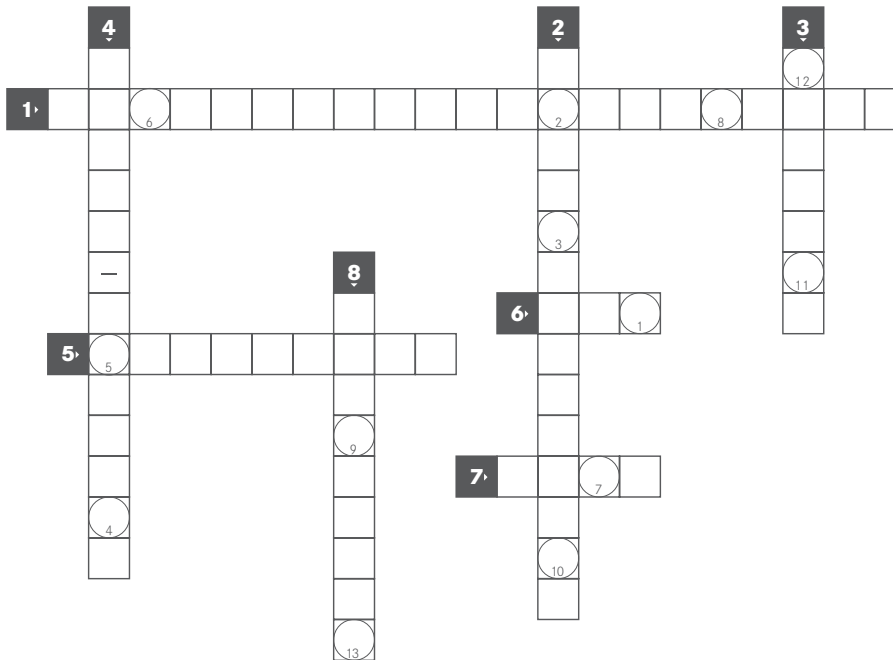
Puzzle

Solve the clues and enter the answers.

Ten participants who send in the correct solution will soon be the proud owners of an MTU table clock. Send the solution word by January 30, 2017, to aeroreport@mtu.de or to:

MTU Aero Engines AG
 Redaktion **AEROREPORT**
 80995 Munich, Germany

Good luck!



Solution word:



- 01 What solution is used as an electrolyte in the PECM process?
- 02 What is the name of the new Bauhaus Luftfahrt study that looks at small airports in inner cities?
- 03 What delivers supplies to inhabitants of remote villages in the Arctic Circle in winter?
- 04 Pratt & Whitney Canada Customer Service Centre Europe GmbH is a ... between MTU Aero Engines and Pratt & Whitney Canada; customers include Tyrol Air Ambulance
- 05 Innovations in aviation are aimed above all at reducing fuel consumption and ... ; according to Prof. Marion A. Weissenberger-Eibl, however, this alone might not be enough
- 06 What is the engineering term for an apparatus to conduct tests that mimic the conditions under which a real-life engine has to operate?
- 07 What is the first name of the aviation pioneer with the surname Lilienthal?
- 08 What does aircraft paint protect against?

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Editor

MTU Aero Engines AG
 Eckhard Zanger
 Senior Vice President
 Corporate Communications and Public Affairs

Managing editor

Dongyun Yang

Editor in chief

Eleonore Fähling

Print version

Antje Endter

Online version

Patricia Hebbing

Address

MTU Aero Engines AG
 Dachauer Straße 665
 80995 Munich, Germany
aeroreport@mtu.de
www.aeroreport.de

Editorial staff

Denis Dilba, Monika Weiner,
 Silke Hansen, Andreas Spaeth,
 Philipp Bruhns, Eleonore Fähling,
 Patrick Hoeveler, Thorsten Rienth,
 Julia Richthammer

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MTU Aero Engines AG, Dachauer Straße 665, 80995 Munich, Germany
aeroreport@mtu.de, www.aeroreport.de