AEROREPORT 01|16

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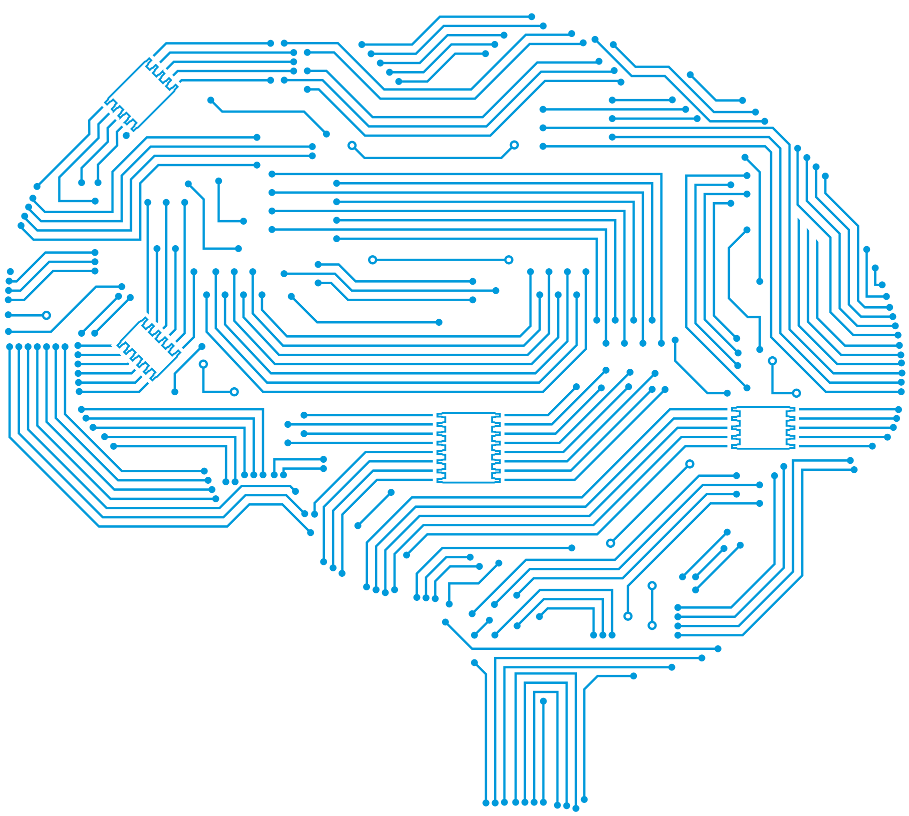

The future is digital

Smart manufacturing in the aviation industry

MARKET

Chain reactions

Supply chains in engine manufacturing

EXPERTISE

Between two worlds

Professor Mirko Hornung from Bauhaus Luftfahrt

TECHNOLOGY

Replacing trial and error with a mouse click

Simulation in development

Deserted ——— *The turning and milling machines in MTU's blisk production facility in Munich are loaded automatically and work around the clock without human intervention thanks to intelligent control systems. Just a skeleton staff is on hand to monitor the process.*

Dear readers,

Let us travel back to the year 2000: text messages on cell phones with monochrome displays were state of the art. Mobile GPS navigation systems in vehicles were just beginning to catch on, and desktop computers with cathode-ray tube screens were standard. Today, smartphones combine all of these—and a host of even more advanced options—in a device weighing no more than two hundred grams. In 2000, this would have been nearly impossible to imagine.

Innovation needs drivers. In communication technology, the driving force was consumers' desire for smaller, lighter devices with more functions. In aviation, there are two main drivers. The first is society, which calls for more and more environmental compatibility. The second is the airlines, which pass their rising cost pressure on to aircraft and engine manufacturers as a demand for higher efficiency. Besides imagination, innovation requires patience: exacting safety requirements and the sophisticated technology they demand mean that aviation industry innovation cycles are much longer than those in other sectors. It takes at least 15 years for today's visions to be realized in engine design.

It was around 2000 when Pratt & Whitney and MTU started to develop the Geared Turbofan™ family of engines. It went into scheduled service at the start of this year as the PW1100G-JM that powers Lufthansa's A320neo. The idea to gear fan and turbine so that both components can run at optimum speed was not a new one. However, new technologies, materials, design methods and manufacturing processes first had to be developed before geared turbofan technology was ready for use in scheduled applications.

At MTU today, we are working closely with our research and industry partners to further improve geared turbofan engines; for example, by drawing on more precise design methods, lighter materials and coatings to reduce emissions. We are also looking into technologies that make development faster and more economical. For instance, simulation and innovative production methods such as additive manufacturing pave the way for bionic design. I think it unlikely that the next generation of airliners 15 years from now will have glass cabins or be largely electrically powered. Their engines, however, will be much more efficient to help them cope with the projected growth in air transport with the required eco-efficiency.

I hope you enjoy **AERO**REPORT's journey of discovery through innovations in the world of aviation.

Yours,

Dr. Rainer Martens
Member of the Executive Board and
Chief Operating Officer, MTU Aero Engines AG

COVER STORY

The future is digital

Connected industry and the internet of things are topics that continue to make headlines. The increasing impact of digital technologies on economic and social life is echoed in the manufacturing world as the advent of the fourth industrial revolution. What is driving these changes, and what do they mean for the aviation industry?

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MARKET

Chain reactions

Supply chains in engine manufacturing: taking the PW1500G for the Bombardier CSeries as an example, **AERO**REPORT illustrates the global dimension of engine manufacturing activities, from the sourcing of raw materials to component manufacturing and from module assembly and engine assembly to final assembly of the aircraft.

Page 16

PARTNERS

LATAM—All of Latin America under one roof

Following the merger of LAN and TAM, both longstanding MTU customers, two of the oldest flag carrier airlines on the South American subcontinent are to be rebranded as LATAM Airlines. The new airline group is one of the ten largest in the world, with a roughly 30-percent share of domestic routes within Latin America and international flights to and from the region.

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CONTENTS

PARTNERS

Joint ramp-up

GF Machining Solutions GmbH, a division of the Swiss industrial group Georg Fischer AG, supplies MTU Aero Engines with specialized milling machines for the blisk production facility and is one of the world's leading providers of machines to the tool- and mold-making industry.

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EXPERTISE

Between two worlds

Envisioning the future of air transport means thinking with creativity and imagination while maintaining a high degree of scientific accuracy, says Bauhaus Luftfahrt executive director Mirko Hornung. In this **AERO**REPORT interview, the professor of aircraft design offers insights into the topics that will define the aviation industry in the coming decades.

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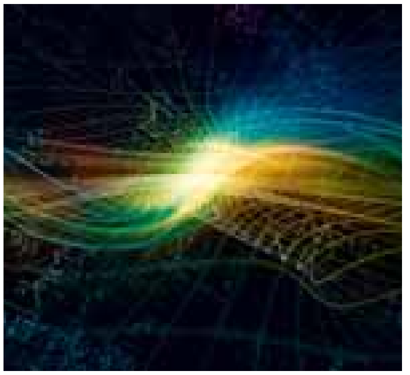

TECHNOLOGY

Replacing trial and error with a mouse click

Simulation is transforming industrial development and production techniques. Virtual testing speeds up the design process, and numerical simulation tools are increasingly being used by aeronautical engineers. Academic and industrial researchers are working hand in hand to achieve progress in this field.

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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.

Go-ahead for PW1100G-JM maintenance

The German civil aviation authority (Luftfahrtbundesamt, LBA) has certified MTU Maintenance Hannover as an approved maintenance organization for the **PW1100G-JM** Geared Turbofan™ engine for the **Airbus A320neo.** This approval is automatically recognized by the European Aviation Safety Agency (EASA) and likewise—under the provisions of existing bilateral agreements—by the Federal Aviation Administration (FAA) in the United States and by Transport Canada Civil Aviation (TCCA) in Canada. Next steps will be similar approvals in other countries such as India, China and Qatar.

E2 jet out of the hangar

Spring offered the public their first chance to see Embraer's next generation of E jets, featuring an improved bypass ratio thanks to new **PW1900G engines.** The engines seem almost bulky sitting with their oversize fans alongside the slimline fuselage. They are not the only new feature: there are also aerodynamically optimized wings, an updated fly-by-wire control system and other overhauled systems aimed at reducing fuel consumption, emissions and noise. Compared to previous E jets, range has also increased. The Brazilian manufacturer holds a market share of over 50 percent in this aircraft segment. The **E190 E2**'s maiden flight is scheduled for this year, and entry into service for 2018. The E2 family also includes the **E175-E2** and the **E195-E2,** which will fly exclusively with PW1000G engines. Depending on the configuration, the E2 jets accommodate between 80 and 132 passengers.

R&D center for turbomachinery

A new research and development center for turbomachinery manufacturing is to accelerate innovation. The Fraunhofer Institutes for Production Technology IPT and Laser Technology ILT have teamed up with RWTH Aachen's Laboratory for Machine Tools and Production Engineering (WZL) and Chair for Laser Technology (LLT) as well as prominent partners from industry to found the **International Center for Turbomachinery Manufacturing ICTM.** Research will focus on all aspects of turbomachinery manufacture and repair. "The ICTM unites experts, pools our forces and allows for excellent pre-competitive research," explains professor Fritz Klocke, director of Fraunhofer IPT and head of the department of manufacturing technology at RWTH Aachen. The network counts 18 other industrial enterprises in addition to MTU Aero Engines, and is seeking to make headway in such areas as machining processes in the use of all-ceramic tools and the finishing of components produced using additive manufacturing techniques.

Green light for CSeries

Back in December, Transport Canada Civil Aviation authority gave its approval to the **CSeries CS100,** quickly followed by a green light from the world's two biggest aviation regulatory authorities, the FAA (Federal Aviation Administration) and EASA (European Aviation Safety Agency). The CS100 is a newly developed short and medium-haul aircraft with seats for up to 125 passengers; the first scheduled airliner is due to enter service with Swiss this year.

Both the CS100 and its big sister, the 160-passenger CS300, fly exclusively with **PW1500G** Geared Turbofan™ engines, in which MTU Aero Engines has a 17-percent stake (see also chart on p. 16).

GE9X: Second test module underway

Even as MTU Aero Engines was celebrating applying the last screw to the Turbine Center Frame (TCF) for the first **GE9X** test engine at the beginning of the year, the teams at MTU were already getting to work on the next module for the second engine to test (SETT). "Of course, development didn't just halt after the design freeze for the first engine to test (FETT)," says Dieter-Eduard Wolf, GE9X program manager at MTU. Further improvements were implemented, and the design optimized. MTU also supplies the TCF for the GP7000 engine program for the Airbus A380 and the GEnx for the Boeing 787 and 747-8. Even so, participation in the GE9X program for the new **Boeing 777X** is still a first, thanks to the sheer size of the component and the extent of MTU's development responsibility.

New record performance

In the **financial year 2015, MTU Aero Engines AG** once again outperformed its earnings forecasts and boosted both revenues and profits: Revenues were up 13 percent on the previous year, while operating profit grew by 15 percent. The highest growth rate was recorded by the commercial maintenance business, where revenues increased by 22 percent, followed by the commercial engine business, which grew by 14 percent. The group's order backlog also increased—by around 12 percent. "That represents a production workload of almost three years," said president and CEO Reiner Winkler during MTU's annual press conference in Munich.

The future is digital

Smart manufacturing in the aviation industry.

Text: *Silke Hansen*

Everybody's talking about it—the Germans, the Americans and even the Chinese. In Germany they call it industry 4.0, in English-speaking countries they call it connected industry or the internet of things. For the aviation industry, it spells change as well. But what exactly is it?

"It's actually quite hard to define connected industry since the term has been used in such a widespread and often highly vague manner. Suddenly everything is tagged 4.0—work, logistics, everything," explains Tobias Strölin from the Fraunhofer Institute for Industrial Engineering IAO in Stuttgart. Strölin prefers to talk of a "digitalization of value creation" and advises that "each company must define connected industry for itself." Already ubiquitous in our personal lives, the internet is coming to manufacturing. Our economies and societies are becoming more and more digitalized, and that is changing the way we work and the way we manufacture. In the future, experts expect that people, machines, plants, logistics and products will be able to connect with one another in real time. Production will become largely autonomous—flexible, efficient and in line with the desires of the individual customer. The result is the smart factory, the textbook example of connected industry.

That this is possible in the first place is thanks to the latest information technology and new capabilities when it comes to processing data: increased storage capacity, higher speeds, a more compact size and better sensors. Meanwhile, huge advances in artificial intelligence have meant that lightweight robots are now available on the market for a comparatively reasonable price.

> *"We in the aviation industry are still at the beginning of the road to connected industry. At the MTU location in Munich, we have operated two partially automated assembly lines for a number of years now, and we're taking that a step further with our largely autonomous, digitalized blisk production center."*

Richard Maier,
Head of Production Development, MTU Aero Engines

The basis of the forward-looking internet of things is technology that relies on what are known as cyber-physical systems, in which products and the means of production can communicate with one another and be connected together in a flexible way. "It's like giving a component legs," says Strölin. Using RFID technology based on electromagnetic fields, the component is able to identify itself and how it is to be processed, and make contact with the production facility. This facility then autonomously decides what is to be done and in what order. After the steam engine, assembly line, electronics and IT, could this really be the new fourth industrial revolution? A vision of the future?

Aviation plays by its own rules

"We in the aviation industry are still at the beginning of the road to connected industry. At the MTU location in Munich, we have operated two partially automated assembly lines for a number of years now, and we're taking that a step further with our largely autonomous, digitalized blisk production center," says Richard Maier, head of production development at engine manufacturer MTU Aero Engines. Other sectors such as the automotive industry are already at a more advanced stage. Even so, taken as a whole, the digitalization of industrial production is still in its infancy; aside from a few specific applications, the first demonstrators, or demo-labs, open their doors at universities and research institutes. "In five years' time, at the end of the testing phase, we expect to see the first competitive advantages, followed by the first smart factories in ten to twenty years' time," calculates Strölin.

Nevertheless, manufacturing in the aviation industry operates by its own rules, and the smart factory concept is limited in terms of its transferability to this sector. To compare, Airbus produces 2.5 aircraft a day—while an automotive manufacturer can produce several thousand vehicles. "It's still series production, but in far smaller quantities. It's a far cry from mass production," says Maier. He also points out that the technical demands

Automated loading ____ *In MTU's blisk production center in Munich, raw components are routed directly to the machines, which adjust their settings accordingly.*

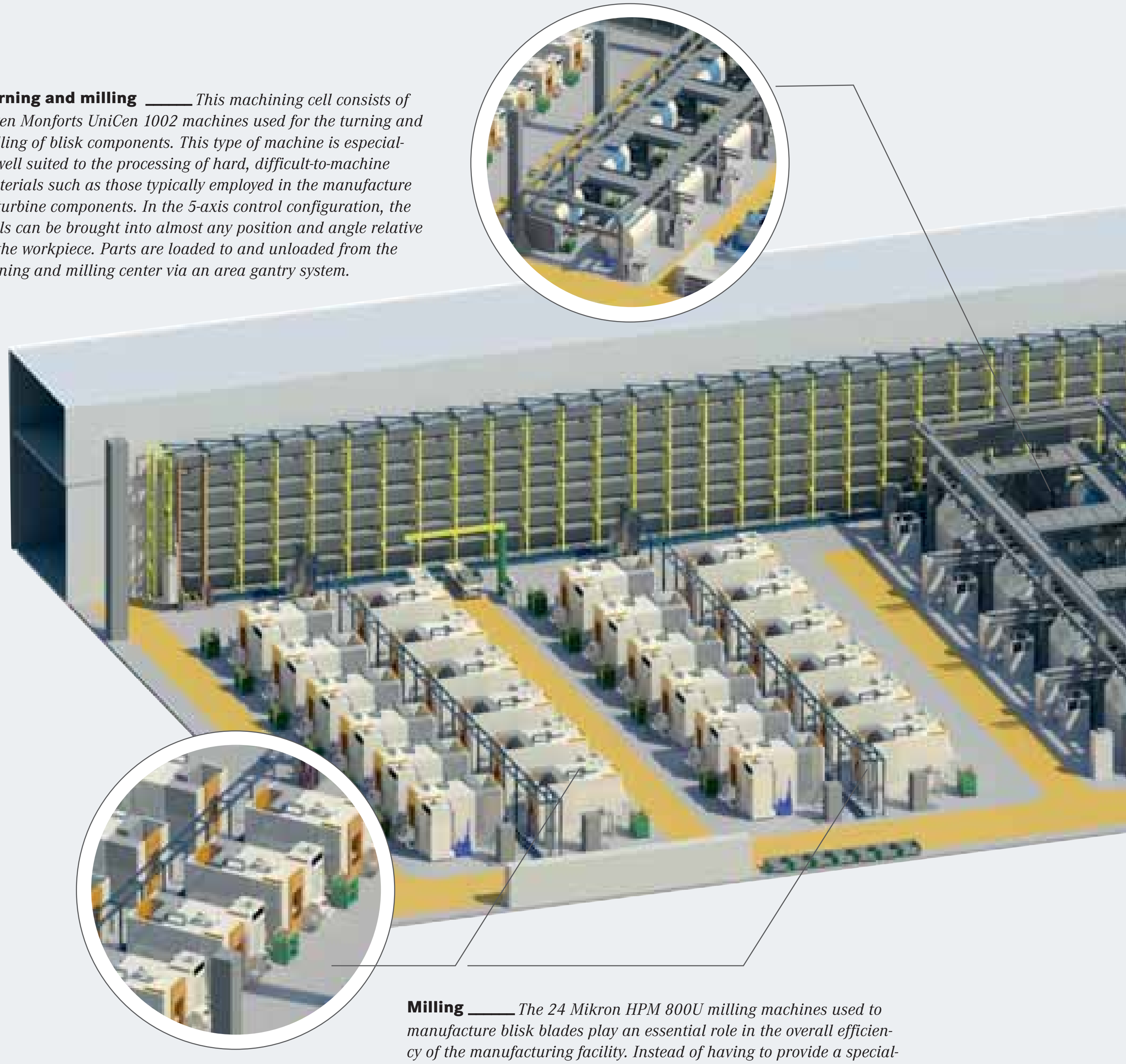
Better than the human eye ____ *The quality assurance processes in the blisk manufacturing facility are supported by computer-controlled optical measuring systems.*

Making friends with robots ——— *Still a novelty in the aviation industry: Airbus researchers are testing ways of integrating robots into manufacturing processes.*

placed on individual components are increasing all the time—meaning more and more processes to be executed, preferably in as integrated a manner as possible. As products become more complex, manufacturing them becomes harder. Stable processes are critical, says Maier. In the aviation industry, a lot is still done by individual manufacture. “We can’t just automate at any price,” says Maier. Nevertheless, automation in engine production is becoming increasingly worthwhile with the introduction of new families of components. This means applying a family concept to a core engine so that it can be scaled for multiple applications. The best example of this is the new PW1000G PurePower® Geared Turbofan™ engine family, which caters to five aircraft manufacturers and their model ranges. As a result, parts are highly comparable and can be manufactured in high volumes. MTU Aero Engines itself manufactures compressor blisks—one of the company’s special areas of expertise—for the PW1000G family. These high-tech components, compressor stages produced in a single piece, are manufactured in a newly built production hall that features a high level of automation and a smart management system. It is the world’s most up-to-date production facility for engine components of this type (see Inside MTU on page 12 of this issue).

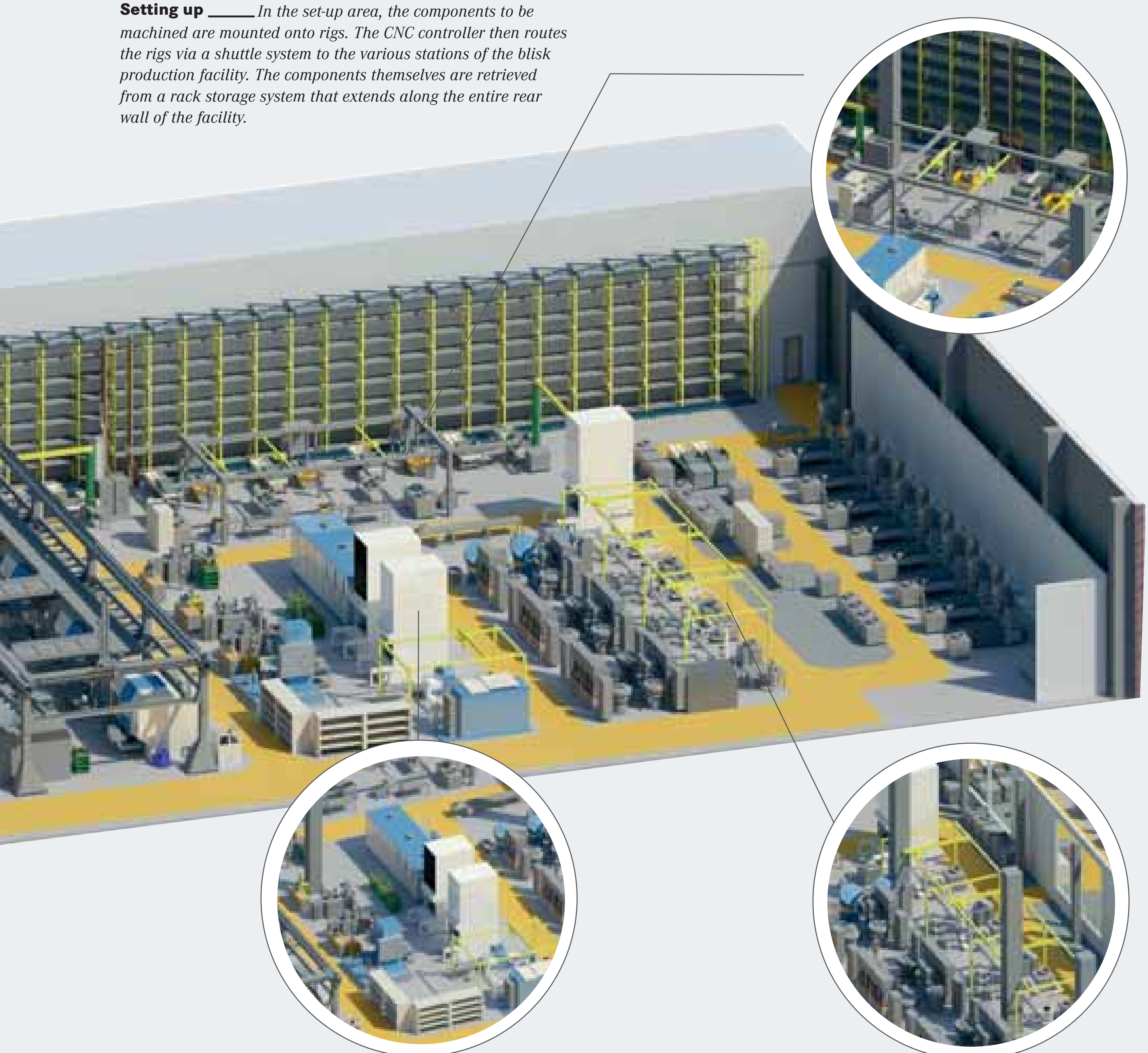
Inside MTU ___ *Automated blisk production*

Turning and milling ___ *This machining cell consists of seven Monforts UniCen 1002 machines used for the turning and milling of blisk components. This type of machine is especially well suited to the processing of hard, difficult-to-machine materials such as those typically employed in the manufacture of turbine components. In the 5-axis control configuration, the tools can be brought into almost any position and angle relative to the workpiece. Parts are loaded to and unloaded from the turning and milling center via an area gantry system.*



Milling ___ *The 24 Mikron HPM 800U milling machines used to manufacture blisk blades play an essential role in the overall efficiency of the manufacturing facility. Instead of having to provide a specially adapted machine for each specific machining task, this solution enables MTU to manufacture all blisks required for the GTF programs in a single, integrated manufacturing cell. The parts are loaded to and unloaded from the milling machines by means of a rack feeder system.*

Setting up ___ *In the set-up area, the components to be machined are mounted onto rigs. The CNC controller then routes the rigs via a shuttle system to the various stations of the blisk production facility. The components themselves are retrieved from a rack storage system that extends along the entire rear wall of the facility.*



Deburring ___ *Deburring is a manual operation in which sharp edges and rough areas of machined components are removed. One of the tasks performed here is slide grinding, to prepare the blisk blades for subsequent polishing.*

Tool presetting ___ *This cell is responsible for configuring the tools as needed for the various steps of the milling process using different machines. Even the slightest error at this point could have serious consequences on the entire production chain.*

Done, and on to the next one
Finished components are automatically collected from the machine, which can then immediately start work on the next workpiece.

Digitalization as a catalyst

"There's a great deal of potential for the aviation industry," says Maier about connected industry. The sector must remain competitive in the face of cost pressure, particularly in high-wage countries. Tom Enders, CEO of the Airbus Group, which has production locations in France and Germany, is calling for the industry "to make use of the opportunities of the digital revolution. That means ensuring that the design, development and manufacture of our products become significantly faster and more efficient as well." The European aircraft manufacturer is working on a factory of the future, in which it tests new manufacturing techniques and integrates them step by step: virtual development worlds for new aircraft, advanced digital technologies for the shop floor, a new generation of robots that works alongside people on the assembly line as well as additive manufacturing. Airbus is picking up the tempo. In its factory of the future, the assembly line will see the greatest increase in automation, where smart robots execute strenuous or repetitive tasks. In 2015, Airbus delivered 635 aircraft—a new record. The company's order books are full to bursting and it is setting its sights on increasing its production rates still further—up to 60 aircraft a month for its bestseller, the A320neo.

"Connected industry provides the foundation for a systematic learning process. It's about learning from data and continuously optimizing processes. The internet of things will help us make complex processes more manageable—and that applies to the aviation industry as well," says Dr.-Ing Christina Reuter from the Department of Production Engineering at RWTH Aachen University. According to the predictions of a Europe-wide study conducted on behalf of the Federation of German Industry, the digitalization of aerospace engineering will contribute ten billion euros a year of gross added value from 2025 onwards. It estimates that the industry will experience a digital revolution as part of a third wave—following the first waves in the automotive industry and logistics business.

In the eyes of the experts, the hurdles for the aviation industry are more regulatory than they are technical. Increased connectivity means a higher risk of cyber attacks—something to which the aerospace industry, with its extremely stringent security regulations, is particularly sensitive. All the same, IT security is the big challenge for all connected industry applications. Cars that drive themselves have long been technologically feasible, but while they do reduce the risk of accident, they bring new risks with regard to data security. "We have to find a reliable way to protect data from unqualified or unauthorized access," agrees Maier.

While there are still hurdles to be overcome, Strölin remains confident. "In ten years' time, we won't even be talking about it, as digitalization will be here." We can expect the gain to be considerable: according to calculations by McKinsey, factories stand to benefit the most from smart connectivity in an internet of things—up to 3.7 billion dollars of added economic value worldwide in 2025.

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

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

Chain reactions

Supply chains in engine manufacturing: the PW1500G for the new CSeries as an example of worldwide value creation.

Text: *Silke Hansen*
Graphics: *Peter Diehl*

The term “supply chain” refers to the entire value creation process for a given product. It begins with the sourcing of raw materials, covers all the various stages of processing that bring the product into its final form, and continues right through to the end customer. For aircraft engines, this process stretches from ore mines in Australia to airlines in China. In today’s world, supply chains are international or even global—and engine manufacturing is no exception.

What makes value creation in this industry so special is its elevated level of technology. Aircraft engines are high-tech products that are full of extremely complex and sophisticated technologies. This has led to a relatively small procurement market in which suppliers are highly specialized. Original equipment manufacturers (OEMs) in the aircraft engine business also market themselves as one-stop providers, but in reality they manufacture only certain parts of their product in house. First and foremost they act as integrators, focusing on their core competencies and running their business on the basis of cooperation in order to spread the economic risks across multiple parties. That is important because of the extremely long nature of development and technology cycles in the aviation business.

Equally important is the fact that aircraft and engines are produced in relatively small quantities rather than as mass-produced commodities. For example, in 2015 Airbus set a new record of 635 aircraft deliveries. In comparison, Volkswagen produces 836,000 cars a year in its Wolfsburg plant alone. That’s why aircraft and their engines need to have a high value by the time they reach the end of the supply chain. The average list price of a CSeries 100 with two PW1500G engines is currently in the region of 71.8 million US dollars.

07 *End customers*

The Lufthansa subsidiary Swiss is the first customer for this new family of aircraft. 20 of the smaller CS100 models are due to replace the airline's aging Avro RJ100 "Jumbolinos". Swiss's pilots have already inspected the new aircraft on site in Canada. After familiarizing themselves with their new workplace, they embarked on some joint flight training across Europe together with the Bombardier flight crew. The CSeries aircraft with their PW1500G engines will cover routes within Europe when they enter regular service.

06 *Assembling the aircraft*

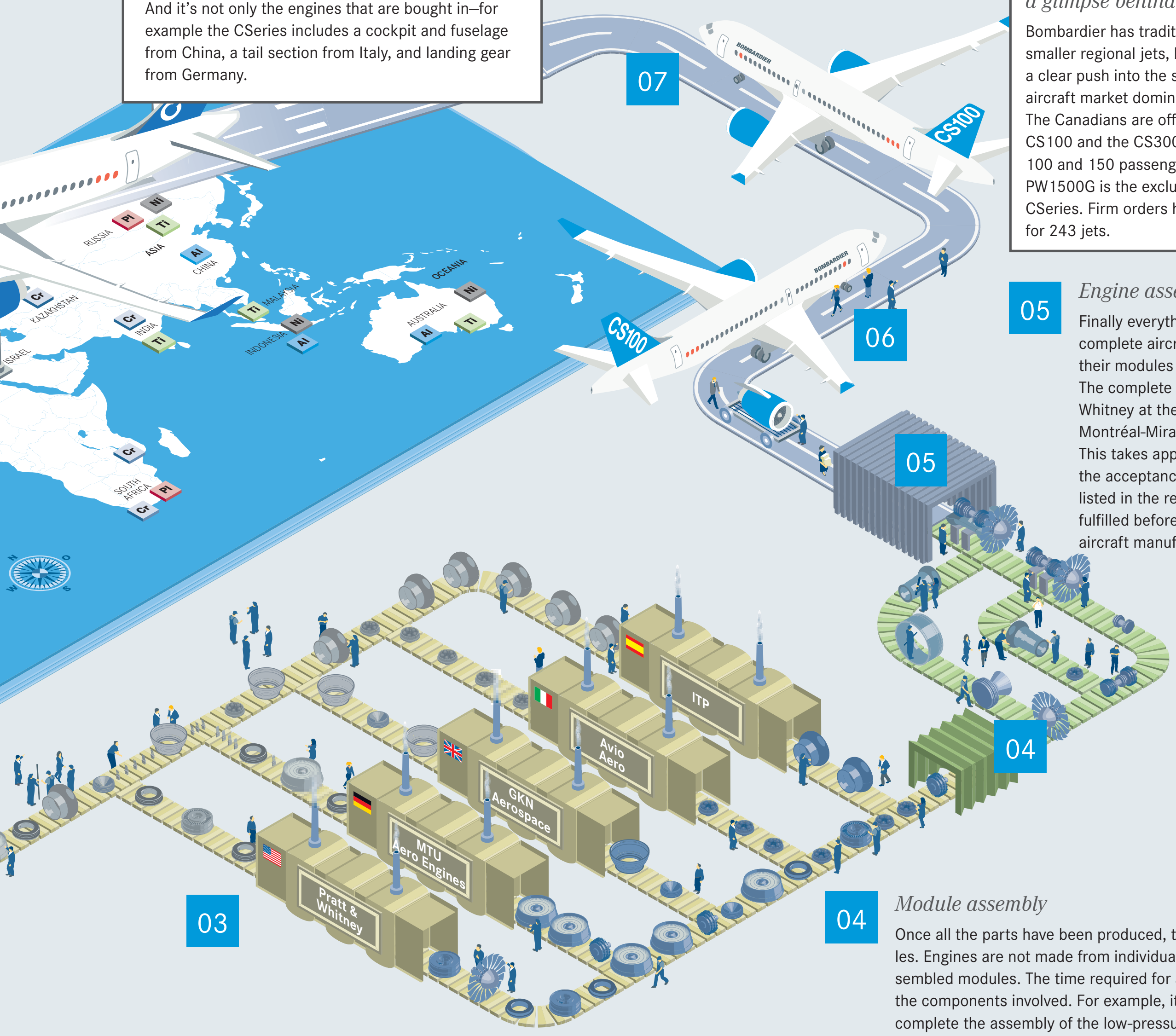
Bombardier assembles the CSeries close to the Pratt & Whitney Canada plant. Another 15 to 20 aircraft are due to be completed this year, each requiring two engines. The manufacturers work simultaneously on multiple aircraft, which are at different stages of the assembly process. 315 deliveries are scheduled to be made by 2020, with annual production of up to 120 aircraft. Although these aircraft are being assembled in North America, the first CS100s will enter regular service in Europe.

Step into: putting together the pieces

The final assembly of an aircraft is like a giant puzzle. All the parts from different suppliers all over the world must reach Canada on time, ready to be installed. And it's not only the engines that are bought in—for example the CSeries includes a cockpit and fuselage from China, a tail section from Italy, and landing gear from Germany.

An aircraft and its engines—a glimpse behind the scenes

Bombardier has traditionally specialized in smaller regional jets, but its new CSeries marks a clear push into the short- and medium-haul aircraft market dominated by Airbus and Boeing. The Canadians are offering two models—the CS100 and the CS300—with seating for between 100 and 150 passengers (max. 160). The PW1500G is the exclusive powerplant for the CSeries. Firm orders have already been placed for 243 jets.



05 *Engine assembly*

Finally everything is ready to produce the complete aircraft engine. All the suppliers send their modules to the OEM, Pratt & Whitney. The complete engine is assembled by Pratt & Whitney at the Mirabel Aerospace Centre at Montréal-Mirabel International Airport in Canada. This takes approximately four months, including the acceptance test on the test bed. All the points listed in the requirements specification must be fulfilled before the engine can be delivered to the aircraft manufacturer, Bombardier.

04 *Module assembly*

Once all the parts have been produced, they are assembled into modules. Engines are not made from individual parts, but rather from pre-assembled modules. The time required for assembly varies depending on the components involved. For example, it takes five working days to complete the assembly of the low-pressure turbine for the PW1500G. It is only at this stage of the process that bought-in parts delivered to the module manufacturer in a finished state come into play.

Where is everything assembled?

- Core engine (high-pressure compressor, combustion chamber, high-pressure turbine):
  Pratt & Whitney, North Berwick, USA
- Low-pressure turbine: MTU, Rzeszów, Poland

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01 *Sourcing raw materials*

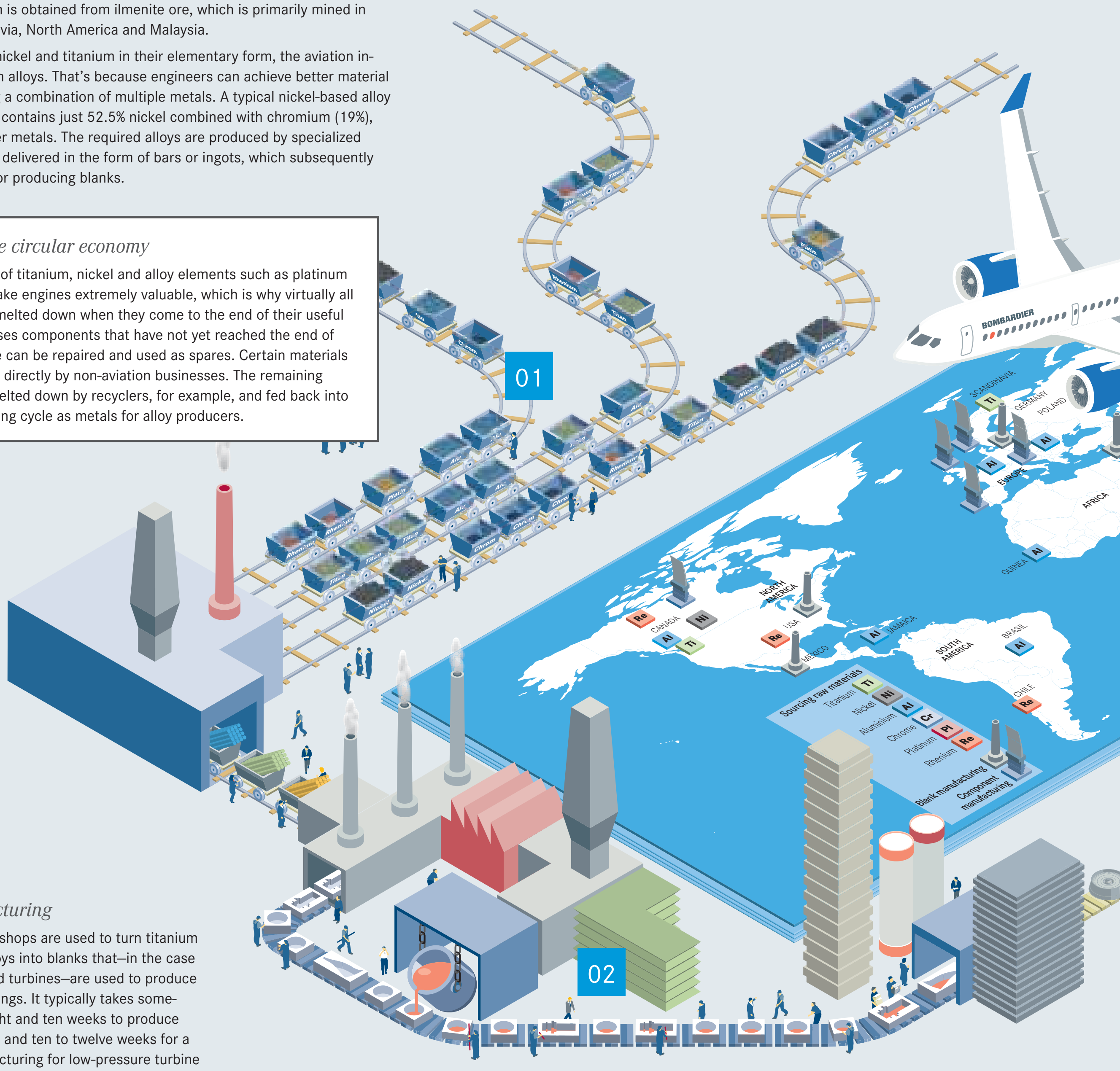
Engines are made from a variety of different materials including titanium, nickel, steel, aluminum, plastics, platinum and rhenium.

The most important of these are titanium and nickel. Titanium is used for the forward section (fan, compressor) while nickel is used in the high-temperature area (combustion chamber, turbine). Nickel ore is mined and then processed to obtain nickel. Major ore deposits can be found in Canada, Australia, Russia and Indonesia. Titanium is obtained from ilmenite ore, which is primarily mined in Australia, Scandinavia, North America and Malaysia.

Rather than using nickel and titanium in their elementary form, the aviation industry uses them in alloys. That's because engineers can achieve better material properties by using a combination of multiple metals. A typical nickel-based alloy (Inconel Alloy 718) contains just 52.5% nickel combined with chromium (19%), iron (19%) and other metals. The required alloys are produced by specialized suppliers. They are delivered in the form of bars or ingots, which subsequently provide the basis for producing blanks.

Step into: the circular economy

The high prices of titanium, nickel and alloy elements such as platinum and rhenium make engines extremely valuable, which is why virtually all their parts are melted down when they come to the end of their useful life. In some cases components that have not yet reached the end of their service life can be repaired and used as spares. Certain materials can be recycled directly by non-aviation businesses. The remaining materials are melted down by recyclers, for example, and fed back into the manufacturing cycle as metals for alloy producers.



02 *Blank manufacturing*

Foundries or forge shops are used to turn titanium or nickel-based alloys into blanks that—in the case of compressors and turbines—are used to produce blades, disks and rings. It typically takes somewhere between eight and ten weeks to produce a blank for a blade, and ten to twelve weeks for a disk. Blank manufacturing for low-pressure turbine blades is carried out worldwide depending on the complexity involved, primarily in Germany, the USA, Mexico and Israel. In comparison to other industries, blanks produced for aircraft engines already feature a high degree of complexity before they are forwarded to the finishing stage.

03 *Component manufacturing*

The blank is forwarded to the "actual" supplier of the component for finishing. Aircraft engines are produced by teams of specialists who work together on individual engine modules.

Who is responsible for the different parts of the PW1500G?

- Pratt & Whitney (USA) as the OEM: fan, high-pressure compressor (rear four stages), low-pressure compressor, combustion chamber
- MTU: low-pressure turbine, high-pressure compressor (front four stages), brush seals
- GKN Aerospace (United Kingdom): turbine exit casing, compressor intermediate case
- Avio Aero (Italy): gear unit
- ITP (Spain): structures, external parts

Example of low-pressure turbine: In the PW1500G, this consists of three stages and approximately 90 part numbers. To assemble this module a mechanic will need to handle a total of 1,228 individual parts. In reality, however, the number of different parts is even greater—MTU and its suppliers clamp and coat the cast blanks to create the finished parts.

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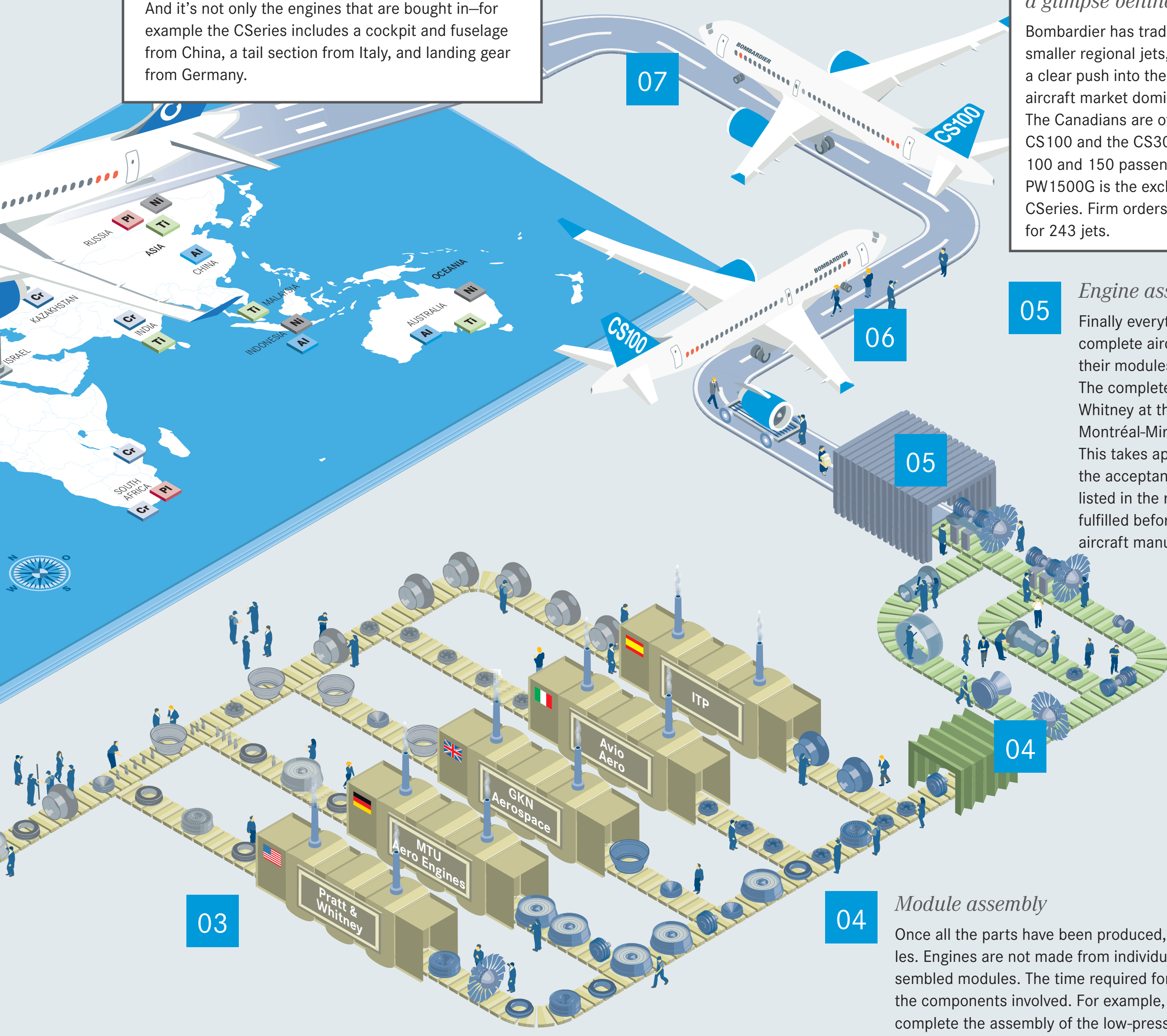

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Three into one

Unlike aircraft, when an engine comes to the end of its service life, it doesn't necessarily have to be scrapped. What happens to the engine depends on the airline or leasing company's specific requirements.

Text: *Achim Figgen*

What exactly is asset management? While there is no need to go into a highly detailed and academic description here, a simpler explanation would certainly be worthwhile. Dick Forsberg, chief strategist at leasing company Avolon, put it as well as anyone some years ago when he said: "Buy well, sell better, and act with care in between." Specifically, then, asset management is about seeking to maximize the value of "assets" (facilities, machines or buildings—or, in the case of the aviation industry, aircraft) employed in pursuit of a given business goal.

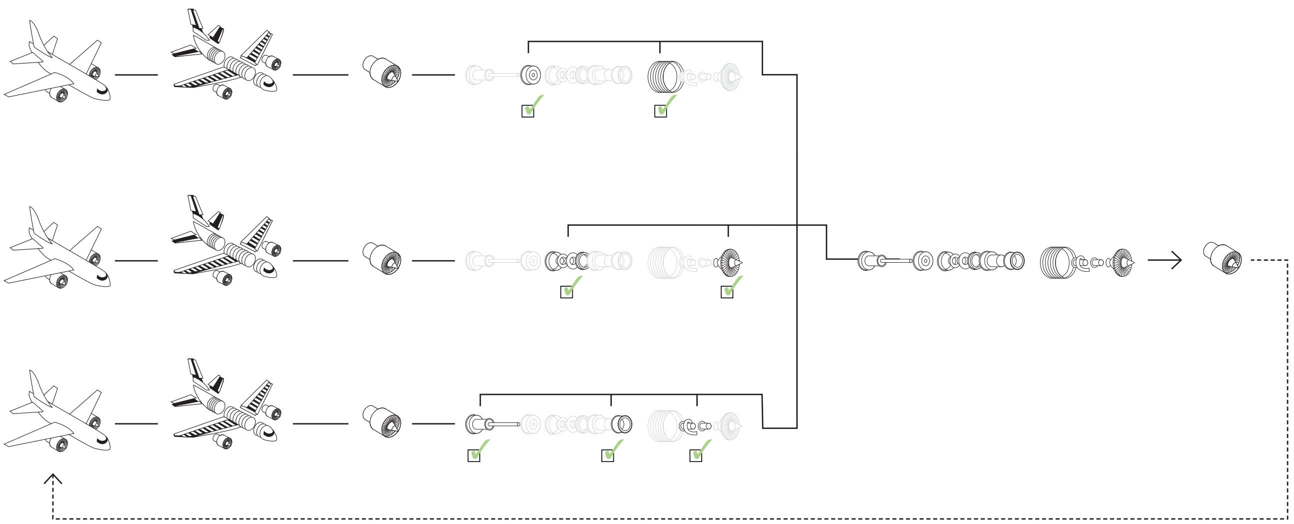
Even so, asset management varies considerably depending on circumstances, such as the nature of the owner—airline or leasing company—and the age of the aircraft. "A 30-year-old Boeing 747 with CF6 engines is still worth millions, but without the engines it's practically scrap," says Jürgen Kuhn, head of corporate development at MTU Aero Engines, highlighting the difference. The thing is, he says, that airframes have a fixed service life, after which the "asset" is good only for scrap.

However, that is not necessarily the case for the various other components of an aircraft—and particularly not for the biggest and most expensive parts, the engines. Engines do have a number of life limited parts (LLP), but once the engine has undergone a comprehensive overhaul it is practically as good as new and can be used for many years to come. Whether that happens depends on a number of factors—not just the general market situation, business circumstances and the owner's plans—but also the type of engine and the range of maintenance and overhaul services available for it.

Let's look at an example. An airline has an engine with around 2,000 flight cycles left in its service life. It is currently fitted to a type of aircraft the airline wants to operate for another five years. However, 2,000 cycles is not enough for five years of operation–at the same time, it wouldn't make sense to replace the life limited parts with brand new ones that would last 20,000 flight cycles or more. The decision is taken to install used replacement

Disassembly ——— *At MTU Maintenance, components with a longer useful life than the engine in which they were originally incorporated can be repaired and reused in other engines.*

END-OF-LIFE ENGINE RECYCLING



How engines can be given a second life _____ *Viable components reclaimed from several different decommissioned engines can be used to construct a reconditioned engine with several more years of useful life.*

parts with 5,000 cycles left in them so that the engine can subsequently be dismantled and any still usable components sold off. In the case that the airline wanted to sell the engine in its entirety once it had left service, it would need to install replacement parts with a much longer service life remaining. There's no doubt that good asset management is a wrestle with a large number of unknowns; at the end of the day, it is about doing what you can to ensure that the engine can still be used in a way that fits in with the owner and their current and future requirements.

All from a single source

MTU Mature Engines Solutions offers operators of older engines—within the MTU Maintenance portfolio, that means engines such as the CF6-80 and CFM56-3—these kinds of solutions. One of the key players in getting these activities off the ground was Southwest Airlines. The U.S. budget airline was approaching the phase-out of its last Boeing 737-500 and -300 aircraft along with their CFM56-3 engines when MTU Maintenance Canada made a proposal to obtain replacement parts for the remaining engines by using the engines from the 737 aircraft being removed from service ("three into one"). This ensures that the phase-out—which is to be completed by 2018—is as efficient and cost-effective as possible.

Dennis Reichel from corporate development at MTU points out the company's advantage as both manufacturer and independent provider of maintenance services. This allows it to offer a complete package from a single source—something a spare parts provider cannot hope to achieve. "We have the market and technical know-how to determine the optimum point at which to retire an engine from service." But it is about more than just taking the engine from the customer and scrapping it. "We can find a use for the individu-

CF6 ENGINE MAINTENANCE

01 ____ *Assembly at MTU Maintenance.*
02 ____ *Visual inspection of a blade segment.*
03 ____ *Removal of add-on parts.*
04 ____ *On-wing testing of engine components.*

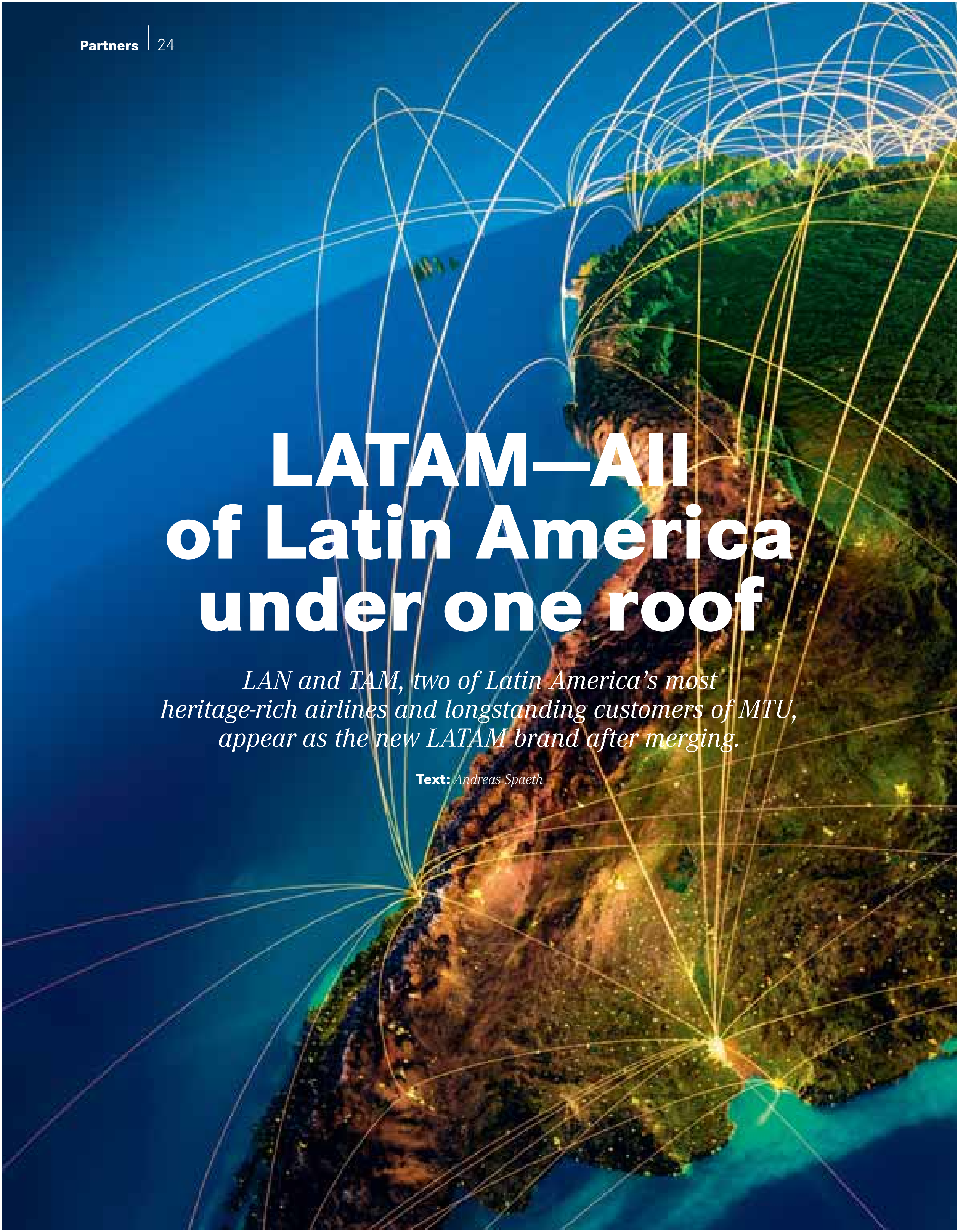
al components because of the number of overhauls we complete within our network," says Reichel. "Also," continues Jürgen Kuhn, "our repair skills surpass those of most overhaul operations and manufacturers, meaning that we can reuse more components and so create added value for the customer."

In a period of extremely low prices for crude oil and kerosene, some airlines are considering putting off the entry into service of new, fuel-efficient but expensive to procure aircraft, preferring to operate the aircraft they have for longer. Depending on the timeline airlines decide on, this means either exchanging life limited parts so that the engines stay fit for further years of service or else handing over in payment to MTU engines that have come to the end of their service life while buying or leasing replacement engines. Ultimately, asset management is all about finding individual solutions for customers' varying requirements.

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

More on this topic: **www.aeroreport.de**

Text:
Achim Figgen is a graduate engineer specializing in aerospace technology. He has written several books on aviation subjects.



LATAM—All of Latin America under one roof

LAN and TAM, two of Latin America's most heritage-rich airlines and longstanding customers of MTU, appear as the new LATAM brand after merging.

Text: *Andreas Spaeth*

Usual picture ____ *Until now, the airlines of each member of the LATAM group flew under their own colors. As of 2016, the aircraft will be repainted in a uniform livery.*

LAN is the abbreviation for Línea Aérea Nacional de Chile and was introduced in 1932 for the Chilean airline founded three years earlier. At the time, flying in Chile meant traveling in single-engine biplanes like the De Havilland Gipsy Moth. TAM stood for Táxi Aéreo Marília in 1961 and was initially a small Brazilian air taxi operator. Both companies grew to become the biggest and most important airlines of Latin America, dominating the markets of their respective home countries. Each carrier was run by a strong dynasty: TAM, always privately held, by its patriarch Rolim Amaro (deceased in 2001) and his family, and LAN, after privatisation in the 1990s, by the Cuetos, who had made a fortune exporting canned fruits, among other ventures. Since 2002, prospering LAN expanded beyond Chile and established affiliates in neighbouring countries, sometimes through the acquisition of local airlines. Since 2004 LAN stood for Latin American Network, and despite being registered in Chile, Peru, Ecuador, Argentina and Colombia, its aircraft flew under the unified LAN brand. After remaining a purely Brazilian domestic airline for long, TAM expanded its route network to the USA in 1997 for the first time, followed by European services in 1999.

Already in 2012, the merger of both airlines was executed, although they kept flying under their respective well-known brands, but under the roof of LATAM holding. LATAM claims around 30 percent market share for flights within and to and from Latin America, and is among the ten biggest airline groups in the world. In 2015, it carried almost 68 million passengers to 140 destinations in 24 countries on its fleet comprising 328 aircraft at last count. The network around Latin America

INCREASED MARKET SHARE

TAM *(in Brazil)* — 45%

\+ LAN *(in Spanish-speaking countries)* — 38%

= LATAM *(in all of South America)* — ~30%

No. 8 *With 328 aircraft and nearly 68 million passengers in 2015, the LATAM Group ranks among the world's ten largest airlines.*

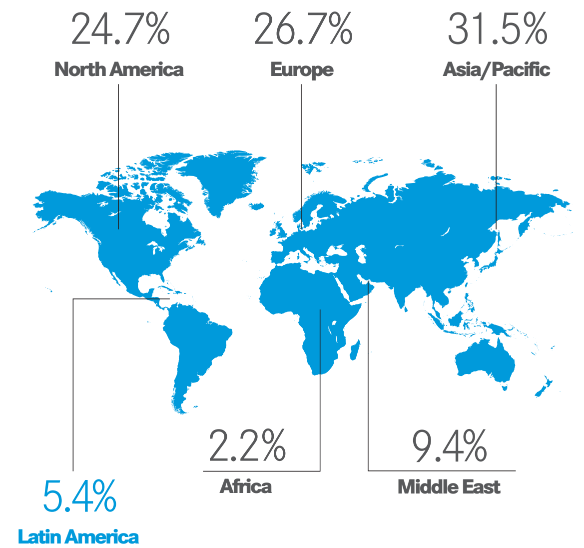
Source: Latam, Ascend Database

LATAM HUBS IN LATIN AMERICA

	Population in million	Passengers/ year
São Paulo (Brasil) Guarulhos (GRU)	11.8	38.9[1]
Santiago (Chile) Pudahuel (SCL)	6.1	16.1[2]
Bogotà (Columbia) El Dorado (BOG)	7.8	25.0[3]
Lima (Peru) Aeropuerto Jorge Chávez (LAP)	8.8	15.6[4]

[1] Aeroporto Internacional de Guarulhos
[2] 2014, Vinci Group
[3] 2013 estimated, El Dorado International Airport
[4] 2014, Aeropuerto Internacional Jorge Chávez

GLOBAL PASSENGER AIR TRAFFIC, FEBRUARY 2016



Source: IATA

is extremely dense with 117 destinations served. At least as impressive is the freight arm LAN Cargo, even serving 144 airports in 26 countries. In total, about 53,000 employees work under the roof of LATAM. Currently Latin America's biggest market, Brazil, faces tough times because of the recession, the deteriorating currency and high duties imposed on aviation. "Due to the size of Brazil, its dire situation is impacting the entire Americas region, airlines in Brazil had combined losses of nearly 400 million U.S. dollars in the first half of 2015", complains IATA, the association of scheduled airlines. LATAM suffered a decrease of domestic passengers in Brazil and other countries in the region by four percent, which was compensated however by an equally big growth in international traffic.

2016 is a special year for LATAM: In August the Games of the XXXI. Olympiad will be held in Rio de Janeiro towered over by Sugarloaf Mountain. Before that, the merger of the former brands LAN and TAM into a common new LATAM identity will be executed. Until 2018, all aircraft are expected to fly with the new LATAM livery, the name of individual countries will no longer appear, exactly like LAN had introduced it successfully in its own group. The new logo in coral and red on an indigo background, which was unveiled in 2015, is supposed to be a compromise in colours and style between the existing brands. "The new brand is born from the desire to capture the best of both identities and legacies and consolidate them to create an even stronger one, an essence that is truly Latin America," explains Mauricio Amaro, president of the Board of Directors. In contrast to other groupings such as Air France/KLM or IAG (British Airways and Iberia), whose airlines continue to fly with separate identities, LATAM has conducted studies in ten countries, with results encouraging the incorporation into one single brand. "This is the first time that an airline group has decided to consolidate under one single brand, and the first time a Latin American group aspires to be one of the best in the world," says Amaro. About 40 million U.S. dollars will be the cost of the rebranding, mostly for changing the liveries of over 300 aircraft.

LATAM is focusing mainly on Airbus jets, currently about 250 aircraft of over 300 to be operated by the group soon come from the European manufacturer. TAM is the launch customer for the Airbus A350 in Latin America, the first scheduled service took place in early 2016. A total of 27 A350-900s and -1000s ordered by TAM are destined to replace older A330-200s. LAN in turn was the first operator of the Boeing 787 in Latin America in 2012, in total the Dreamliner fleet will be consisting of 32 787-8s and -9s. Both airlines together also boast a fleet of 43 Boeing 767-300ERs. Under the common brand, both the fleets and the route network will be further streamlined. The vision is clear: "LATAM created a unique partnership in the industry that resulted in the largest airline group in the region," says CEO Enrique Cueto, "LATAM will be a brand that builds a culture dedicated to taking care of its clients."

Inside MTU

MTU at LATAM's side

An important factor in the success of LAN and TAM has always been MTU Maintenance, which has been maintaining the V2500 engines of the TAM A320 family aircraft since 1999 and since then also has been looking after the GE90 engines of the Boeing 777 fleet. Until 2013, LAN operated a fleet of Airbus A318 jets with PW6000 engines, partially developed and assembled by MTU. "We constantly extended the cooperation," says Christoph Heck, Vice President Sales The Americas at MTU Maintenance, who has been in close touch with the customer since a long time. "MTU is proud to have contributed to this success story. The merger doesn't change anything for us, as we have long-standing excellent contacts with both airlines and continue this," according to Heck. The V2500 engines are ferried by air cargo from São Paulo and Santiago to the facilities of MTU Maintenance in Hanover. "The customer is rewarding the efforts of the whole team here," enthuses Christoph Heck.

ENGINES IN USE AT LATAM

V2500
Backbone of the A320 fleet
TAM is one of the biggest customers using the V2500 to power its fleet of A320s. MTU is a partner in this engine program, and MTU Maintenance has been providing MRO services for this engine since 1999.

GE90
Air freight giant
Since the beginning of this year, MTU Maintenance has been responsible for maintaining the GE90 engines that power LAN's fleet of B777 air freighters.

Well-traveled ___ *The LATAM Group's V2500 and GE90 engines fly to Hannover for maintenance. Here, they wait for a test run at MTU Maintenance before they return to service somewhere in Latin America.*

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

Joint ramp-up

GF Machining Solutions GmbH is a division of Georg Fischer AG and a global leading provider of machines to the tool- and moldmaking industry, as well as to precision parts manufacturers. The term "solutions" is not just part of the name—it's a dictum.

Text: *Thorsten Rienth*

+

Power station ——— *The Mikron HPM 800U milling machines provided by GF Machining Solutions can be adapted to the machining requirements of many different types of component. They enable all blisks employed in the GTF engines to be manufactured on a single unit.*

In the end they must all be exactly the same: absolutely identical high-speed milling machines. Every installed pipe, every screw, every circuit board, every small engine—right down to the software. “We rely on absolutely accurate reproducibility,” explains Walter Sürth. “Only machines that are exactly the same in construction will also produce exactly the same results.” The director of blisk production for MTU Aero Engines in Munich is fastidious. With good reason—after all, he’s dealing with tolerances to within an accuracy of a few hundredths of a millimeter.

A single machine for all applications

His milling machines are not only required to produce exactly the same results every time. They have to do so at high speed and with a high degree of reliability. The blisks are used above all in Pratt & Whitney’s PurePower® PW1000G family of engines with Geared Turbofan™ (GTF) technology. And blisk production is being massively ramped up: until recently, MTU was producing around 600 of these components each year; by the end of 2016, production capability is set to increase to 3,500.

The Mikron HPM 800U milling machines manufactured by GF Machining Solutions represent a kind of life insurance for the ramp-up. “Machines of this type are capable of producing all blisks for the GTF programs on a single unit. Normally you need a specially adapted machine for each separate application,” Sürth points out.

It is these characteristics that make the Mikron HPM 800U the most technically advanced machine in GFMS’s portfolio. Although portfolio isn’t really the right term. “The machines have been adapted to the specific demands of blisk production at MTU,” explains Michel Eder, GF Machining Solutions’ key account manager for MTU. Components are automatically allocated to the milling processing centers without restricting access for the operator—an ideal connection to the automatic loading system at the blisk production center in Munich.

GFMS delivered the first Mikron HPM 800U to the production facility at the end of 2011. In total, 24 units are being successively supplied, tested and finally put into industrial operation. The machine pool should be complete—and the production center operating at full capacity—by the end of 2016. Until then at least, Eder will continue to commute between Schorndorf and Munich to assist in the industrialization of the machines.

The first parts to be produced on the machines are already in the air. The PW1100G-JM engine powers the Airbus A320neo, which Deutsche Lufthansa put into scheduled service at the start of the year. Derivatives of the engine are currently undergoing flight testing on the Bombardier CSeries—also scheduled to enter regular service this year—as well

“We rely on absolutely accurate reproducibility. Only machines that are exactly the same in construction will also produce exactly the same results.”

Walter Sürth
Director Blisk Production, MTU Aero Engines

Machines in service ______ *By the end of 2016, no less than 24 Mikron HPM 800U milling machines will be in operation at MTU.*

as on the Mitsubishi Regional Jet (MRJ). Embraer's second-generation E-Jets and the MS-21 from the Russian manufacturer Irkut will also be powered by the PW1000G and are in the midst of development.

Living manufacturing solutions

GF Machining Solutions is one of three divisions of the Swiss industrial group Georg Fischer AG. According to the latest figures, the division's approximately 3,000 employees generated annual sales of around 900 million euros at 50 sites worldwide. The company describes itself as a global leading provider of machines to the tool- and moldmaking industry, as well as to precision parts manufacturers.

The Swiss company develops and manufactures the necessary electric discharge machines, high-speed and high-performance milling machines, and 3D laser surface texturing machines. It also supplies everything else required to operate the machinery, such as spare and wear parts, consumables such as wires, electrodes, filters, and graphite. And—of course—automation solutions. "We don't just have 'solutions' as part of our name; we also live these solutions on a day-to-day basis," says CEO Heiko Benz. "We see ourselves as more than a supplier of machines. For us, the focus is on providing solutions."

This approach has earned the Swiss company a place in the production facilities of nearly every big name in the manufacturing industry. At BMW's tooling and moldmaking center, for instance, two GFMS milling processing centers have been in continuous operation since the beginning of 2012. Fitted with pallet magazines, tool changers and zero-point clamping systems, the centers outsource non-productive processes, such as set-up and clamping procedures or tool adjusting, from main time to parallel units. A second example is Otto Klumpp GmbH. This family-run business, based in the southwest of Germany, sells injection-molded plastic products and injection molding tools. The company recently commissioned a fully automatic and autonomous linear cell assembly. A linear robot connects a milling machine with an EDM machine in the cell, controlled by shared CellManager software. The company operates the facility in a three-shift rotation; two of the shifts run automatically, without an operator.

For some time now, GF Machining Solutions has focused on more than pure and simple machine production. "Our ambition is to play a pioneering role in the development of innovative products and solutions," says CEO Benz.

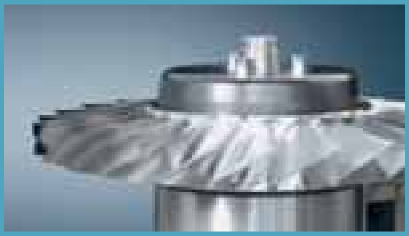
Take electrical discharge machining, for example. This technology makes it possible to machine electrically conductive materials of any hardness and with the highest surface qualities.

The company recently launched its "rConnect" system, a central communications platform for milling, EDM and laser texturing. Behind this is a remote analysis system for the machine tool industry. This gives manufacturers the option of authorized remote assistance provided by the respective GF Division plants. The key ideas here are the smart factory, connected industry (also known as industry 4.0) and minimum machine downtimes. And of course, here too, maximum customization is an important criterion.

Specialized demands call for specialized machines

At MTU Aero Engines, this not only concerns seamless integration of the machines and the loading system. "The aviation industry has to comply with very strict documentation requirements for the individual stages in the manufacturing process," key account manager Eder explains. The same applies to safety requirements and the running times of the machines—which, he adds, are utilized almost to the very last minute. "We have an agreed running time of 6,000 working hours per machine and year," which corresponds to 250 days' continuous operation. "This is a promise we made good on."

Blisk _____ Blisk is an abbreviation for "blade integrated disk". The components are used in the form of stages in state-of-the-art low- and high-pressure compressors. Instead of attaching the blades to the disk, blisks are integrally manufactured by milling them from a single blank. This manufacturing method reduces the weight of the parts and increases their stability. However, due to the increased complexity it also makes them significantly more challenging to produce. In the future, the construction may also be put to use in turbine stages.



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

Between two worlds

Envisioning the future of air transport means thinking with creativity and imagination while maintaining a high degree of scientific accuracy, says Bauhaus Luftfahrt Executive Director Mirko Hornung.

Text: *Denis Dilba*

Professor Mirko Hornung ——— *Executive Director Research and Technology, Bauhaus Luftfahrt e.V., and Professor of Air Transport Systems and Aircraft Design at the Technical University of Munich*

"It makes sense to develop new airplane configurations only if they offer significant advantages over the conventional design. That's why planes still look much the same today."

Mirko Hornung (44) was appointed Chair of Aircraft Design in the Department of Mechanical Engineering at the Technical University of Munich in 2010. That same year, he also became an Executive Director of Bauhaus Luftfahrt. As a scientist and lecturer Prof. Hornung focuses on conceptual aircraft design, aircraft integration and evaluation. He studied and received his doctorate from the Department of Aeronautical Engineering at the University of the Bundeswehr (Federal Armed Forces) in Neubiberg near Munich. His dissertation on reusable space transport was awarded a research prize in 2003. Until 2009, he worked at EADS (now Airbus), where his responsibilities included the preliminary development of future air transport systems.

For decades, visions of the future have repeatedly portrayed weird and wonderful aircraft that resemble rays, arrows, or even flying saucers. Yet today's planes look much the same as they did at the dawn of commercial air travel. When is that going to change?

Prof. Mirko Hornung: The question we should be asking is: does it have to change at all? It makes sense to develop new airplane configurations only if they offer significant advantages over the conventional design. That's why planes still look much the same today. So far, other configurations haven't proved so much better that they would be worth implementing. If we're talking about enhancement of just a few percent, we can usually achieve this through continuous improvement. It also has to be said that the industry hasn't been idle either. While aircraft exteriors might not appear to have changed much since the Boeing 707, the interior is quite a different story. Over the past seven decades of commercial air flight, we have made substantial improvements to our aircraft. In that time we also reduced

fuel consumption by almost 70 percent compared to the very first passenger jets, like the Boeing 707.

What research priorities and technological developments do you see defining the industry over the next two decades?

Hornung: All forecasts indicate that the number of aircraft is set to triple by 2050. The targets have been set—lowering CO_2 emissions by 75 percent, significantly reducing nitrogen oxide emissions, and lessening noise—and give rise to a wide range of topics. Airplanes are only one piece of the puzzle; airports also play a role, as does fuel supply and the transport system as a whole. One driving force will certainly be the continued development of energy and propulsion systems. This area shows highly promising technological approaches that we are exploring in close collaboration with MTU Aero Engines. For instance, we have recently been looking into new cycles, so-called composite cycles, in which different thermodynamic cycles are combined in order to once again dramatically improve engine efficiency. There still seems to be a lot of untapped potential here. Electric-hybrid propulsion systems—that is, a combination of electric motor and internal combustion engine—are of course also a topic for us. Only a few years ago, people were saying there's no way they can work in a larger aircraft. But the idea no longer sounds quite so absurd.

Wait a moment, are you saying that electric-hybrid propulsion systems can work in larger passenger aircraft?

Hornung: In theory, yes. But it's something that has to be examined very closely. It's been proved that in principle it would be possible. One of our main tasks now is to look at how we need to develop the individual components and technologies; in other words, what has to happen if electric-hybrid propulsion systems are to represent an advantage when operating aircraft. Right now we still lack an adequate understanding of the necessary components, such as batteries, generators, electric motors, and modified turbo components.

You also mentioned that airports and flying-related infrastructure need to be further developed, too.

Hornung: That's right. For instance, we are currently looking at ways to improve aircraft ground handling activities and their interaction with the terminals and the airport infrastructure. This also depends on future aircraft sizes. Another topic, in particular for megacities with ten million inhabitants or more, is how to get airports closer to the city center. Nowadays they are usually miles out of town, so most of the journey from door to door is spent getting to and from the airport. Yet in cities this size, ground transport is notoriously slow. Overall, this means that on shorter and medium-haul routes, flying is becoming a less attractive option. What can we do to change this situation? One key driver here will be noise reduction. Making aircraft quieter is the only way to increase acceptance for airports that are located closer to residential and business areas and can be reached more quickly.

Wouldn't one way of reducing noise simply be to develop aircraft that can take off vertically? Like the Harrier jet?

Hornung: The short answer to this is yes. But you can't cheat physics. You still have to generate the thrust for vertical take-off, which produces a high level of local noise and also consumes significantly more kerosene than conventional takeoffs and landings. A vertical takeoff would have to be able to hold its own against present-day solutions in terms of both eco-friendliness and economic viability. For this reason, no one considers it feasible for the mass market.

Some of the concepts you are elaborating at Bauhaus Luftfahrt will never see the light of day—or at least not as originally intended. I can imagine this can lead you to question the point of it all.

Hornung: This is indeed a subject that comes up regularly. Our ambition is not to say this or that will or must be the next

"We want to explore new technologies and understand where their potential lies for air travel. In this way, we create awareness for them and offer food for thought—outside a company's normal development environment."

product. We want to explore new technologies and understand where their potential lies for air travel. We then communicate these findings. In this way, we create awareness for them and offer food for thought—outside a company's normal development environment. Our job is to show that there are still a lot of issues in aviation that are as yet unresolved. But also that there are possible solutions out there.

Wouldn't it be better for the companies concerned to find these solutions themselves?

Hornung: Testing out ideas within the company context is extremely difficult. As soon as you investigate a new technology and communicate it to the outside world, everyone jumps to the conclusion this is going to be that company's next product. It's actually a feasibility study, which doesn't necessarily have anything to do with a product. You have to make a clear distinction. Something else we find time and again is that it is much easier for independent and autonomous research institutions to enter into dialog with sectors from which technologies could be adopted or modified. This is because such institutions don't have a vested interest the way corporate entities do.

Devising innovative problem-solving approaches requires you to examine the issues from many different angles. Does this mean that Bauhaus Luftfahrt has to draw on a whole variety of experts?

Hornung: This is precisely what we do. We work with a really colorful mix of experts: social scientists, ethnologists, economists, geographers, engineers from various disciplines, physicists, analytical chemists. They all contribute their scientific expertise and their own perspective. This, incidentally, might initially have nothing to do with aviation. What they all have in common, however, is their ability to work scientifically, understand technologies, approaches, and theories in their own area of expertise, and transfer these into another context.

"I have to admit I'm constantly leaping back and forth between these two worlds. It's one thing to have an idea—in a spontaneous creative process. It's quite another to examine its plausibility and its potential; in other words to decide what you can actually do with it. That's hard scientific work."

Professor Mirko Hornung,
Executive Director Research and Technology, Bauhaus Luftfahrt e.V.

What does that mean exactly?

Hornung: The team analyzes social trends, socio-economic constraints, and scientific publications on new technologies. It then tries to understand and evaluate them, and examine what ramifications they may have on air transportation. For instance, what possibilities does a given technology with such and such core characteristics offer you? Is there a problem area in aviation where it could be meaningfully used to create value, provided it meets certain criteria?

So, on the one hand you have to think freely and creatively and recognize technological approaches and conceivable applications at an early stage. At the same time, you have to analyze what possibilities the current state of the art offers with a high degree of scientific accuracy ...

Hornung: ... and that's precisely the challenge. I have to admit I'm constantly leaping back and forth between these two worlds. It's one thing to have an idea—in a spontaneous creative process. It's quite another to examine its plausibility and its potential; in other words to decide what you can actually do with it. That's hard scientific work. It's extremely challenging—but also very exciting.

Can you give us a current example?

Hornung: Energy recovery in engines using thermoelectric elements. We became aware of this technology some years ago and took a closer look. It was interesting, but very low efficiency ratios rendered it practically useless for applications in aircraft. However, our analysis did show that if such thermoelectric generators, which are capable of producing electricity from waste heat, were ever able to achieve higher efficiency coefficients, then things could get exciting. And this is exactly what has happened over the past few years. A recent study conducted as part of the German aviation research program has revealed that this method of energy recovery could in fact make a contribution today. You simply have to get over the "it'll never work" mentality.

Bauhaus Luftfahrt
Neue Wege.

Bauhaus Luftfahrt e. V. ——— Founded in 2005 and headquartered in Taufkirchen near Munich, the non-profit association defines itself as an interdisciplinary think tank for the future of mobility and air travel. The association's team of around 50 natural scientists, humanists, and social scientists elaborates comprehensive future scenarios and models for the European aviation industry. In this, it cooperates closely with industry and science—albeit independently and in the public interest. Bauhaus Luftfahrt is sponsored by the Bavarian Ministry for Economic Affairs and the Media, Energy and Technology, as well as by the Airbus Group, IABG, Liebherr Aerospace and MTU Aero Engines.

Everyone said the Geared Turbofan™ engine would never work either. Too complex, too expensive. It'll never be tenable; it'll never be approved. Now we can see that it does work: it's flying. So the barrier can be overcome.

In your example, developing those technologies until they were usable happened over a longer period of time. Isn't it possible that one day aircraft might, after all, look very different than they do today?

Hornung: As I said, if a technology emerges that justifies a change, then yes. Electric or hybrid propulsion systems could bring about a dramatic change in an aircraft's layout. But until then we still have to overcome considerable technological hurdles. Perhaps there are other technologies that we don't even know about at the moment. But I can promise you one thing—we're keeping our eyes peeled.

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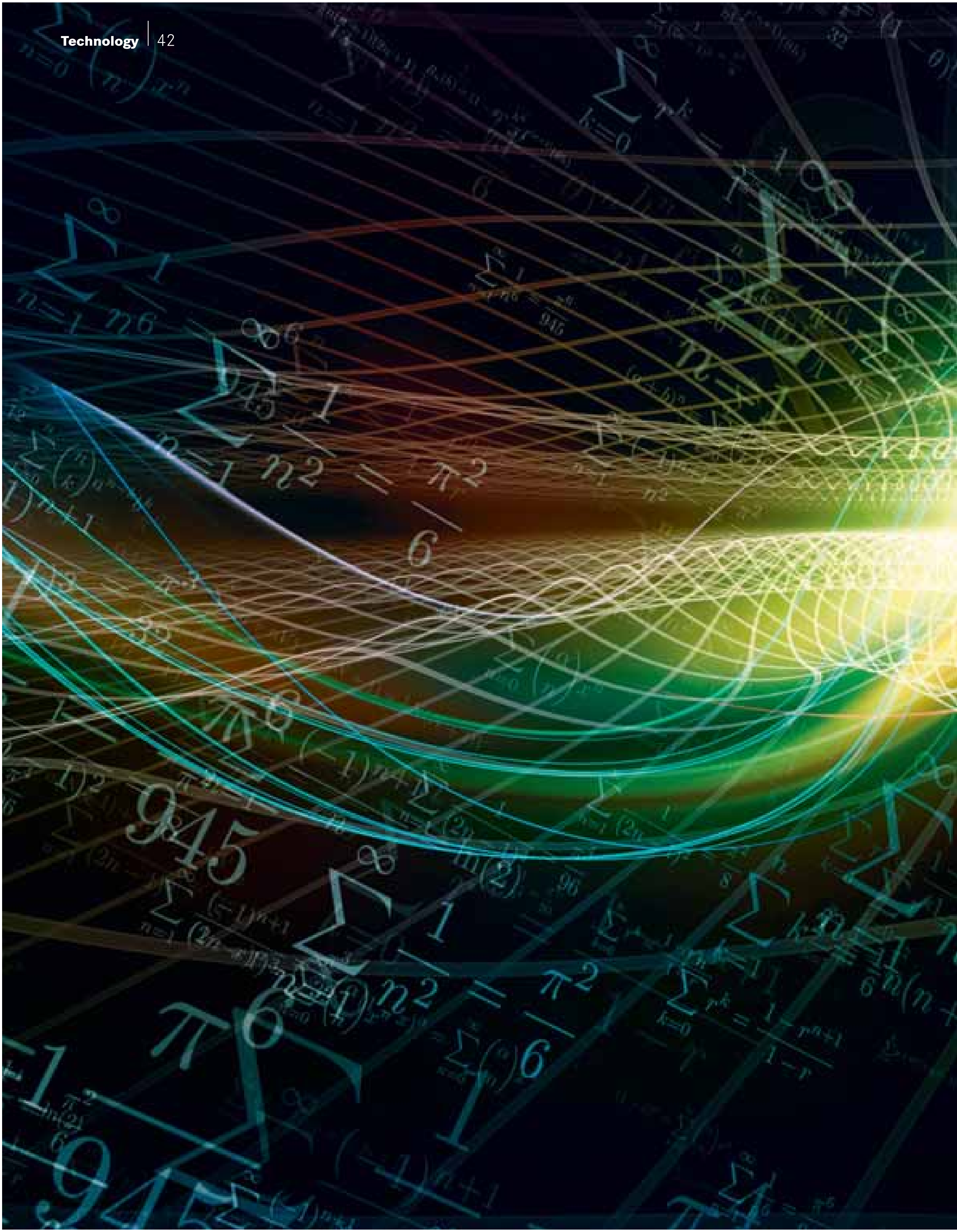
More on this topic: **www.aeroreport.de**

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



Replacing trial and error with a mouse click

Simulation techniques are transforming development and production—including in the aviation industry. Virtual manufacturing makes processes faster, more efficient and more cost effective.

Text: *Monika Weiner*

Every nick costs money. If an engine is to operate at maximum capacity, the surfaces of the turbine components must be smooth as glass. When you consider that compressed air is flowing over the surface at speeds of up to several hundred kilometers per hour, even the tiniest imperfections cause disruptive turbulence. Manufacturing blade-integrated disks, or blisks for short, also calls for ultimate precision. Cutting out a component with such a complex geometry from sheets of titanium a meter across is a real challenge. “Even the smallest of vibrations in the cutting head leave tiny scores in the surface, which can be remedied only with time-consuming post-processing. In the worst case, the whole blisk is unusable and you’re left with scrap that cost the same as a small car,” says Thomas Dautl, head of the manufacturing technologies department at MTU Aero Engines.

The chatter marks left by the cutting machine are a problem he has been grappling with for years. “Some blisks were affected, others not—and nobody knew exactly why.” It took the simulation experts to get to the bottom of the puzzle. With the help of computer models, they discovered that the rotation of the cutting head can trigger resonances in the titanium sheet. Tiny differences in the geometry and composition of the sheet are all that decides whether it begins to vibrate and divert the cutting head from its programmed course. The simulations were also able to uncover how to prevent the unwanted vibration, for instance by fitting damping elements or altering the processing speed. Production implemented the recommendations and suddenly the problem of chatter marks was eliminated.

Key technology for the aviation industry

Computer programs instead of trial and error. The routine applications of simulation technology in the aviation industry are numerous: Optimizing aircraft aerodynamics; cutting fuel consumption; reducing noise pollution; increasing safety; and making material selection and production processes more efficient. “Numerical simulation is a key technology for the aviation industry. Simulations are irreplaceable in developing engines and aircraft, optimizing them and getting them to market quicker,” says Dr. Edmund Kügeler, head of the numerical methods department at the German Aerospace Center’s (DLR) Institute of Propulsion Technology. “The advantage of simulations over a conventional test bench is that they are cost effective: You can sit at your computer and run through designs and parameters without having to build costly test objects or conduct expensive experiments. Simulation and optimization technology provides an automated way to find the best solutions from your computer.”

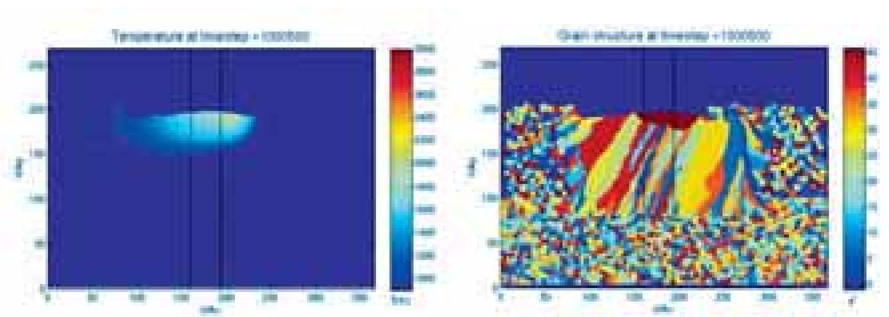
MTU has made use of software tools for years to solve problems with vibrations. Traditionally, though, simulations have only been capable of looking at an individual manufacturing step. “There are specific tools for the various tasks, all varying in their level of detail and mostly incompatible with one another,” notes Thomas Göhler, a specialist in computer-aided analysis in materials development at MTU. “Since it’s almost impossible to link between the individual simulation steps, important information is lost: For instance, the material properties of a titanium sheet are important not only for controlling the cutting head but for the blisk’s performance, too.”

“There’s no doubt in my mind that simulation technology has a lot more to offer than we have utilized to date,” agrees Dr. Andreas Fischersworring-Bunk, head of materials and damage modeling. “We could boost the efficiency of engine building enormously if only we could find a way to model and optimize the entire manufacturing process from materials development through to final testing.” In pursuit of this goal, he is working together with an interdisciplinary team on a new, cross-system approach.

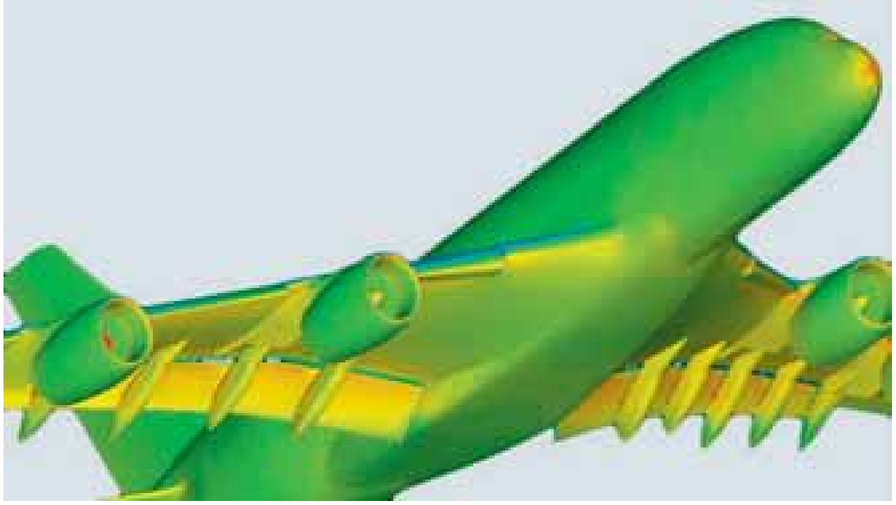
Linking together the results from individual simulations

The answer may lie in a new approach going by the name of ICM²E, short for

ADDITIVE MANUFACTURING SIMULATION



Comprehensive testing ______ *The simulation of the additive manufacturing process enables the homogeneity of the metallic ingredients to be tested.*



Numerical simulation
Simulation of the pressure acting on a passenger airliner during the landing approach.

> *"Numerical simulation is a key technology for the aviation industry. Simulations are irreplaceable in developing engines and aircraft, optimizing them and getting them to market quicker."*

Dr. Edmund Kügeler,
Head of the Numerical Methods department at the German Aerospace Center's (DLR) Institute of Propulsion Technology

Integrated Computational Materials and Manufacturing Engineering. Researchers around the world are using this still new method to optimize materials development and manufacturing by linking together the results from individual simulations. Their goal is to coordinate all the parameters from materials development through the entire production process so as to obtain a finished part that has exactly the desired properties.

In order to adapt the ICM²E concept to the requirements of MTU as an engine manufacturer, Thomas Göhler and his team had some pioneering ground to cover. The fruits of their labor can be seen on the screen in the materials specialist's office, where a virtual laser beam is racing over virtual metal powder. Tiny blue granules melt and fuse together, punctuated by the odd red spot—tiny inhomogeneities just micrometers in size. A component takes shape layer by layer. Too slow? Göhler clicks with his mouse and the speed doubles. Now, though, you can see bigger red spots, inclusions where the powder has not fused properly. Thanks to a new simulation tool developed by Göhler's team in collaboration with researchers from the Fraunhofer Institute for Mechanics of Materials IWM, it is now possible for the first time to see the impact of laser energy and speed on a material's properties. Doctoral student Tobias Maiwald-Immer then takes the granule size and error rate determined in the course of the simulation and exports it into the next piece of software, which visualizes the material's structure. Now you can see how the crystals grow: "By combining the various

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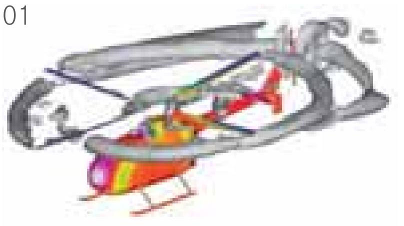

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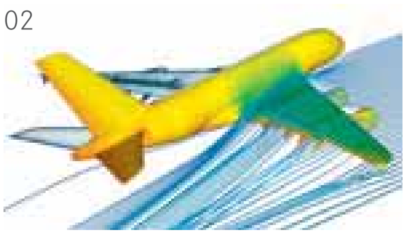

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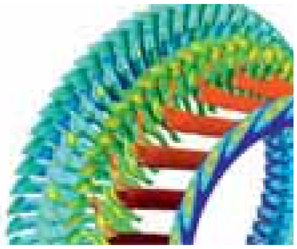

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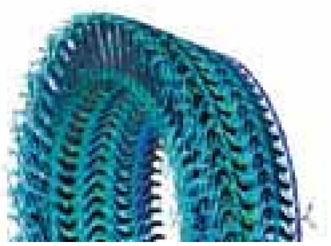

01 ____ *Computer simulation of vortexes generated by helicopter rotor blades.*
02 ____ *Numerical simulation of aerodynamic flows acting on an Airbus A380.*
03 ____ *Simulation of the temperature distribution in a two-stage low-pressure turbine.*
04 ____ *Simulation of turbulence effects on a two-stage low-pressure turbine.*

simulation tools, we can demonstrate for the first time how manufacturing parameters during laser sintering impact a material's strength and elasticity," says Göhler.

Machine setup based on the computer model

The component we saw taking form on Göhler's screen actually does exist; MTU already series manufactures the borescope boss using selective laser sintering. The optimum machine settings came from the computer model. "A comparison with physically manufactured materials indicates that the simulation predictions correlate with the actual results obtained during laser sintering," says Fischersworring-Bunk.

It is just as much a success for project partner Dr. Dirk Helm, who heads the Manufacturing Processes business unit at Fraunhofer IWM. "In this project we have laid the groundwork for the industrial application of ICM^2E and demonstrated what the approach can achieve. The simulation makes it very clear how small changes in the process chain affect material properties. This means we can accurately deduce the manufacturing parameters required to produce a component of extremely specific properties."

Now the engineers at MTU want to simulate how the individual manufacturing steps affect the quality of the final blisk. "It's a particular challenge since we get the raw materials from external suppliers, who have to be included in the process," says Fischersworring-Bunk. "Only they can provide the raw data we need to optimize the various processing steps and achieve the performance we require."

Simulation-assisted product and manufacturing development

That's not the end of it: integrated simulations can also be used to calculate how long it takes to manufacture a component, where there are savings to be made and how to run machines at optimum capacity. "Our goal is a simulation-assisted process of product development that covers everything—from microscopic material properties through all the stages of manufacture and all the way to the finished engine," says Dautl. A Herculean task when you consider that that means factoring in 1,000 components.

Trends in simulation development

	Physically based predictions	Confidence in evaluation	Simulation automation	Computing efficiency	Multi-discipline analysis and optimization
Goal	Model real interactions rather than simplified correlations.	Increasing substitution of experiments with simulations.	Accelerate and simplify work processes, multi-user functionality.	Run computing operations simultaneously, efficient handling of increasing quantities of data.	Virtual linking of all specialist disciplines required to develop and manufacture engine components.
Method	Factor in materials' composition, production process, microstructure, interior defects, mechanical properties, workability and performance in operation.	Systematic comparison of results from simulations and experiments.	Link simulations that build on each other, automatic evaluations.	Further development of hardware and software for faster, simultaneous computation in high-performance computer centers.	Virtual linking of all specialist disciplines required to develop and manufacture engine components.

Simulation in the aviation and its applications

	Aircraft	Structural mechanics	Engine technology
Goal	Cost savings in the development process. Improved airflow for fuselage and wings; reduce air resistance; prevent turbulence.	Cost savings in the development and testing of new materials; modeling of composite materials' capacity.	Cost savings in the development process. Improved material properties; high-performance, quiet and extremely efficient engines.
Applications	Aerodynamic simulations help to optimize the aircraft's shape and so minimize air resistance and fuel consumption.	Simulations allow researchers to calculate the form and stability of new, weight-saving composite materials.	Simulations allow for the optimization of both individual components and complex systems; by selecting the right materials and manufacturing processes, it is possible to guarantee the required component performance and service life.

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

More on this topic: **www.aeroreport.de**

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

Flexible and stable

Because every order is different, aero engine maintenance makes great demands of the shop production system. Read on to learn more about modern production control at MTU Maintenance from the perspective of a trainee.

Text: *Nicole Geffert*

No two engines are alike. They all differ with respect to their type, age and the conditions under which they have operated. Accordingly, there's no one-size-fits-all solution when it comes to maintenance. The extent of disassembly and repair is always different—as are customer requirements. And all the while, maintenance operations demand rapid turnaround times and punctual delivery.

"What this means is that our production system must be both flexible and stable," says Oliver Weller. Weller is an industrial engineer with a specialty in production management and is a trainee in production planning and management at MTU Maintenance. During his studies, Weller analyzed production systems in the automotive industry. "The processes involved in engine maintenance are more complex," he says, "the reason being that the workscope agreed with the customer is different for each engine."

Is it a complete engine, modules or individual components to be repaired? Is the engine coming in for a regular shop check-up or was it damaged in an unforeseen incident? Before disassembly has even begun, the engine is examined for hidden damage using borescoping. "If our specialists discover anything out of the ordinary, our customer managers can quickly get in touch with the customer and adapt the workscope as necessary," says Weller. "That allows us to better plan and manage the shop visit."

Then there's the question of capacity: How many employees with what qualifications are needed for this engine type? What tools are needed? What materials and replacement parts? Do individual components need to be sent to external suppliers for repair? "Our biggest challenge is keeping capacity in the shop consistently high so as to guarantee a stable process," says Weller.

All operations and processes are clearly defined. The MTU locations in Hannover and Ludwigsfelde have introduced a production and management system that combines the specific requirements of each individual engine with coordinated, assembly line workflows in the shop and in the supply chain. "It's what customers expect. Ultimately the goal is to get the engine back on wing as quickly as possible so that the aircraft can return to operation."

Nevertheless, there are situations that call for flexibility. Weller recalls an example: "The workscope in this assignment was to partially disassemble the high-pressure compressor. However, during the inspection our experts uncovered further damage to the component. The workscope was extended in consultation with the customer and we had to react to that in production management."

Inside MTU ___ *JET–MTU's trainee program*

JET is a junior position and trainee program that MTU offers at all its locations in Germany. It is aimed at graduates and young professionals with an outstanding track record. Trainee positions are advertised for specific areas, meaning that applicants know from the very beginning where they will be placed after they complete the 18-month program. Trainees benefit from an individual training program that includes placements at the interfaces where they will work in the future, and receive expert, methodical and personal training. Accompanying JET qualification sessions offer trainees the chance to build their network and share experience.

The process is managed and monitored using integrated IT management systems that coordinate all measures and monitor progress. All deadlines and milestones are planned out from the moment the engine arrives at the shop. Another key to success is the ongoing consultation among all the departments involved. “Right at the start of my traineeship I got an insight into just how complex the processes are when there are more than 30 interfaces, all of which I had to get to know,” recalls Weller.

Every detail counts. “To be able to plan and manage in the most effective way possible, we need to know the manufacturing processes as well,” explains Weller. “That way it's easier to spot where in the process things could get tight.” He also gained insights and mastered new tasks in disassembly and work planning. “That really honed my sense for what events incur what costs—for instance defective goods in production or when a component is processed for a second time.”

In each assignment, Weller worked independently on his own project. At MTU Maintenance Zhuhai in China, he was tasked with optimizing a process to ensure that parts sent to external suppliers for processing return on time for assembly. “The emphasis was on internal production processes,” he says. Together with a team of ten others, he found the solution: Critical components were identified so that they could be positioned earlier in the report and processed as a priority. “I was impressed with how results-driven the team was and by how receptive everyone was to the new project,” he says looking back.

Weller is now back in Hanover. His traineeship comes to an end in late summer 2016, when he will begin work in production planning and management. “Besides my fascination with the high-tech product that is an engine, that was one of the key reasons for starting as an MTU trainee. I knew where I was going to end up.”

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

More on this topic: **www.aeroreport.de**

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

Boeing and MTU

Milestones for two successful companies

Boeing is celebrating its 100th anniversary this year. Almost from the beginning, Boeing and MTU Aero Engines with its predecessors have left an indelible mark on the history of aviation. Some of the milestones in their shared history are listed below.

BOEING

Scheduled maiden flight of the Boeing 777X. — **2020**

Boeing 787 Dreamliner enters service with All Nippon Airways. — **2011**

First flight of the Boeing 787 Dreamliner. — **2009**

Maiden flight of the B777. — **1994**

Maiden flight of the Boeing C-17 Globemaster. — **1993**

Maiden flight of the Boeing 757. — **1982**

As the European launch customer, Lufthansa takes delivery of its first 747 jumbo jet. Two years later it is the first airline to place the cargo version of the 747 into service. — **1970**

Maiden flight of the B747. — **1969**

Model 80 with Hornet radial engines from Pratt & Whitney is Boeing's first aircraft that is designed especially for passenger service. — **1928**

William Boeing founds the Pacific Aero Products Company, based in Washington State. One year later its name is changed to Boeing Airplane Company. — **1916**

MTU Aero Engines

2020 — *Since 2014, MTU has been participating in the development of the GE9X, which will carry the new Boeing 777X aloft as of 2020.*

2012 — *Cargolux is the first airline to fly a B747-8F with MTU TCFs.*

2008 — *MTU takes on responsibility for the turbine center frame (TCF) of the best-selling GEnx for B787 and B747-8.*

1995 — *MTU joins the development program for the PW4098, designed to power the Boeing 777-200 and -300. The world's most powerful commercial engine at that time develops a takeoff thrust of 436kN.*

1979 — *MTU becomes an OEM partner in the development and production program for the PW2000, which has both commercial (Boeing 757) and military (Boeing C-17 Globemaster) applications.*

1971 — *MTU is selected to manufacture components of the CF6-50 engine for the Boeing 747.*

1969 — *MTU (Motoren- und Turbinen-Union GmbH) is created through the merger of the aircraft and diesel engine operations of Daimler-Benz and MAN.*

1934 — *BMW AG hives off its aircraft engine activities.*

1928 — *BMW-Flugmotoren GmbH obtains a license from Pratt & Whitney for the manufacture of the Hornet radial engine.*

1916 — *BMW is created from the company formed in 1913 as Rapp Motorenwerke GmbH.*

MTU patents

Additive manufacturing

Additive manufacturing—or 3D printing—speeds up the process of manufacturing components with highly complex geometries. It is an indispensable tool in the industrial production environment. MTU Aero Engines is continually developing enhancements to these production methods, and counts among the top 10 patent applicants in this domain.

FILINGS BY ORIGIN

80 percent
4 countries

China, Germany, Japan and the US account for roughly 80 percent of all 3D printing patent filings

NUMBER OF PATENTS

104 patents

Number 7 among the top 10 worldwide

TOP 10 PATENT OWNERS IN 3D PRINTING SINCE 1995

01	*3D Systems*	*US*	*200*
02	*Stratasys*	*US*	*164*
03	*Siemens*	*DE*	*145*
04	*General Electric*	*US*	*131*
05	*Mitsubishi*	*JP*	*127*
06	*Hitachi*	*JP*	*117*
07	*MTU Aero Engines*	*DE*	*104*
08	*Toshiba*	*JP*	*103*
09	*EOS*	*DE*	*102*
10	*United Technologies*	*US*	*101*

Source: World Intellectual Property Report (WIPO) based on PATSTAT statistics, April 2015

Stronger market position

MTU Maintenance 2015 in figures

2.1 billion U.S. dollars in orders won by MTU Maintenance in 2015. This increases the order backlog by nearly 25 percent compared with 2014.

45 new customers placed their trust in MTU Maintenance in 2015.

More than 250 new contracts signed in 2015, or an average of more than one per working day.

Over 30 different engine types in MTU Maintenance's portfolio, more than any other MRO provider in the world.

11 percent of the market for maintenance of CFM56 engines is held by MTU Maintenance, making it the biggest independent service provider for this engine.

More than 16,000 shop visits have been logged by MTU Maintenance since the company was founded 35 years ago.

The **AERO**REPORT *brain teaser*

ORIGINAL

FAKE

Find the five deliberate errors in the picture below.

Ten participants who send in the correct solution will soon be the proud owners of an MTU Bluetooth speaker.

Send your answers to this quiz (as scan or clipping) by September 10, 2016 to aeroreport@mtu.de or by post to MTU Aero Engines AG, Editors **AERO**REPORT, 80995 Munich, Germany.

Good luck!

The spot-the-difference picture in this issue of **AERO**REPORT *shows the automated loading of parts to a milling machine used to manufacture PW1000G blisks in MTU's blisk production center in Munich.*

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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 Hebting

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

Editorial staff
Denis Dilba, Anja Dörr,
Eleonore Fähling, Achim Figgen,
Nicole Geffert, Silke Hansen,
Andreas Spaeth, Thorsten Rienth,
Monika Weiner

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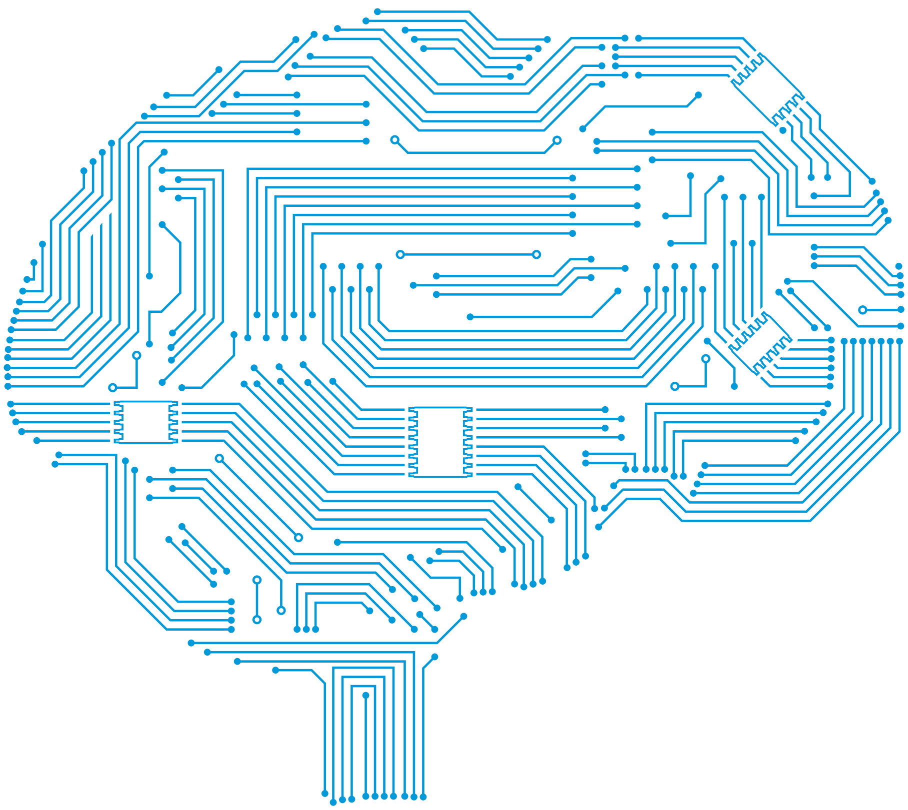

AEROREPORT
MTU Aero Engines AG, Dachauer Straße 665, 80995 Munich, Germany
aeroreport@mtu.de, www.aeroreport.de