

AEROREPORT 02|15

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



Room for growth

Widebodies make aviation profitable

PARTNERS

Research summit
*Scientific mission
in Iceland*

EXPERTISE

Material development
in aviation engineering
Interview with Prof. Körner

TECHNOLOGY

How much precision
is enough?
Non-destructive testing



Cost-effective flying — *Modern widebody aircraft,
here: Airbus A330, Airbus A350 XWB, Airbus A380.*

Dear readers,

The aviation industry will continue to grow in the coming years and decades. Experts around the world expect that, in 2034, airlines will be transporting more than seven billion passengers—that's double today's volume. Given the current state of the art and how fleets are structured, that would mean doubling the amount of kerosene as well as injecting twice as much CO₂ and nitrogen oxide into the atmosphere. Above all, it means much more air traffic at the hubs and urban centers that are the destinations for these airline passengers. This is where I see one of the key challenges for the aviation industry. How do we achieve growth, in terms of both traffic and business, while not harming the environment any more than we do today?

According to calculations by the German Aviation Association (BDL), fuel consumption of a commercial aircraft averages just about four liters per hundred passenger kilometers. This is little more than that of a high-speed train. Fuel consumption of today's widebody jets on long-haul routes is even lower. And technology continues to advance, with lighter materials and improved aerodynamics and engines reducing fuel consumption and emissions. What's more, airlines are more careful than ever to ensure that they are using their fleets to best advantage by assigning the optimum-sized aircraft to each route. On long-haul routes, widebodies have proven themselves particularly economical.

Widebody aircraft and their engines are our focus topics in this issue of **AEROREPORT**. Our cover story offers an exciting look at their history. When it comes to the cargo versions, some are so large you could play soccer in them. On their 2016 world tour, rock band Iron Maiden will transport all their crew and equipment in a B747—flown by singer Bruce Dickinson and leased from MTU customer Air Atlanta Icelandic.

In an interview with Professor Carolin Körner, Chair of Metals Science and Technology at the University of Erlangen-Nürnberg, we examine the possibilities offered by advances in materials. Producing highly complex structures made of new materials is made possible in part by additive manufacturing, a technique used by MTU's partner EOS. Both companies are working together to further refine this process.

I wish you pleasant reading on a journey of discovery through the world of aviation.



Yours,

A handwritten signature in blue ink that reads "Reiner Winkler". The signature is fluid and cursive, with the first name and last name clearly distinguishable.

Reiner Winkler

Chief Executive Officer



COVER STORY

Room for growth

As passenger volumes and the number of long-haul flights increase, economical flying becomes ever more important. Widebodies provide the necessary efficiency.

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MARKET

The workhorses of the skies

IATA forecasts the air cargo market to grow 4.1 percent annually up to 2018. Widebody aircraft are the preferred method of transport when it comes to ensuring that cargo reaches its destination quickly and securely.

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PARTNERS

Research summit

Rare aircraft are on a scientific mission in Iceland. Equipped with state-of-the-art technology, they are carrying out research missions for various academic disciplines.

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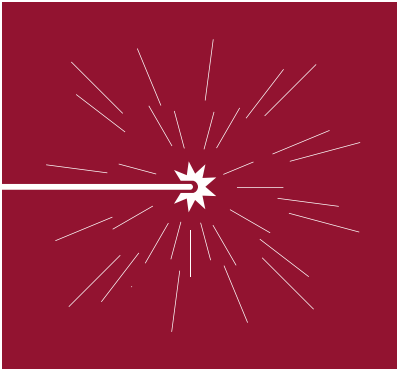
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**PARTNERS**

Layer by layer

New production processes lead the way forward. For six years, MTU Aero Engines's partnership with EOS GmbH has proved one of its most successful cooperative ventures.

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**EXPERTISE**

Material development in aviation engineering

New materials are the key technology in developing future aircraft and engines. Yet there is still plenty of untapped potential, says Prof. Carolin Körner, Chair of Metals Science and Technology at the University of Erlangen-Nürnberg, in an **AEROREPORT** interview.

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**TECHNOLOGY**

Right in the middle of it all

High temperatures, enormous pressures, high speeds: the conditions in an aircraft engine are incredibly tough. The turbine center frame has to be able to withstand the strain.

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TECHNOLOGY

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

MRJ takes off



With the maiden flight of the **Mitsubishi Regional Jet (MRJ)** in November, a new Japanese passenger jet has taken to the skies for the first time in half a century. This moment has been a long

time coming for the Japanese aviation industry—the last aircraft developed and manufactured in house for commercial flights was the YS-11 twin-engine propeller aircraft, which went into service on August 30, 1962. With the MRJ, the Japanese plan to break into the market for mid-sized regional jets starting in 2017. The manufacturer, Mitsubishi Aircraft Corporation, developed two variants: the MRJ90 with space for 90 passengers, and the somewhat smaller MRJ70, for around 70 guests. Both will be powered by Pratt & Whitney's PW1200G from the PurePower® engine family. MTU Aero Engines, which carries a 15 percent share in this program, developed and manufactured the entire high-speed low-pressure turbine, the forward stages of the high-pressure compressor and three brush seals.

7,000th shop visit at the Hannover site

MTU Maintenance Hannover has achieved another milestone in its 35-year history by repairing its 7,000th aircraft engine. The milestone engine happened to be the GE90, the world's largest engine, which powers the Boeing 777 family. Weighing in at eight tons, it has a fan diameter of over three meters and maximum thrust of 115,000 pounds. The engine was sent in for repairs by AeroLogic,



a cargo airline that has been collaborating with MTU Maintenance since 2012. "Repairing engines of this class requires specially trained and qualified personnel," says Ulf Weber, Managing Director at AeroLogic. As one of Germany's top employers, MTU Maintenance Hannover is celebrating not only its 7,000th shop visit, but also 25 years of vocational training in Hannover.

Air Canada with new fleet of Dreamliners

By the end of 2019, a total of 37 Dreamliners will replace older models in the **Air Canada** fleet. The new jets will also add capacity for expanding intercontinental connections. While Canada's largest airline has been using the 787-8 for over a year already, it took delivery of the first Boeing 787-9 of the lengthened Dreamliner version in August. The first two destinations for the lengthened "9", which is around six meters longer and has seating for another 298 passengers, have already been determined: Delhi and Dubai. Until the opening of those new routes in early November, Air Canada has been utilizing the new and—thanks to the two GENx engines—highly efficient jets between Toronto and



Vancouver. In September and October, the lengthened Dreamliners were also under way between Toronto, Munich and Milan.

Clean Sky demonstrator ready to go



All requirements satisfied, all preparations complete. As of mid-October, the **Clean Sky demonstrator** at MTU Aero Engines in Munich is “target to fire”: testing can begin. Launched in 2008 as part of the Clean Sky European technology program, the project is now entering its final phase. The goal is to use the demonstrator, based on the CSeries PurePower® PW1500G engine, to develop new engine technologies. These in turn are to make next-genera-

tion aircraft even more eco-efficient. MTU’s demonstrator, called “SAGE 4”—Sustainable And Green Engines—is one of five engine demonstrators in the SAGE consortium. It has been designed to showcase the maturity of new technologies for high-pressure compressors and low-pressure turbines, MTU’s flagship components. These technologies include lighter, more temperature-resistant materials and new design solutions for blades and housings, which could be used in the next generation of Geared Turbofans™.

PW1900G flight testing started

Flight testing of the engine that will power **Embraer’s E190-E2** has started: In November the Geared Turbofan™ engine which is based on the PW1500G for the Bombardier CSeries flew on Pratt & Whitney’s 747SP flying testbed at the company’s Mirabel Flight Test Center near Quebec in Canada. The PW1900G is the fourth of a total of six PW1000G engine variants to be airborne. The engine family in which MTU Aero Engines holds

stakes between 15 and 18 percent has so far completed more than 23,000 hours of testing. PW1900G ground testing has been running on Pratt & Whitney’s East Hartford/CT test stand since July. The aircraft manufacturer in Brazil, meanwhile, is testing the engine software in an “Iron Bird”. Entry into service is scheduled for 2018.

GE38 completes maiden flight



Successful first flight of the new heavy-lift transport helicopter **CH-53K**: On October 27, the helicopter took to the skies for the first time from its manufacturer Sikorsky’s proving ground in West Palm Beach, Florida. The premiere was not only an important milestone in the qualification of the whole system but also a key moment for its engine, the GE38, developed by GE Aviation together with MTU Aero Engines. With a share of 18 percent in the program and responsibility for the engine’s power turbine, this is the first time that MTU has had full responsibility for an entire assembly on a U.S. military engine program.

The half-hour flight marked the start of a 2,000-hour flight testing program. MTU was also closely involved in the earlier engine test program. “Around a third of the tests were conducted at MTU and were deemed valid and successful,” explains Dr. Robert Bader, head of GE38 development. They included turbine stress tests on the rotating system, using technology developed by MTU in house, and special testing such as water and hailstone ingestion tests and bird strike tests. “GE certified our data quality as excellent,” Bader reports. Having already delivered the first two modules for the system demonstration and test articles (SDTA) program last year, MTU is planning more deliveries in 2015 and 2016. “We are well prepared and highly motivated to continue to work together with GE to make this program a success” said Claudia Gaab, MTU’s Program Manager for the GE38.

“King Stallion” is the reverential name that the U.S. Marine Corps has given its new CH-53K heavy-lift transport helicopter. In 2019, it is set to replace the CH-53E “Super Stallion” currently in service. Compared to its predecessor, the new helicopter will nearly triple the payload to 27,000 pounds (13.5 tons).





Room for growth

From the first jumbo jet to today's twin-aisle: widebodies make aviation profitable.

Text: Achim Figgen

Birth of the jumbo

“If you build it, I’ll buy it.”—“If you buy it, we’ll build it.” This brief exchange between Pan Am founder Juan Trippe and Boeing chief Bill Allen transpired in the mid-1960s, just at the start of the widebody era. At that time, long-haul routes were served by the Boeing 707 and Douglas DC-8: quad jet aircraft with a fuselage diameter that permitted six seats per row, three on either side of the aisle.

With passenger volume increasing rapidly, it was only a matter of time before this design would become too small. Douglas responded to the airlines’ requests for a larger aircraft by extending the DC-8 into the “Super Sixties” series. Boeing’s 707 sat too low to the ground to pursue this approach, which is why it decided to completely redesign the aircraft. Juan Trippe was only too happy to agree—the charismatic and unconventional head of Pan Am had searched long and hard for a revolutionary solution and had little interest in one that provided only a small increase in passenger capacity.

At this time, it was widely assumed that passenger air transport would soon be dominated by supersonic aircraft, such as the British-French Concorde or Boeing’s planned 2707. This meant that any subsonic aircraft had to be able to double as a freighter.

In redesigning the 707, Boeing based the plans on a military transport concept that lost the contract to Lockheed’s C-5 Galaxy, developed in the mid 1960s. The cockpit was moved “upstairs” to make way for a gigantic nose cargo door for freight, giving the Boeing 747, soon nicknamed “jumbo jet”, its distinctive hump.

The C-5 Galaxy itself also played a key role in the “birth” of widebody passenger jets (sometimes referred to as twin-aisle aircraft). For this aircraft, GE Aviation and Pratt & Whitney designed completely new turbofan engines with a high bypass ratio. These laid the groundwork for the later CF6 and JT9D commercial engines, whose performance made the construction of the jumbo jet and subsequent widebody aircraft possible in the first place.

Jets for high-volume routes

On January 22, 1970, the first scheduled flight of a Pan Am jumbo jet took off from New York for London—one day later than planned. This delay was symptomatic of the difficulties faced by Boeing as it attempted to pioneer the widebody passenger jet. Much more serious than the initial unreliability of the JT9D engines, however, was the oil crisis of the early 1970s and the undeniable fact that, for many routes, the jumbo jet was simply too large.

THE FIVE LARGEST AIR PASSENGER HUBS IN THE WORLD (NUMBER OF PASSENGERS)



Dubai, UAE (DXB)
71,548,061



London, GB (LHR)
68,310,701



Hong Kong, HK (HKG)
64,767,139



Paris, FR (CDG)
58,780,759



Amsterdam, NL (AMS)
55,537,414

International passenger traffic — The figures comprise all passengers boarding and disembarking at the respective airport over the period from April 2014 to April 2015.

THE FIVE LARGEST AIR CARGO HUBS IN THE WORLD (MEASURED IN TONS)



Hong Kong, HK (HKG)
360,000



Incheon, KR (ICN)
212,097



Dubai, UAE (DXB)
204,075



Shanghai, CN (PVG)
202,865

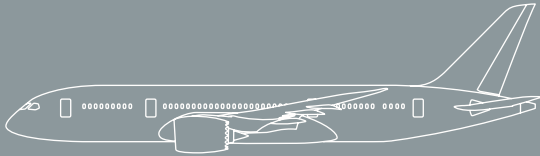


Taipei, TW (TPE)
174,013

International freight traffic — The volumes comprise the total freight and airmail loaded and unloaded at the respective airport in tons during the month of April 2015.

Modern widebody aircraft

Boeing 787-8 Dreamliner _____ *First flight: 2009; length: 56.7 meters; wingspan/width: 60.1 meters*

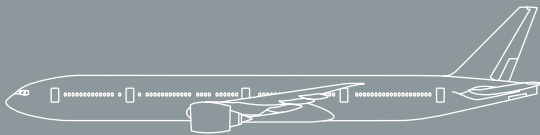


Boeing 787-8 Dreamliner

Twin-aisle widebody

210-250 passengers
approx. 220 tons take-off weight

Boeing 777-300 _____ *First flight: 1997; length: 73.8 meters; wingspan/width: 60.9 meters*



Boeing 777-300

Twin-aisle widebody

370-550 passengers
approx. 300 tons take-off weight

Boeing 747-8 _____ *First flight: 2011; length: 76.3 meters; wingspan/width: 68.5 meters*

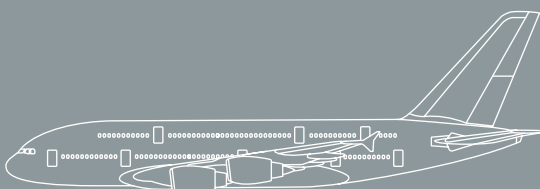


Boeing 747-8

Twin-aisle widebody,
partial double-deck

470-600 passengers
approx. 450 tons take-off weight

Airbus A380 _____ *First flight: 2005; length: 72.7 meters; wingspan/width: 79.8 meters*



Airbus A380

Twin-aisle widebody, double-deck

540-850 passengers
approx. 575 tons take-off weight

WIDEBODY AIRCRAFT AND ENGINES FROM 1960S TO TODAY

Widebody aircraft type:



First flight:



First engine test run:



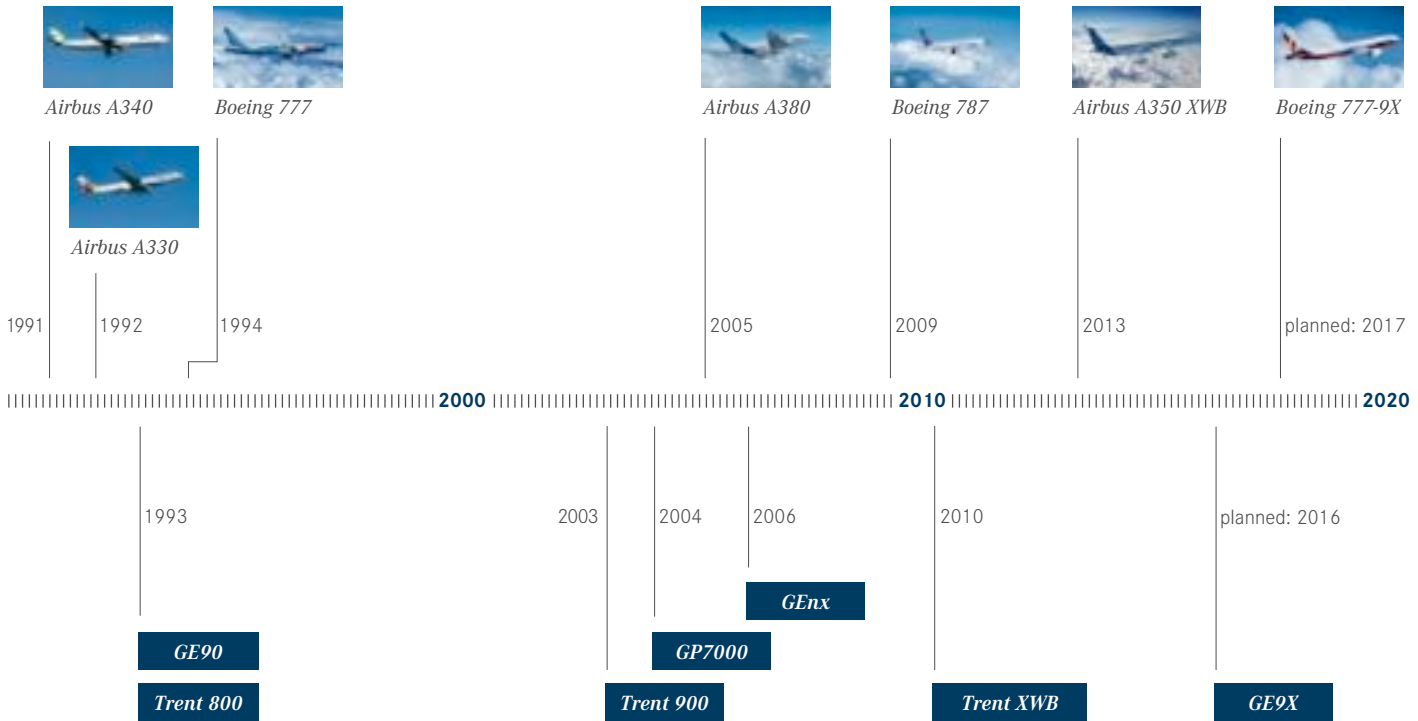
Yet even the somewhat smaller widebody models that competitors launched on the market at virtually the same time also struggled. In the mid-1960s, American Airlines executive Frank Kolk wrote a strategy paper in which he established the requirements for a future widebody jet for high-volume medium-haul routes: a carrying capacity of about 300 passengers and powered by just two engines. However, McDonnell Douglas and Lockheed decided to give their new jets three engines. The DC-10 was put into service on August 5, 1971, followed almost a year later by the L-1011 “TriStar” on April 26, 1972. Both of these were initially used predominantly on U.S. domestic routes, and later branched out into intercontinental travel. As they did so, they increasingly replaced the smaller quad-jet single-aisle model; it was substantially less profitable due to its lower carrying capacity, and its low-bypass engines made it a good deal louder.

Crossing the Atlantic on two engines

Twin-jet aircraft of the sort Kolk envisioned were then indeed built—not by one of the established U.S. manufacturers, but by

a newcomer from the other side of the Atlantic. The A300 was developed within the Airbus consortium led by France and Germany with British and eventually Spanish involvement. It took off on its maiden flight on October 28, 1972 and was in regular service as of May 1974.

Hardly anyone at the time could have guessed what fundamental changes the arrival of this European jet would trigger in the industry. For one thing, Boeing and its peers were confronted with a competitor that conquered half the global market within about four decades and also proved to be a deciding factor in Lockheed’s withdrawal from the commercial market and McDonnell Douglas’s being forced to seek refuge in a merger with Boeing. For another, the A310 (based on the A300) and, to an even greater extent, the Boeing 767, which appeared on the market at roughly the same time, made it possible to fly long-haul routes with twin-jet aircraft. Airlines could now offer nonstop connections outside of the major aviation hubs.



Measured in flight time, the distance that a twin-engine jet is allowed to be from an alternative airport in the case of engine failure increased steadily, thanks primarily to the major boost in the reliability of the modern turbofan engines. The first transatlantic flights were flown with the A310 and B767 in the mid-1980s; today it is possible to receive ETOPS (extended-range twin-engine operational performance standards) certification for five hours and longer, depending on the type of aircraft. This means that even jets equipped with only two engines can fly virtually any route in the world without making a detour.

Bigger and farther

But the engines didn't just get more reliable; they also became more powerful, so that the aircraft size at which two engines were no longer sufficient kept getting bigger and bigger. Twin-jet models were soon able to hold their own when it came to range, as well. In the early 1990s, Airbus put the quad-jet A340, which can theoretically transport up to 440 passengers, on the market beside the A330. The latter was just as large but had only two

engines, and actually sold much better. Another major twin-engine success was Boeing's "Triple Seven," which made its debut in the mid-1990s. In the engines they developed for the aircraft, GE Aviation, Pratt & Whitney, and Rolls-Royce pushed dimensions and performance to hitherto unseen levels.

This trend became particularly evident when new versions of the A340 and Boeing 777 were launched on the market at the start of the millennium. In terms of range and passenger capacity, they were clearly designed as successors to previous 747 models. The twin-engine 777-200LR and -300ER performed as well as or better than the A340-500 and -600, and did so at lower cost. Airbus took this lesson and implemented it in the A350 XWB; since then, models smaller than the A380 are also based solely on a twin-engine design.

Where to next?

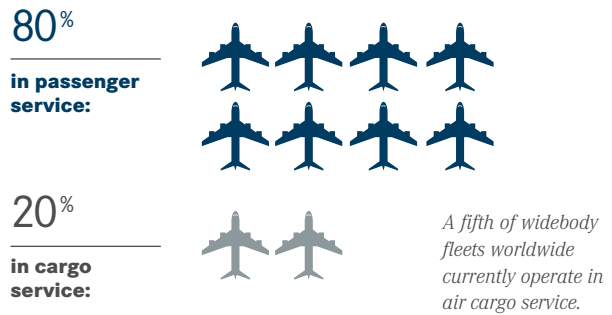
As twin-engine aircraft become ever more efficient—seat kilometer costs of the A350-1000 and Boeing 777-9 models currently

in development are expected to match those of the A380—it raises an important question: Are aircraft like the A380 or the only slightly smaller 747-8, the latest jumbo jet, even necessary? “Sales of widebody aircraft with two decks are not going as well as they were forecast to ten years ago,” states Dr. Marc Le Dilosquer, Director, Market Analysis at MTU Aero Engines. In fact, airlines are currently holding off on new orders, although this may also have to do with changes in the market environment. The rapid growth of Persian Gulf airlines has shifted traffic flows; passengers wishing to travel from Europe to destinations in the Asia-Pacific region no longer automatically fly via Hong Kong, Singapore or Bangkok. They are also no longer limited to Qantas Airways, Singapore Airlines, Thai Airways International or Cathay Pacific, carriers that dominated these routes for decades. But if Airbus equips the A380 with new engines, thus regaining the former operating cost advantage over the smaller twinjets, then the A380’s biggest customer, Emirates, will purchase still more of the world’s largest passenger airliner.

Spacious _____ The view of the upper deck bar (above) and economy class of an A380.





PASSENGER AND FREIGHT SERVICES





Source: Flightglobal Fleet Analysis, 2015

At any rate, John Leahy, Head of Sales at Airbus, remains confident. The number of mega-cities, which Airbus defines as cities that see more than 10,000 passengers a day on long-haul flights, is expected to nearly double over the next 20 years from 47 today to 91. Leahy makes a clear case that this will create demand for aircraft like the A380. But Randy Tinseth, Vice President Marketing at Boeing Commercial Airplanes, counters this with arguments that are just as convincing. In the past ten years, the number of flights to places such as Tokyo’s Haneda and Narita Airports or Seoul’s Incheon International—in other words, airports in precisely such mega-cities—has grown between 26 and 33 percent. At the same time, the number of available seats declined at a double-digit rate. Tinseth concludes that the market is demanding higher frequency rather than larger aircraft.

That the lion’s share of long-haul passenger routes will be handled in the future by twin-jet aircraft might indeed be indisputable. However, it’s still too soon to bid the A380 adieu. Don’t forget that the jumbo jet didn’t become the best seller it is remembered as today until the completely redesigned 747-400 version went on the market—more than 20 years after the first prototype made its maiden flight. 

 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 and he has written several books on aviation subjects.

Inside MTU _____ *Widebody engine expertise at MTU Aero Engines*



Proven technology _____ *a CF6-80C2 at MTU Maintenance.*



Putting a giant through its paces _____ *a GP7000 on a test rig.*

For more than four decades, MTU Aero Engines has actively participated in developing and manufacturing widebody engines, and during that time, its role has only increased in importance. Its story began in the early 1970s with GE Aviation CF6, one of the most successful turbofan engines of all time. Now used in the A330, B747 and MD-11, to name just a few, the engine features MTU parts in its turbine and compressor.

GE competitor Pratt & Whitney is involved in production of the PW4000, one of three engines for the original versions of the Boeing 777. MTU was able to land the contract for developing the low-pressure turbine, which it manufactures to a large extent in house.

For the A380's engine, the GP7200, MTU developed and now manufactures the low-pressure turbine and the turbine center frame. In addition, MTU produces components for the engine's

high-pressure turbine, putting its program share at a proud 22.5 percent (see "Making a good thing even better" on page 22).

MTU develops and builds the turbine center frame for GE's GEnx engine (used in Boeing's 787 and 747-8) and the GE9X, which will power Boeing's new long-haul models 777-8 and 777-9 (see "Right in the middle of it all" on page 40).

But MTU does more than just develop and manufacture widebody engines—these also currently account for about a third of all overhaul work at MTU Maintenance in Hannover. The CF6 is the most important product at the moment and is expected to remain so for some time, according to Norbert Möck, Director GE Programs at MTU Maintenance. The halls in Hannover have also already seen more specimens than planned of the GE90, which was added to the portfolio three years ago.





The workhorses of the skies

Widebody cargo aircraft.

Text: *Silke Hansen*



Widebodies lead the field

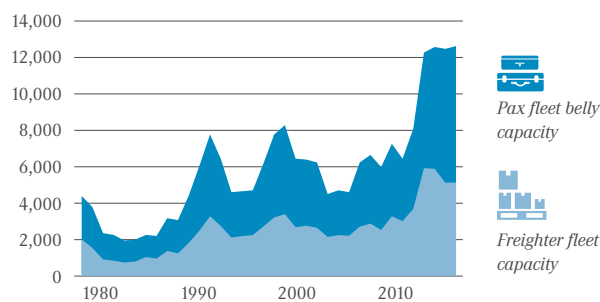
Air cargo does of course boast spectacular deliveries, but the gargantuan special freighters used in these instances—Airbus’s Beluga, the Boeing 747-400 Dreamlifter, and even the world’s biggest aircraft, the Antonov AN-225—in fact play a minor role in day-to-day air cargo operations. The real workhorses of the sky are the widebody cargo aircraft. “These are the aircraft that get the bulk of cargo transportation done, particularly over long distances,” says Lars-Dean Hutt, Senior Powerplant Engineer at Air Atlanta Icelandic, a freight specialist from Iceland (see Inside MTU). Worldwide there are 1,700 cargo aircraft in service, of which 1,100 are widebody aircraft. The fleet is a mix of purpose-built freighters and converted former passenger aircraft. “The proportion of newly purchased widebody freighters is extremely high, since converting aircraft adds significantly to their weight, making them less efficient than purpose-built freighters,” explains Dr. Marc Le Dilosquer, market expert at MTU Aero Engines. Boeing is the undisputed leader in this market. Of the four models currently available, three are built by Boeing—the 777-200ERF, 747-8F, and 767-300ERF—and the fourth is Airbus’s A330-200F.

Fewer stops, faster package transit times, competitive costs

“The advantages of using widebody aircraft for cargo transportation are their range, trip cost, and cargo volume capacity,” says Paul Chase, Chief Operating Officer of U.S. cargo airline Southern Air. With a focus on express deliveries, Southern Air has five 777F aircraft in operation for DHL on a loan basis. “Thanks to the new, fuel-efficient generation of widebody aircraft, we can serve cargo routes with fewer stops, faster package transit times, and competitive costs,” says Chase.

Air cargo’s guiding principle is to maximize weight and volume, since customers pay by the kilogram and cubic meter, not per flight. This is where widebody aircraft clearly lead the field. “You could play football in a jumbo freighter,” says Hutt to put it into perspective.

AIR FREIGHT CAPACITIES (TONS)



200% Increase in air freight capacity since 1980.

Source: International Air Transport Association (IATA)

“The advantages of using widebody aircraft for cargo transportation are their range, trip cost, and cargo volume capacity.”

Paul Chase,

Chief Operating Officer of U.S. cargo airline Southern Air

Many cargo airlines swear by widebody aircraft and have the jumbo jet as a part of their fleet. “The 747 freighter in particular has the unique advantage that the aircraft nose can be opened for loading.” This allows goods of almost any length to be transported.


In contrast, the smaller narrowbody freighters are available only as converted ex-passenger aircraft. “They’re a comparatively cheap option with sufficient range and efficiency,” says Le Dilosquer. Their specialty is airmail, and they are particularly popular in the USA for delivering mail and packages by air.

World trade determines global freight market

Heavily dependent on world trade, the air cargo market remains under pressure. In 2009, the market suffered a massive collapse in the wake of the financial crisis and high oil prices. Market share was lost to transportation by land and by sea. Since 2010, designs for container ships have been getting increasingly massive, which has led to soaring cargo capacity on the global freight market. Still, 2013 saw the beginning of an air cargo recovery, followed by the comeback year of 2014 with 5.8 percent growth. Is it a sustainable trend? The International Air Transport Association (IATA) forecasts growth of 4.1 percent per year up to 2018. IATA’s CEO Tony Tyler says: “After several years in the doldrums, an average of more than 4 percent growth would be a marked improvement. Since 2011, for example, growth in freight tons has averaged just 0.6 percent per year.” But as Tyler also points out, a volatile oil price and competition from sea and rail could also endanger the positive trend: “The air cargo industry certainly cannot afford to be complacent.”

What is striking are the big regional variations. With the globalization of supply chains, Asia has risen to become the biggest market. The most important air cargo routes run from North America to Asia and from Europe to Asia, followed by North America to Europe. Together, these routes account for around 49 percent of all revenue ton kilometers (RTKs). Widebody aircraft dominate the routes. The East-West passageways are also the biggest markets for sea cargo. But new markets are emerging. The Middle East, for instance, is exhibiting growth rates of 15 percent a year. IATA expects that by 2018 the United Arab Emirates will climb to third place in the top ten biggest international air cargo markets, behind only the USA and China.

However, growth does not translate automatically into increased demand for new air freighters, even if Boeing expects to supply 840 new and 1,330 converted air cargo aircraft by 2033. More than 70 percent of them will be big widebody aircraft with over 80 tons of cargo volume capacity. Still, the market has to contend with overcapacity. There is a whole temporarily decommissioned fleet that must be reabsorbed before the next increase in demand for new freighters in line with sustained growth. For the time being, many freighters are left gathering dust. “There are large numbers of 747s parked away, both converted aircraft and factory-built freighters,” says aviation analyst and industry expert Richard Evans. Some could now be brought back into service, he reckons.

Over the last couple of years, there has also been strong growth in “belly cargo,” which sees cargo transported in the holds of passenger aircraft. The Boeing 777 is perfect for this since, unlike the bigger A380, it can transport a great deal of additional cargo alongside a full complement of passenger luggage. Emirates makes great use of this, for instance. It’s a turning point that really stands out, and that is set to become more pronounced with the 777X, according to Le Dilosquer. 

Freight giants _____ *Widebodies’ high loading capacity and range make them suitable for air cargo transport. Atlas Air and Aerologic have 747 and 777 cargo aircraft in operation.*



Inside MTU _____

Flying Iron Maiden



When Iron Maiden set off on their 2016 world tour, frontman Bruce Dickinson will personally be flying the band right around the globe—roadies and staging included. Dickinson, a qualified pilot, will be hiring the jumbo jet for the trip from Air Atlanta Icelandic. The airline is a longstanding MTU customer and an expert when it comes to this sort of wet lease—under which the airline provides the customer with a complete package including aircraft, crew, maintenance, and insurance, with the airplane in the desired paint scheme and the crew in the requested uniform. Air Atlanta Icelandic is Iceland’s biggest airline and transports passengers and cargo on behalf of other airlines. “Wet leasing is very common in the air cargo business,” explains Lars-Dean Hutt, Senior Powerplant Engineer for the airline. The cargo fleet consists of eight Boeing 747-400 aircraft—both purpose-built and converted freighters. Customers include Saudia Cargo and Air Bridge Cargo.

Air Atlanta Icelandic entrusts MTU Maintenance with the upkeep of its CF6-80C2 jumbo engines. The air cargo business demands punctuality and reliability—and it’s no different for the engines. MTU’s portfolio of customers reads like a who’s who of the air cargo industry: Atlas Air, Southern Air, Aerologic, Cargolux, DHL and UPS all send their engines to MTU shops for maintenance. “Air cargo demands just the same high standards of quality and safety as passenger transport,” explains Hutt.



Air vs. sea

Road, rail, sea, or air—almost all of the items in global supply chains can be transported using one of these methods. When it comes to international freight, however, there are often only two viable alternatives: air or sea. In 2013, 9.5 billion tons worldwide were transported by sea, and 42 million tons by air.

24h In September 2014, Boeing 777 and 747 freighters flew the new iPhone 6 fresh from the production line in central China to the USA. Cell phones are an area in which the pace of innovation is extremely rapid, which means that days spent transporting goods by sea makes for a huge **time loss**. While just one percent of the world’s total freight tonnage is transported by air, the value of those goods amounts to 35 percent of the global total. In 2012, the German Federal Statistical Office calculated the average value of a ton of air cargo at 70,669 euros, as compared to an average value of just 1,896 euros for a ton of shipping cargo. Goods transported by air are generally capital intensive—computers, medical technology, machines, and vehicles, for instance. There’s also a need for speed when it comes to aid transport, time-sensitive deliveries, parcels, and replacement parts. Express carriers such as UPS or FedEx owe their existence to the speed of air transport. Likewise, goods that spoil easily—for instance fresh fish—must also be delivered quickly, that is why they end up taking the aerial route. **Advantage: Air.**

17 **Reliability and safety** are further factors that speak in favor of transport by air. Aircraft stick to strict schedules and fulfill the stringent safety requirements of the aviation industry—and both these facts are huge positives when transporting goods that require strict discretion such as diamonds,

Speed	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Reliability and safety	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Capacity	<input type="checkbox"/>	<input checked="" type="checkbox"/>
CO₂ emissions	<input type="checkbox"/>	<input checked="" type="checkbox"/>

gold bars, or Formula 1 race cars. What is more, air freighters offer the ideal conditions to transport temperature-sensitive cargo such as live animals or cut flowers. **Advantage: Air.**

☒☒ When it comes to maritime transport, it is container traffic that has really grown over the past years, with the volume transported growing by an average 7.4 percent per year. A Boeing 777F has a cargo **capacity** of around 100 tons, while the container ship “Gudrun Maersk,” for instance, can carry some 105,000 tons. Combined with lower fuel costs, shipping’s enormous capacity makes sea freight many times cheaper. Transporting a given weight on a container ship costs just ten percent of the equivalent air price. **Advantage: Sea.**

CO₂ Although the higher **fuel consumption** and therefore higher **CO₂ emissions** of aircraft make air cargo less environmentally friendly per journey than transportation by ship, aviation is catching up: according to IATA figures, aviation is responsible for some 2 percent of worldwide CO₂ emissions, while shipping accounts for around 4 percent. Moreover, the energy efficiency of aviation has been increasing continuously for years. This also applies to air cargo—thanks to more modern fleets and more efficient use of cargo space. For example, the freight-only 777F emits 16 percent less CO₂ compared to a 747-400F. **Advantage: Sea (still) wins out per cargo journey.**

In June this year, DHL opened a new rail freight route between Hamburg and Zhengzhou in China. The goods train takes 17 days to make the journey—faster than by sea and cheaper than by air. Clearly, there is competition ahead for air and sea freight alike.

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

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

Unique advantage — 747-400 freighters such as this one operated by Polar Air Cargo can be loaded through the nose of the aircraft.



Making a good thing even better

The GP7000 engine—one of two variants for the A380—got its certification almost ten years ago.

Text: Achim Figgen

Every now and then, aviation history allows itself to take an ironic turn. Take the GP7200, one of two engine variants offered for the world's largest commercial airliner. Airbus and the A380 customers really have Boeing to thank for this engine's existence. Back in the mid-nineties, Boeing began the first of several attempts to bring to market a commercial airplane that was based on the 747-400 but that would carry even more passengers. The only problem was that none of the three major engine manufacturers was in a position to supply a suitable engine for the planned 747-500X and 747-600X super-jumbos—and none of them showed any real interest in developing such an engine.

So as 1995 turned to 1996, GE Aviation, Pratt & Whitney and Boeing started exploring the idea of a joint venture bet-ween the two U.S. engine manufacturers with the aim of producing at least one suitable new engine. In May 1996, the cooperation agreement was signed and work began on a new engine dubbed GP7000.

Although it wasn't long before the 747-500X/600X project was shelved, the money invested was by no means wasted. In the summer of 1996, Airbus launched its Large Aircraft Division, and two years

after that, in May 1998, the Engine Alliance announced plans to develop the GP7200—the "2" is Pratt & Whitney's designation for Airbus—for the world's largest commercial airliner, at that time still called the A3XX. The 747-500X/600X engine was to be named GP7100.

Best of both worlds

The GP7200 brought together the best of both worlds: GE Aviation was responsible for the high-pressure section, which largely followed the design of the 777's engine, the GE90, with the individual components modified to accommodate the A380's lower thrust requirements. Pratt & Whitney also adapted its contribution to the 777, the PW4000, this time giving the hollow titanium fan blades crescent-shaped leading edges rather than straight ones.

Although the Engine Alliance is a joint venture between GE Aviation and Pratt & Whitney, that doesn't mean that these two companies alone manufacture the entire engine. On the contrary, a considerable portion of the work was contracted out to other manufacturers. GE's long-term French partner Snecma is responsible for supplying the high-pressure compressor, while the low-pressure compressor comes from Techspace Aero in Belgium. But the largest contract package went to MTU

Aero Engines. All told, Germany's leading engine manufacturer supplies 22.5 percent of the GP7200, handling the development, production and assembly of the full low-pressure turbine and the turbine center frame as well as production of blisks for the high-pressure turbine.


500,000 flights and counting

Since the A380's launch customer, Singapore Airlines, opted for the Trent 900 from competitor Rolls-Royce, the GP7200 had to get in line behind the British engine for certification (December 2004) and commissioning (October 2007). The GP7200 completed its first ground test run in March 2004, and in December that same year, flight tests got under way on the left wing of a GE-owned Boeing 747-100. Around a year later, shortly before the end of 2005, the new engine received certification from the U.S. Federal Aviation Authority (FAA) and on August 25, 2006, the first mega-Airbus powered by GP7200 engines took off. The time for the GP7200 to prove itself in practice came on August 1, 2008. That was when Emirates, by far the most important customer for the world's largest commercial airliner, carried out the first commercial A380 flight from Dubai to New York. The A380 and the GP7200 proved to be a winning combination: since this engine entered service, over 99.9 percent of the around

half a million flights it has powered have taken off on time. The Engine Alliance calculates that, by choosing the GP7200 over its British competitor, airlines could save as much as one million dollars per operational aircraft per year.

Further improvements

To help maintain this edge, the company works continuously to improve its products. An upgrade to the high-pressure turbines that was announced in summer 2014 has already been installed in 50 new engines and is available for retrofitting. The new equipment raises the exhaust gas temperature (EGT) margin by up to 10°C and performance by around half a percent. A new kind of control unit software that is currently undergoing endurance testing at MTU Aero Engines in Munich was designed to lower metal temperatures in the high-pressure turbine by 40°C and reduce fuel consumption during ascent by one percent.

While the Engine Alliance can be satisfied with its engine's performance, its sales figures are a different story. At present, demand for quad-jet widebody aircraft—a category that includes the Boeing 747-8 as well as the A380—leaves something to be desired. Nevertheless, Wolfgang Hiereth, Director GE Programs at MTU Aero Engines, remains convinced that getting involved with the GP7000 program was the right move. First, he is not inclined to give up on this particular market, and is confident that Airbus will continue to find buyers for the A380. And second, the GP7200 helped open the door for MTU to get involved in the next generation of GE widebody engines—the contract to develop and manufacture the GP7200's turbine center frame led to work on the GEnx (787, 747-8) and the GE9X (Boeing 777-8X and -9X). And of course MTU Maintenance also benefits from contracts and from the expertise it gains from maintaining widebody engines. 

GP7200 AND A380

- 01 ____ *An improved GP7200 arrives at MTU Aero Engines in Munich for endurance testing.*
- 02 ____ *Integration of fan blades before testing.*
- 03 ____ *A GP7200 on a test rig.*
- 04 ____ *Airbus A380 during take-off.*



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

Research summit

*Rare aircraft carrying out special missions met in Iceland in summer.
Their task: flying in the service of science.*

Text: *Andreas Spaeth*







All systems go for scientific research _____ Left: A NASA McDonnell Douglas DC-8, built in 1969 (behind), and a Gulfstream, wait for their mission to test new laser technology for wind measurement. Right: NASA research pilot Wayne Ringelberg in the cockpit of the DC-8.

A DC-8, a Gulfstream III, a Dornier 228 and a Falcon 20 meet up in Iceland. The question is: What are they doing there, this illustrious group of rather exotic aircraft so rarely seen in action? Answer: They're on a scientific mission. Iceland's northern latitude makes it a popular starting point for aeronautical research missions from both sides of the North Atlantic. This past summer, research aircraft from the German Aerospace Center (DLR) in Oberpfaffenhofen, in the German state of Bavaria, met there with their American colleagues from NASA's Palmdale facility in California. The two oldest planes were NASA's McDonnell Douglas DC-8 and the DLR's Dassault Falcon 20, built in 1969 and 1974, respectively. These veterans worked as a team to test a new laser technology for measuring wind. The results helped advance the development of the latest wind lidar (light detection and ranging) system, which can measure winds over the North Atlantic more precisely, enabling meteorologists to generate more accurate weather forecasts. ESA will start using the new system on one of its weather satellites in late 2016. The DLR's Dornier 228, however, like NASA's Gulfstream aircraft, only touched down in Iceland for a brief stopover. Prior to that, it spent several days flying over Greenland, testing new radar-imaging techniques for measuring the condition of the "eternal ice" up to 50 meters deep from the air.

"The aircraft grow with each task required of them. From a technical standpoint, they're state of the art: the airframes may be old, but they're equipped with all the latest technology," explains DLR pilot Steffen Gemsa after touching down at

Keflavik airport in Iceland. He has just completed a four-hour flight from Greenland in a twin-engine Dornier Do 228, built in Oberpfaffenhofen in 1991. Flights like this one are strenuous. The unpressurized cabin means that the pilots have to wear oxygen masks at altitudes above 10,000 feet (around 3,300 meters), often accompanied by protective clothing to keep out

"These aircraft can do things that no other plane can do, and they are constantly being adapted to face new challenges. You can't buy that off the rack."

Steffen Gemsa, DLR research pilot

the arctic cold. There's no catering on board, and according to Gemsa, there's no time to eat, anyway. "We live on coffee and biscuits." But even this small pleasure is in short supply: "There's no toilet on board, so we have to strategically plan our coffee consumption. We have a one-cup limit before takeoff." Despite everything, Gemsa loves his job. For the flight captain, who has already accrued over 7,000 flight hours at the controls of four different DLR research aircraft, "every flight is a special experience, even if we're sometimes in the air for eight hours a day."

“We conduct three to six campaigns a year, and it can take two to three weeks just to incorporate and calibrate the tools each time—longer than the mission itself, in some cases.”

Wayne Ringelberg, NASA research pilot

The aircraft he flies are just as unique as his profession. “They’re all irreplaceable one-offs. Our Dornier 228 was retrofitted with new engines and five-blade propellers in 2014,” Gemsa explains. “The reason we use such old aircraft is that their technology and sensor systems have undergone so much development over the years that the capabilities of these machines are inimitable. They can do things that no other plane can do, and they are constantly being adapted to face new challenges. You can’t buy that off the rack.” Cost is another reason that research aircraft are usually older models, as notoriously tight scientific budgets aren’t large enough to cover the procurement of new aircraft. “A new plane costs between 30 and 50 million euros, which is more than research projects can afford. All research aircraft have a service life of some 30 to 40 years, so they’ll retire when we do,” says Gemsa with a laugh. But at 43, the pilot is no more ready for the scrap heap than his 24-year-old Dornier.

NASA owns and operates the only passenger DC-8 in the world to still be flying

Impressive stuff, but without a doubt the real eye-catcher in Iceland is the only passenger DC-8 in the world to still be flying—and at 46, the plane is even older than Gemsa. Despite its four engines, the big bird is amazingly quiet in flight—almost silent, even during take-off. This is due mainly to its newer CFM56 engines, which fall under noise category III (quiet). They were fitted in 1986 to replace the much shriller Pratt & Whitney JT3D turbofans that used to power what was then the DC-8-62. This aircraft, which now carried the serial number “-72”, had originally been supplied to Alitalia as a DC-8-60 with production number 458 from the factory in Long Beach, California in May 1969. In 1979, the machine changed hands, flying for the Dallas-based American company Braniff International Airways until 1982. This marked the end of its life as a passenger aircraft: in February 1986, NASA acquired the plane, which had some 40,000 flight hours on the clock, for use as a research aircraft. It took two years of modification work, but the DC-8 had now become an ideal research platform for all kinds of scientific missions from various academic disciplines. The aircraft

RESEARCH AIRCRAFT

- 01** _____ *Traces of the NASA DC-8’s former life as a passenger aircraft can be seen in the overhead baggage compartments.*
- 02** _____ *View out the window of the German Aerospace Center’s Dornier Do 228, which underwent its first state-of-the-art retrofit in 2014.*



SPECIAL AIRCRAFT, SPECIAL TEAM

- 01** _____ *Measuring instrument on the wing of the NASA DC-8.*
- 02** _____ *Flying researcher from NASA and the German Aerospace Center, at Keflavik Airport.*
- 03** _____ *Measurement probe on the nose of the German Aerospace Center's Falcon 20.*
- 04** _____ *Camera on the belly of the Falcon 20.*



is based at NASA's Armstrong Flight Research Center at Edwards Air Force Base in Palmdale, in southern California.

As aircraft go, the DC-8-72 is very economical for long research missions. Scientists can use it to fly nonstop for 11 or even 14 hours to reach remote regions of the globe, enabling them, for instance, to travel from Punta Arenas, Chile to Antarctica and back. "The DC-8 is a very solidly built, robust aircraft based on 1960s design principles. It meets even the toughest requirements, and it can be deployed anywhere in the world," says NASA research pilot Wayne Ringelberg. The strength of the fuselage is particularly important when it comes to the installation of scientific instruments, which require various openings

to be cut in the outer skin or windows to be replaced with panels carrying entire batteries of sensors. "These older aircraft designs feature a lot of built-in leeway, something we don't find in modern machines," Ringelberg adds. "With four engines, the main advantage of the DC-8 is its redundancy on long flights." In order to measure biofuel emissions, NASA's DC-8 was recently required to fly into the contrails of the DLR Falcon. "We had to keep our speed quite low, but ascend as high as we could go," Ringelberg recalls.

A test flight crew usually comprises some 25 people: two pilots and a flight engineer in the cockpit; a navigator in the forward cabin; two mission managers responsible for coordinating the scien-

tific work on board, positioned near the navigator; and two safety technicians to oversee the measuring instruments and provide assistance in emergency situations. That makes a total of eight NASA personnel. Then there are generally an additional two or three scientists per installed instrument on board, bringing the total up to about 25 people working in the very spacious cabin originally designed to accommodate up to 175 passengers. Today the space is filled only with wide, former first-class seats that are mostly surrounded by instruments for all kinds of measurements. Particularly striking are the huge, rectangular windows of the DC-8, which put the famously generous windows of a Boeing 787 or an Airbus A350 to shame.

Another remarkable feature, of course, is the analog cockpit, with its instrument panels full of dials and pointers laid out before the pilots and flight engineer. "Our avionics are based on a modern flight management system, but the autopilot is still original," Ringelberg explains.

Overall, the NASA DC-8 spends 300 to 400 hours in the air each year. "We conduct three to six campaigns a year, and it can take two to three weeks just to incorporate and calibrate the tools each time—longer than the mission itself, in some cases," Ringelberg explains. The DC-8 has one distinctive property that the scientists value particularly highly: it allows them to drop probes directly from the cabin through a tube. The DC-8's indestructible airframe seemingly knows no limits in terms of flight hours; to date this aircraft has completed approximately 54,000. "We expect to keep flying it for at least a decade," says Ringelberg. But the time will eventually come when it will be too difficult to obtain spare parts from cannibalized aircraft. Ringelberg wouldn't call his DC-8 a dinosaur—it is, after all, only three years younger than he is. "Put like that, it sounds so negative. I prefer to see it like a well-kept antique car."



The DLR's “all-purpose weapon” — an A320 in research service



D-ATRA — The largest research aircraft in the German Aerospace Center's fleet is an A320 built in 1997 and formerly used as a passenger jet.

Like most aircraft working in the service of science, the Airbus A320 with the serial number 659 is no longer an entirely new aircraft. Its maiden flight was in January 1997, after which it spent almost ten years as a passenger aircraft for Aero Lloyd and Niki. But since the end of 2008, the A320 has been flying as a flight test platform for the DLR in Braunschweig. The A320 is equipped with two International Aero Engines V2500 engines, which MTU Aero Engines helps to develop and produce. The Advanced Technology Research Aircraft, which carries the fitting registration D-ATRA, is the largest of the DLR research aircraft. The fleet, which comprises

a dozen airplanes and helicopters, is the largest civilian aircraft fleet for research use in Europe. The D-ATRA has completed a variety of test series covering very different research areas, such as wake vortices and high-lift research. For the latter, the A320 has a special concept for high-performance and noise-reducing wing flaps. Missions can also involve unusual tasks, such as flying over the airfield at a maximum height of 15 meters in a bid to collect as many insects on the nose as possible—all part of research being conducted into future ultra-smooth laminar airfoils.



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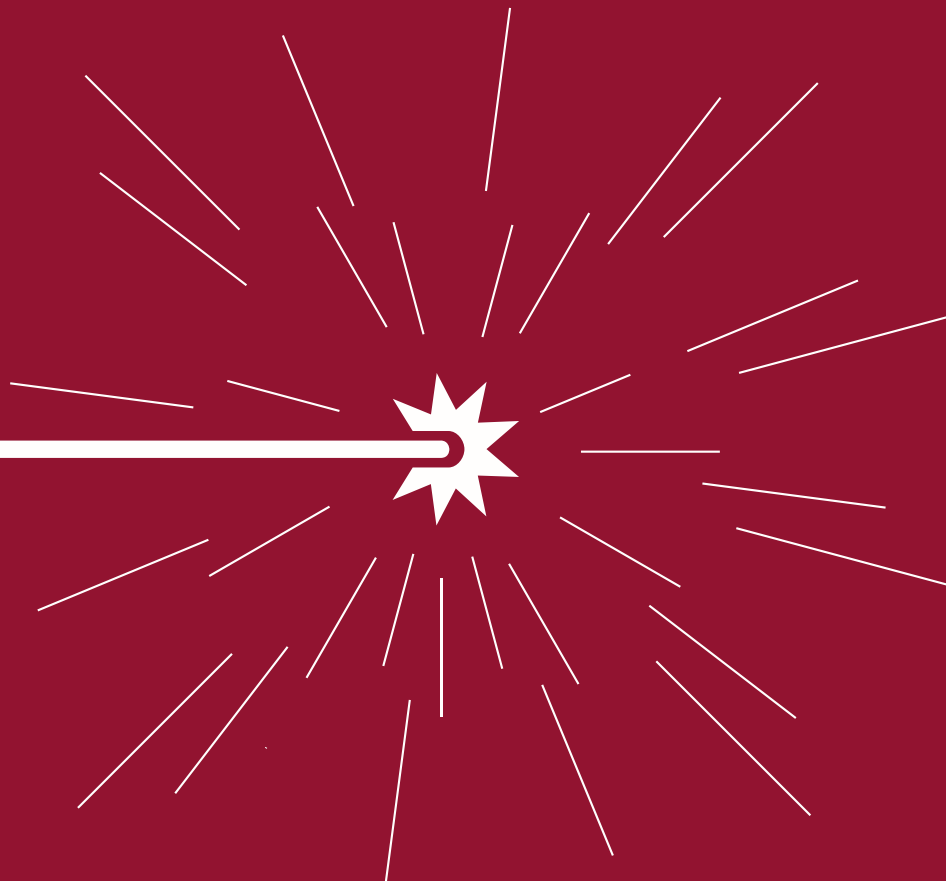
Text:

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.

Layer by layer

3D printed into highly complex structures, extremely light and incredibly stable. The small Munich suburb of Krailling represents the success story of additive manufacturing like no other place on Earth.

Text: *Thorsten Rienth*



Aviation industry products manufactured using additive processes: fuel injection nozzle, turbine wheel and ultra-light seatbelt buckle (from left).



In the mid-1980's, Dr. Hans J. Langer was working for an American company and, while visiting a customer, saw how its engineers were using liquid photopolymers to produce plastic parts layer by layer. The energy required for this process came from a laser. Langer was astounded. What if this process could also produce functional components? "The image of a bird bone came to mind—a complex hollow body that is nevertheless strong and light."

Langer spoke with the company's senior management. He proposed entering a world that he called electro-optical systems, or EOS for short. Technology was the next logical step in the company's evolution, he explained. Instead of producing just components, it had to be possible to use lasers, ultrafine metal or polymer powders and the right software to manufacture complete systems. Senior management declined, but the Munich-based physicist couldn't get the idea out of his head. He looked for and found an investor, gave his notice and branched out on his own. Twenty-five years later, Langer is CEO of the EOS group. Headquartered in Krailling, near Munich, EOS is the world leader in technology and quality for high-end additive manufacturing solutions.



Limited only by creativity

The display cabinets in the company's showroom narrate how the company got to where it is today. It all began with model helicopter housings, connectors and robot grippers. Over time, products became increasingly sophisticated. The last of the display cabinets contain objects that look like sponges, but that are made of metal; highly effective heat exchangers that accommodate unprecedented surfaces in a volume of a few cubic centimeters; a small build platform on which up to 450 dental crowns and bridges customized for individual patients can be manufactured in one production run. The possibilities for application are limited virtually only by customer creativity. Examples range from a robot whose gripper simulates an elephant's trunk to a toy manufacturer's hollow mold cores that

can be cooled much faster because the cooling follows their contours, doubling production throughput time for these parts.

However different the end products may be, they all have one thing in common: producing them using conventional methods would be considerably more costly, if it is even possible at all. EOS calls its method laser sintering. Since this technology can be used to process existing—and therefore already approved—materials, it was practically predestined for the aerospace industry, as well.

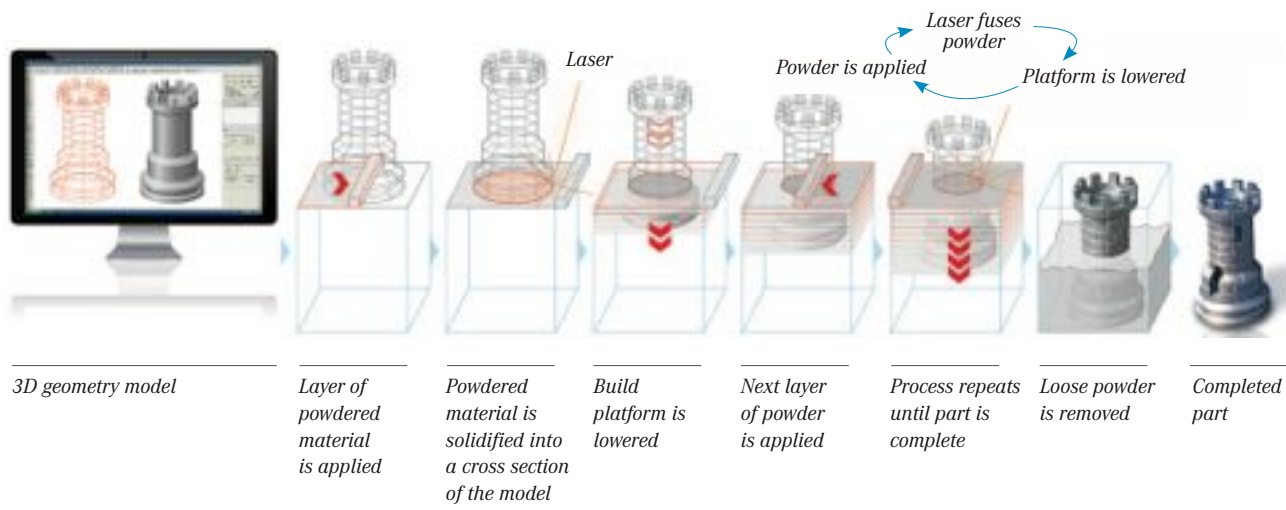
A laser builds components layer by layer

From a technical perspective, laser sintering involves three-dimensional micro welding techniques. Instead of milling workpieces from solid blocks, thus removing material, the powder-based EOS machine builds them layer by layer from metals, plastics or composites. A coating machine gradually applies very thin layers to the build platform. A powerful laser melts the powder at the precise locations specified by the computer-generated component construction data, and joins it with the layer below. The component is thus constructed additively—that is, layer by layer. In the most extreme case, each layer of metal has a thickness of just 20 micrometers, or 20 thousandths of a millimeter.

Almost any shape that can be designed with a 3D CAD program can be produced using this method. Design-driven manufacturing, where design dictates the production process, is edging out conventional methods where manufacturing sets the design limitations. This new approach allows for highly complex structures with delicate details, small batch sizes at acceptable unit prices, and highly customized products.

The process behind it almost seems like a game. The laser hops across the powder like miniature fireworks in fast motion. "But it's much more challenging than it looks—there are millions of weld joints involved," explains CEO Langer. It's not enough to

GENERAL FUNCTIONAL PRINCIPLE OF LASER-SINTERING



“It requires a lot of experience and a clear understanding of what factors influence the component quality and how they can be adjusted accordingly.”

Dr. Hans J. Langer, founder and CEO, EOS Group

just feed the machines with data and wait until the finished component comes out a couple of hours later. “It requires a lot of experience and a clear understanding of what factors influence the component quality and how they can be adjusted accordingly.”

A look at EOS’s figures shows just how fast this technology is growing. The company is aiming for more than 240 million euros in revenues in 2015. It would be the second consecutive year in which EOS grew more than 40 percent in one year. In the current year alone, the number of employees has increased by about 100, to some 740 worldwide. They work practically around the globe: in the U.S., China, Finland and Italy. Following the 2014 completion of the Technology and Customer Center, EOS is now building another new structure in Krailling. Langer estimates that his company will sell and install over 1,500 systems for its customers in the next three to five years—almost exactly as many as it has sold throughout the company’s entire history, from 1989 to today.

From “rapid prototyping” to volume production

The origins of industrial 3D printing lie in “rapid prototyping,” the building of visual and functional prototypes. In times of shorter and shorter market cycles, the importance of faster production

development and market launch is growing. 3D print engineers are no longer the stereotypical nerds who wear thick horn-rimmed glasses and tinker on futuristic devices. This technology is finding its way into volume production.

There is hardly a major industry player whose production facilities don’t include machines from Krailling. The Munich-based automotive manufacturer BMW, for example, was one of its first partners. EOS likewise works closely with Siemens, and there are also some EOS machines in operation at MTU Aero Engines in Munich. The first one went into operation in 2009—one of the first to ever be used in the aviation industry. MTU initially used it in toolmaking, for instance for coolant injection nozzles, grinding wheels and attachments with complex internal structures.

“Our focus was not initially on producing engines quickly,” explains Dr. Karl-Heinz Dusel, who is in charge of additive manufacturing activities at MTU. “We wanted to understand the technology from the beginning.” MTU now uses additive manufacturing to produce borescope bosses for the A320neo engine PW1100G-JM. “Seal carriers with integrated honeycomb seals are the next components we intend to use this technology for,” indicates Dusel.



ADDITIVE MANUFACTURING

- 01** ____ *New headquarters of MTU's partner EOS GmbH in Krailling near Munich.*
- 02** ____ *Additive manufacturing of a guide vane cluster at MTU Aero Engines: The laser fuses metal powder, which solidifies again in seconds.*
- 03** ____ *Borescope boss for A320neo's PW1100G-JM engine, manufactured using additive methods.*




Inside MTU ____ *Optical tomography*

When it comes to quality issues, there can be no compromises in the aviation industry. To ensure quality as effectively as possible in components produced by additive manufacturing, MTU Aero Engines and EOS GmbH developed, as part of a strategic partnership for quality assurance, a new kind of quality assurance tool for metal-based additive manufacturing. The first result of this partnership is an optical tomography (OT) method developed by MTU that enhances the modular EOS monitoring portfolio. In addition to numerous sensors that monitor the general system state, the camera-based OT technology checks the exposure process and the melt behavior of the material at all times to ensure optimum coating and exposure quality.

Reproducible quality and process stability

As is so often the case, both sides benefit from the partnership. "From our perspective, it's incredibly important to work with someone who truly understands additive manufacturing," says Dusel. Merely producing prototypes isn't enough. "For volume production, reproducible quality and process stability are crucial." In other words, precisely the same concepts that are essential for EOS. "For us, it's about mastering design principles," explains Felix Bauer, Business Development Manager Aerospace at EOS. "Only when we have achieved that can we develop processes that create genuine added value for industry."

Is industrial 3D printing the new industrial revolution? Bauer shakes his head. "We won't replace today's manufacturing processes, but with additive manufacturing, we offer an additional option—it's a matter of what the best choice is for a given application." This will require some creative rethinking among engineers, companies and universities. Bauer likes to tell the story of a professor who, following a presentation Bauer gave a few years ago, sheepishly admitted: "I recently failed a student because he designed something that couldn't be produced using conventional manufacturing methods—it would have worked using an additive method." 



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Text:

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

“When it comes to development potential, we’re talking perhaps about a fifty-dimensional space.”

In the search for new materials, there is still plenty of potential out there, says Prof. Dr. Carolin Körner, who heads the Chair of Metals Science and Technology at the University of Erlangen-Nürnberg. The goal, particularly for aviation applications, is to use new alloys and innovative processes to make materials lighter, better and more stable.

Text: Eleonore Fähling

Professor Körner, you study how heavy, stable metal can be made light. Will we have turbine blades made of metal foam in the next twenty years?

Prof. Dr. Carolin Körner: The answer is a definite yes and no. Metal foam is literally foamed metal, so it’s porous and light. But its mechanical characteristics make it unsuitable as a material for manufacturing complete turbine blades. However, locally porous blades are a conceivable option, perhaps with a cellular structure inside to act as a heat exchanger or with a porous surface for effusion cooling to replace the cooling holes method generally used today. So it’s a no to blades made of foam, I’m afraid, but engine manufacturing will be able to use concepts from the development of lightweight metals.

Generally speaking, what limits the application possibilities of materials in engine and aircraft manufacturing?

Körner: Materials have become a key lever in the development of new aircraft and above all new engines. When it

comes to further developing materials for aircraft engines, various approaches are being pursued: developing components with integrated functionality—such as components with porous structures—improving tried-and-tested alloys, and using new materials such as intermetallic compounds, whose properties lie somewhere between those of metals and those of ceramics.

After all, if engines are to become more efficient, then the turbines must run faster, for example, and the materials used in the turbines must withstand constantly increasing mechanical and thermal stresses. Although compounds and intermetallics are suitable for this role, they are difficult to manufacture and process. They present entirely new challenges to production engineering: How do I cast or forge a blade out of an intermetallic alloy such as titanium aluminide? And how do I then join it to the disk? Generally speaking, the melting point is the maximum physical limit for the use of a material. If the material is to be used for industrial applications, another consideration is manufacturing, which can be very complex and expensive and can therefore also limit its use.



What application possibilities do you see for lightweight metals in general and why do we need them?

Körner: Lightweight construction is important wherever people are looking to save resources and to reduce fuel consumption and emissions. Nature is our model here: bones, for example, are lightweight components, with a compact external shell and a cellular, so to say foamed core. This makes bones light while also providing stability and good damping characteristics. We try to transfer these principles to metal construction. A problem with the use of lighter materials is the loss of rigidity and the associated vibrations and noise. So you have to stiffen the design while simultaneously increasing its damping properties—the material has to fulfill several functions. In the case of metal foam, for instance, this multi-functionality is present: the material offers rigidity, effective damping, high energy absorption and good permeability. By embedding piezo elements, the metal component can even become active. For example, piezo elements can apply vibrations, so a possible application is on the aircraft's wing: instead of moving the wing

with hydraulically controlled movable flaps as is done today, you could move the wing directly using actuators embedded in the material. Research into this technology is already under way.

We are able to grow metals like crystals, we create intermetallic compounds, and we can manufacture metal components in 3D printers—where are the limits to innovation in the development of metallic materials?

Körner: Creating alloys is an age-old practice, and you'd be forgiven for wondering if any great progress was possible at this stage. However, we are really just at the beginning. When it comes to development potential, we're talking, perhaps, about a fifty-dimensional space. We've only explored tiny corners of it to date. We've been following the same principle probably for millennia now: you take a base element such as aluminum, iron or nickel and you add further elements in various proportions. The new alloys created in this way are then tested and empirically evaluated. In the case of nickel-base alloys, which are used primarily in modern aircraft engine manufacturing,



Professor Dr. Carolin Körner _____

Head of the Chair of Metals Science and Technology at the University of Erlangen-Nürnberg.

Professor Dr. Carolin Körner studied theoretical physics at the Friedrich-Alexander University of Erlangen-Nürnberg (FAU). She obtained a Ph.D. in 1997 at the FAU's Faculty of Engineering under Professor H.W. Bergmann for her work on the interaction between ultra-short laser pulses and metals. She qualified as a university lecturer in 2007 with a thesis on the manufacture and simulation of lightweight metal foams for material sciences.

Since 2011, she has been Head of the Chair of Metals Science and Technology at FAU. In addition, she heads a working group at the Joint Institute of Advanced Materials and Processes (ZMP) in Fürth and at Neue Materialien Fürth GmbH (NMF). Her main areas of interest are additive manufacturing, light metal casting, cellular materials, composites and process simulation. She has been working closely together with MTU Aero Engines to develop new materials for many years.

“We now practice combinatorial material development: based on thermodynamic models and using numerical algorithms, we search for promising combinations among the virtually endless number of possibilities, and then we analyze and evaluate only these specific candidates.”

we've already begun to move away from this template. We now practice combinatorial material development: based on thermodynamic models and using numerical algorithms, we search for promising combinations among the virtually endless number of possibilities, and then we analyze and evaluate only these specific candidates. This is much more efficient than the old empirical approach.

Why can't we make do with the alloys we already have?

Körner: To give an example, so-called 3D printing—the additive manufacturing of components layer for layer from metallic powder using laser or electron beams—presents us with completely new problems and opportunities. One advantage of additive manufacturing is the rapid solidification of the metal, which yields unprecedented homogeneity in the alloy. Now we need alloys that exploit this potential. This would allow us to avoid the separation processes that are an inevitable consequence of conventional casting methods. The inhomogeneities in a cast blade can be a few hundred micrometers in size, and the blade



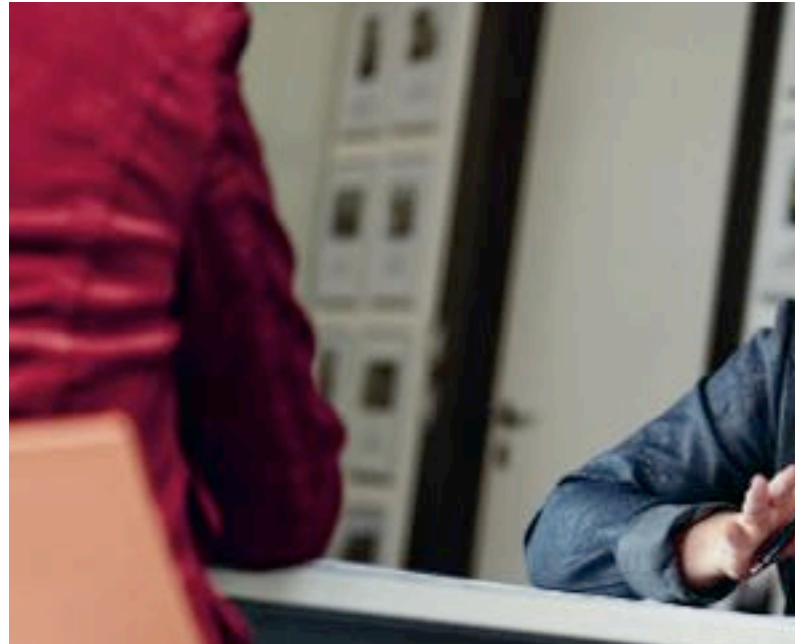
subsequently has to be heat treated for several hours. With additive manufacturing, the inhomogeneities are reduced to a few micrometers, and the heat treatment is accomplished in a matter of seconds.

Which requirements must future materials satisfy in the aviation industry?

Körner: They must become increasingly lighter while also becoming more and more stable. In particular, the requirements for creep resistance, oxidation resistance and weight will continue their upward curve. At the same time, the demands placed on manufacturing processes will also rise. Titanium aluminides, for example, are very light, temperature resistant and creep resistant, but they are very difficult to process in terms of casting or forging, and also in terms of ablation. New methods may be needed here.

Which new techniques for manufacturing metal components will we be using over the coming years? And which methods will they replace?

Körner: At the moment, additive manufacturing is positively booming. However, I believe enthusiasm will cool a little after a while. After all, just because something can be done doesn't mean that it's cost effective to do it, and that's not even mentioning technical limits, some of which we may not even be aware of yet. Additive manufacturing opens up new design possibilities that we have to get to know before we can properly use them. Whereas production-oriented design was often the guiding principle in the past for the manufacture of components and workpieces, application-oriented design is now becoming possible (see also "Layer by layer", p. 30). In the course of this transition, optimization methods will also gain in importance, such as computational improvements of component geometries under stress, which is known as topology optimization. However, I don't think additive manufacturing will completely replace another production method. If you can cast a component, then you should cast it: casting is still much more cost effective.



“There’s always interplay between design and materials.”

Professor Dr. Carolin Körner

Why is innovation in materials so important? Have all the development possibilities in design been exhausted?

Körner: There’s always interplay between design and materials. If I fully exhaust the design possibilities, I’ll come up against the physical load limits of the materials. In a piston engine, for instance, if I optimize the fluid mechanics of combustion in the piston—that is, improve the topology of the piston such that it works more efficiently—this usually results in higher pressures and temperatures being generated in the piston. To withstand these, I will then most likely need to use other materials.

Could advances in material development one day deliver replacements for the rare metals currently used in aircraft manufacturing?

Körner: We certainly hope so—for elements such as scandium, which greatly increases the strength of aluminum alloys but is also extremely expensive. Thanks to the effective way they change the characteristics of other materials and alloys, even when added in very small quantities, rare earths have gained in importance, and people are searching systematically for alternatives with similar properties. Rhenium, for example, significantly increases creep resistance in nickel-base alloys, but it’s also very expensive and available only in limited quantities and from a handful of providers. Research is currently ongoing into whether and how it might be possible to replace it with a material such as tungsten. When the necessity is there to find something else, then people generally manage to find something.





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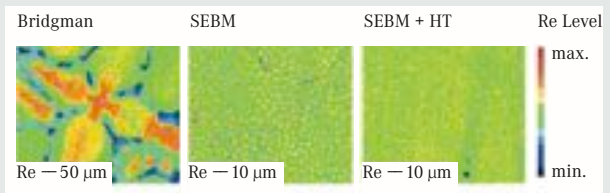
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Text:
Eleonore Fähring is MTU's Editor in Chief for AEROREPORT and has been in charge of the MTU employee magazine for over 15 years.

GLOSSARY

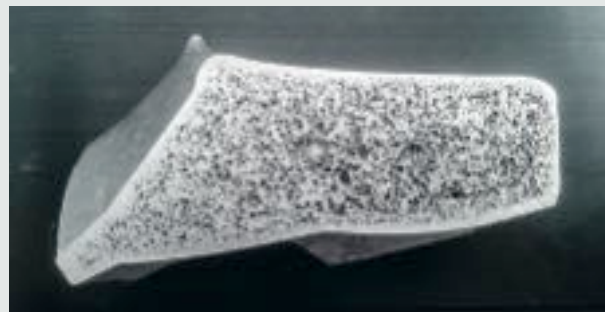
Homogeneity In this context, the term refers to the even distribution of atoms and molecules, for example in alloys. Because of rapid solidification, the homogeneity of workpieces manufactured using additive methods is much greater than that of cast workpieces.



Distribution of rhenium in an alloy (CMSX-4): left, in a cast workpiece; center, in an additively manufactured workpiece; right, additively manufactured with four minutes of heat treatment.

Intermetallic compound A homogeneous compound of two or more metals that, unlike alloys, possesses lattice structures that differ from those of its constituents. Because of the particularly strong bonding between their disparate atoms, intermetallic compounds are usually harder, more brittle and more creep and temperature resistant than their original metals. However, they are also difficult to process using conventional manufacturing methods. From a chemical perspective, intermetallics fall between metals and ceramics.

Metal foam Umbrella term for foamed metallic materials. Metal foam has a low density and weight combined with high structural rigidity and strength. Among its various applications, metal foam is used as a crash absorber in rail vehicles and for damping vibrations in machine tools.



Die-cast aluminum component with foamed core.

Right in the middle of it all

Turbine center frames for widebody engines.

Text: Patrick Hoeveler



GE Aviation widebody engines have a key German-made component in their turbines: MTU Aero Engines develops and manufactures turbine center frames for the GP7000, the GEnx and, since recently, also the GE9X.

High temperatures, enormous pressures, high speeds: the most challenging conditions in an aircraft are concentrated in the engine. Right in the middle of it all is the turbine center frame (TCF), which plays a key role in every turbofan. Its name may sound a little dry and technical, but its position in the engine reveals its importance: the TCF is situated between the high-pressure turbine and the low-pressure turbine, where it fulfills two important functions. It connects the high-pressure shaft's rear bearing with the housing and forms an aerodynamic transition duct between the high-pressure and low-pressure turbine. "This area is subject to very high stresses, because bearing loads are conducted to the outer casing through the TCF structure. In the event of faults, such as a broken fan blade, the turbine center frame must be able to withstand the resulting loads in terms of mechanical integrity," explains Dr. Martin Metscher, Head of Development for the GE9X at MTU Aero Engines. In addition, the component has to permanently withstand temperatures in excess of 1,000 degrees Celsius.

TCFs essentially consist of two main component groups. The first of these is the hub strut case, which is the load-bearing structure and takes the form of a casing with several struts assembled around a hub with an integrated bearing. The second main group is the struts' panels and fairings—also known as the flowpath

hardware—which form the channel for hot gas flowing from the high-pressure turbine. In addition, there are various seals, and finally, oil lines and cooling air channels, through which oil and air are conveyed through the TCF to the turbines and the bearing.

High-tech manufacturing for best seller GEnx

MTU gained its foothold in this field with the engine for the Airbus A380, the Engine Alliance GP7000. The TCF for this engine builds on the design used in GE Aviation's GE90 and was adapted and optimized by MTU engineers. To date, the company has delivered over 400 units. "MTU wanted to position itself as a center of expertise for GE turbine center frames," says Metscher. The final breakthrough came in 2008, when MTU was also entrusted with responsibility for this component for the GEnx, which powers the Boeing 747-8 and 787. Again, the German company's specialists in Munich were able to optimize the center frame and quickly ramp up production. GE received the first segment in late August 2011, and in May 2012, Cargolux put a GEnx with an MTU turbine center frame into service in a Boeing 747-8. Since then, over 700 units have left the production facilities at MTU's headquarters. On average, one turbine center frame is manufactured per day.

The high production rate is no walk in the park, and not only because of the almost 3,000 individual parts that make up each TCF. "Manufacturing TCFs is a complicated business," explains Metscher. "We work with very large parts that are difficult to machine due to the high requirements they have to meet in terms of temperature levels and strength values." Assembly is largely carried out using classical methods, but it still poses challenges

due to the very high accuracy requirements. After all, the housing defines the position of the bearing, which is important for maintaining component clearance in the entire high-pressure area. Optimum clearance, in turn, remains indispensable for the high efficiency of the entire engine, which is vital for ensuring low fuel consumption. Although some components have a diameter of around 1.5 meters, even a mere one-millimeter deviation would be too much. The two production lines are characterized by their high degree of automation. “We’re defining the state of the art here with new production machines that drill and then screw components together. We’re trying out partly automated manufacturing, and we work virtually around the clock. Our strength lies in the fact that manufacturing, assembly and engineering are strongly intermeshed in one location,” says Metscher. The company’s U.S. partner agrees: “MTU brings a wealth of experience and technological expertise to the table, in both manufacturing and maintenance. We’re delighted to have MTU as a partner for this and for future engines,” says Tom Levin, General Manager GEnx at GE Aviation.

New manufacturing techniques

The latest turbine center frame, which MTU is now developing for the Boeing 777X’s GE9X engine, promises further progress. “Particularly with regard to the struts in the hub strut cases, we’re considering whether we could, in the future, manufacture them using additive methods.” In this innovative manufacturing technology, a laser fuses components and builds them up layer for layer from a metallic powder bed. Compared with casting parts, additive methods significantly reduce manufacturing costs. Metscher also points to improvements in design: “The TCF for the GE9X had to be even lighter than the design for the GEnx. Thanks to our experience and improved design methods, we were able to further optimize the components through classic design evolution.” Assembly of the first housing begins in Munich at the end of the year. It will then be tested in an engine for the first time at GE Aviation in 2016. The GE9X is due for commissioning in 2020; over 800 engines have already been sold. ✈️



High-tech manufacturing _____ assembly of a GEnx turbine center frame.



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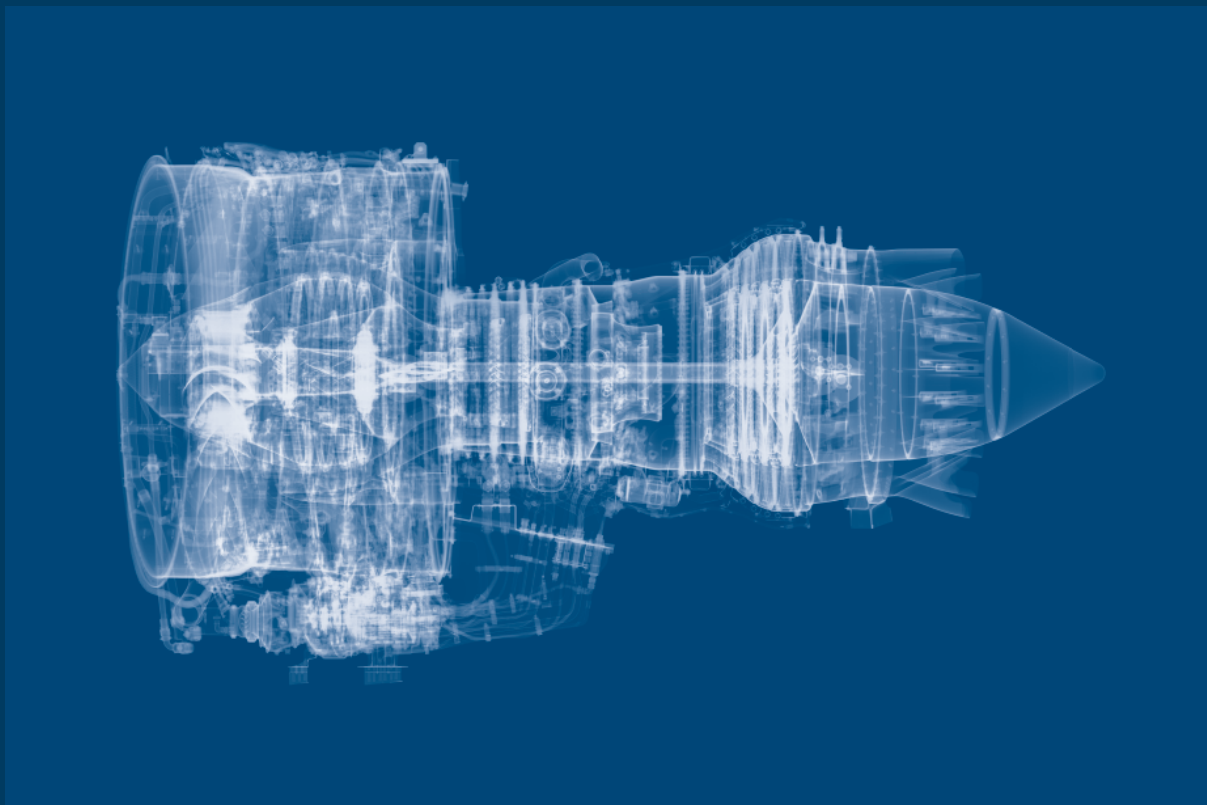
Text:

Patrick Hoeverler has been a member of the editorial team at aerospace magazine FLUG REVUE for some 15 years. His responsibilities there include the engines, regional aviation and history sections.

How much precision is enough?

How non-destructive testing methods contribute to aviation safety.

Text: *Monika Weiner*



Is it large, bulky or heavy? Engineers at the Fraunhofer Development Center for X-ray Technology (EZRT) in Fürth are used to dealing with oversized items. In their high-energy hall, which is equipped with an XXL computed tomography (CT) scanner, they examine objects every day that are too large for normal materials testing facilities. This includes such items as entire automobiles before and after crash testing, a T-Rex skull still half covered in sediment, and now, in connection with a feasibility study, even two exhibition pieces: a radial engine and a test engine on loan from MTU Aero Engines' company museum. The images produced here are impressive, and not just in terms of aesthetics. "Even the 2D X-ray images show an incredible amount of detail. The resolution is high enough to see whether all of the components have been properly installed," says Fraunhofer researcher Dr. Michael Böhnel. "The full 3D CT scan provides even more precise information. For instance, we can use it to determine the clearance on a fully assembled aircraft engine."

Detecting defects tenths of millimeters across

"As attractive as the images are, XXL computed tomography is, unfortunately, not suitable for use in routine production or maintenance inspections," explains Dr. Hans-Uwe Baron, Senior Manager, Non-Destructive Testing at MTU. "We don't want to discover defects only after everything is already assembled. Right now, however, the imaging resolution is still too low for materials testing in the aviation industry." Baron and his team work on different scales of magnitude. The defects they are looking for measure only several tenths of a millimeter in size. Finding these tiny defects in large components is the future challenge for the researchers at Fraunhofer EZRT.

Achieving the highest quality standards through the highest precision

Minute hairline fractures or material inhomogeneities that are hardly perceptible with the naked eye can have devastating consequences in the aviation industry, says Baron. "With components that rotate at tens of thousands of revolutions per minute, a failure can cause an aircraft engine to explode."

For 27 years, the mechanical engineer has been searching for defects both small and miniscule. This is a constant challenge, as the job of locating defects is becoming ever more demanding. When he began his career, faults measuring 0.8 mm in size were still considered tolerable, while today the bar is set at 0.2 mm. But a lot has also changed in the intervening years, both in the sky and on the ground. Aircraft engines offer better performance today thanks to higher speeds and lightweight construction, and inspection officers also have entire arsenals of ultra-precise high-tech equipment at their disposal. In production and maintenance operations, X-ray, ultrasonic, thermographic, magnetic powder, penetration, turbulence and corrosion testing are performed on a routine basis. One thing all of these techniques have in common is that they are "non-destructive"—they leave no trace of stress or damage in the inspected materials. This is particularly crucial in the aviation industry where, for one thing, the components are extremely expensive, so for economic reasons alone, there is much reluctance to destroy them. Another consideration is that random sample testing is not sufficient—all components must undergo testing during the production process. Only in this way is it possible to meet the highest quality standards.



NON-DESTRUCTIVE TESTING

- 01 ___ *Diagnostics for penetrant testing.*
- 02 ___ *Visual inspection with magnifying glass and surgical light.*
- 03 ___ *Thermographic testing of a CF6 rotor blade.*
- 04 ___ *Testing titanium billets on an ultrasonic lab machine using phased array technology.*
- 05 ___ *Eddy-current testing of a fan disk.*

Such standards are common at the international level. Organizations such as the European Aviation Safety Agency (EASA) define exactly which components must be inspected, and how, when and by whom the inspection must be performed. All processes are regulated down to the last detail, and inspection officers at the various levels must be certified for the respective processes. “Of course we meet all regulatory requirements,” says Baron. “At the same time, however, we try to design and, if possible, automate the processes to be as efficient as possible.”

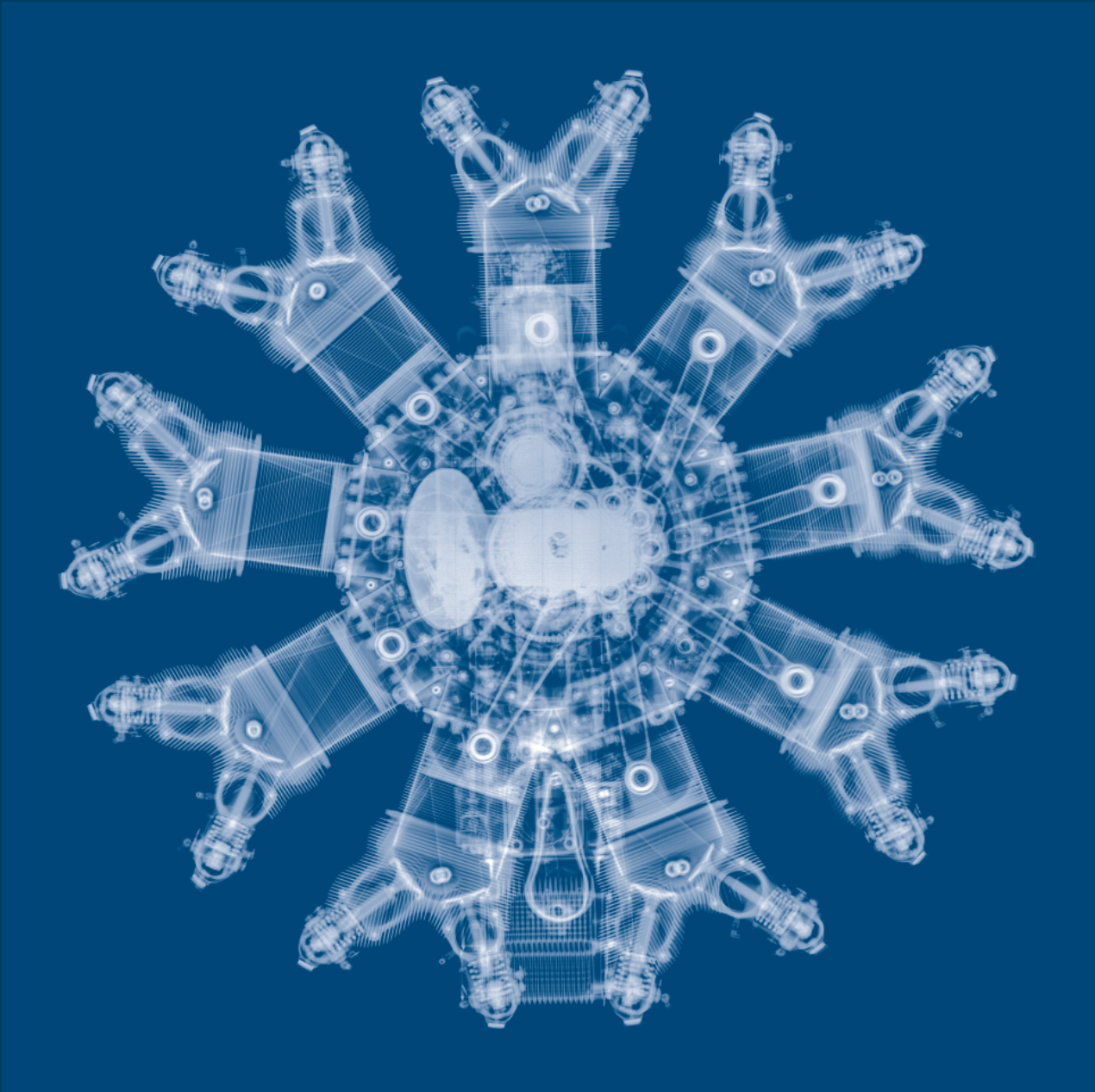
The right test for each component class

The question of which tests a component must pass before being used in the aviation industry depends on the potential damage its failure could later cause. The designers separate the various aircraft engine components into classes 1 to 3, with the first class including parts whose failure would represent the greatest danger. For instance, a turbine disk, or blisk, that ruptures during flight poses a high risk, since the fragments can damage the wings or the fuselage.

Class 1 parts must therefore be tested more stringently than all the others. The MTU facilities have equipment for ultrasonic, X-ray, penetration and turbulence testing. The most laborious tasks are frequently carried out by robots, which can lift heavy parts, transport these parts to the next testing station, or scan their surfaces using the ultrasound probe. “Measurement tasks can be automated, as can some of the data analysis, but only test engineers can perform the final interpretation. They have the last word,” explains Baron.





The requirements for the second component class, which includes turbine blades and casings, aren’t quite as stringent. They routinely undergo penetration and X-ray testing, and in some cases even X-ray CT scanning. Engineers have largely automated the latter in recent years by having a robot transport the components into an X-ray chamber and, afterwards, sort out all of the components that deviate from the standard. Only these components need be reviewed by the inspection officer. A further process step entails the thermographic inspection of turbine blades. This relatively new procedure is used to determine whether the ceramic coatings have adhered properly and whether the cooling channels are open.

The third class includes veneers, fasteners, and mounting fixtures that are not safety critical and that can be replaced during any routine check if failure is suspected. For these components, it is sufficient to conduct penetration testing and a traditional visual inspection—the latter, incidentally, is a requirement for all class 2 and 3 components. The visual inspection is the only process that hasn’t yet been standardized, as the method in which it is carried out depends on the individual inspector. “It’s here that



Insight — Aviation industry and medicine both rely on extremely stringent safety and quality standards. It's no surprise, then, that both the medical and materials inspection fields use similar imaging methods, such as X-rays, ultrasound and computed tomography. Images of a nine cylinder radial aircraft engine (this page) and a jet aircraft engine (page 42), both on loan from the MTU Museum, were created inside the XXL computed tomography scanner at the Fraunhofer Development Center for X-Ray Technology.

OVERVIEW OF NON-DESTRUCTIVE TESTING METHODS IN THE AERO ENGINE INDUSTRY

<i>Name of testing method</i>	 <i>Ultrasonic testing</i>	 <i>Penetration testing</i>	 <i>Etching technology</i>	 <i>Turbulence testing</i>
<i>How it works</i>	Foreign body inclusions, pores and cracks are made visible using sound waves: Because the propagation of the sound-waves is affected by the density of the material, it is possible to determine whether or not the material is homogeneous using the signals that pass through it.	Fluorescent dyes make surface pores and cracks visible: Components are consecutively dipped into colorpigmented oil, removed, cleaned, sprayed with developer and illuminated with UV light.	Surfaces are etched using chemicals. The optical changes that occur in this process are material dependent.	Inhomogeneities become visible by altering the induction of an electric field.
<i>Resolution</i>	Resolution from 0.4 mm, inspection depth up to 20 cm.	Defects from 0.2 mm are identifiable.	Resolution from 0.2 mm.	Resolution from 0.2 mm.
<i>Applications</i>	Inspection for freedom from defects in base material.	Crack testing.	Locating chemical inhomogeneities.	Crack testing.
<i>Application areas in the aircraft engine industry</i>	Component class 1 disks and blisks.	All component classes.	Component class 1 disks and blisks.	Drilling holes in component class 1 and 2 disks and casings.

we expect the most innovation in the future, such as the use of digital inspection plans that specify the tasks and assist with documentation,” says Baron. The Industry 4.0 era has taken hold here, as well. Yet a truly radical level of automation and optimization, such as is common, for instance, in the automotive industry, will not soon materialize in aviation due to the industry’s high standards.






Zero defects? It’s only a question of perspective

So where do we go from here? “The trend toward ever more stringent fault tolerance specifications will continue,” says Baron. At the same time, automation is gaining ground, with ever greater speed and precision. Steffen Bessert at the Fraunhofer Institute for Nondestructive Testing (IZFP) offers his take on the

current state of research: “Development trends are moving in the direction of thermography with active stimulation, as this is contactless and can be automated. Minute defects are also increasingly being detected using CT technology, which is being correlated ever more with CAD design drawings. This will allow inspectors and designers to locate and classify defects with even greater precision in the future.”

And will there come a time when defects have been completely eliminated? “For technological reasons, there will likely never be such a thing as absolutely zero defects,” says Baron. “However, our ability to reliably pinpoint increasingly minute defects will continue to grow.”



 <i>Magnetic particle testing</i>	 <i>Visual inspection</i>	 <i>X-ray</i>	 <i>X-ray CT</i>	 <i>Thermographic inspection</i>
<p>Magnetic particles reveal disturbances in the magnetic field: If a metallic component is magnetized, the particles will arrange themselves parallel to the field lines. Cracks in the component will disturb the homogeneity of the field—the particles make this visible.</p>	<p>Inspection officer checks components.</p>	<p>Radiographic scanning of components produces two-dimensional images that make defects within the components visible.</p>	<p>Components are rotated inside an X-ray scanner, and afterwards the radiation is measured. The sum of the scans provides a 3D image. The three-dimensional images provide a look inside the components and make tiny defects visible such as those that can occur when drilling cooling channels into the turbine blades.</p>	<p>Measurement of the heat that disperses within a component: The heat is generated using two flash lamps directed at the component. A camera detects how much heat drains off. Irregularities in the heat drainage indicate poor bonding between the component and the surface coating.</p>
<p>Resolution of 0.2 mm.</p>	<p>Resolution from 0.2 mm without magnifying lens.</p>	<p>Resolution from 0.2 mm, dependent on wall thickness.</p>	<p>Resolution from 0.1 mm, dependent on wall thickness.</p>	<p>Resolution from 0.5 mm, dependent on distance to surface.</p>
<p>Testing of magnetizeable steel components.</p>	<p>Testing of all components.</p>	<p>Locating foreign body inclusions and pores.</p>	<p>Measurement of wall thicknesses and internal geometries, such as rear panel tapping holes that can occur during laser drilling.</p>	<p>Inspection of bonding between metal and ceramic. This is a relatively new technique.</p>
<p>All magnetizable components. Used especially in the maintenance of older engines with steel components of all component classes.</p>	<p>All component classes.</p>	<p>Cast components, welding seams, turbine blades with cooling channels in component classes 1 and 2.</p>	<p>Turbine blades with cooling channels and composite materials in component classes 1 and 2.</p>	<p>Heat insulation layers on casings and turbine blades as well as abrasible linings in component classes 1 and 2.</p>



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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.

Blackbird turns 50

The legendary Lockheed SR-71 still holds world record

Looking like it might have come from Q's workshop in a James Bond film, the Lockheed SR-71 Blackbird is in fact from the same period, completing its maiden flight in **December 1964** and entering service with the U.S. Air Force in **January 1966**. Commissioned by the CIA, it was developed in the legendary secret "Lockheed Advanced Development Project Unit," better known as

"Skunk Works." Only **32** of these stealth reconnaissance aircraft were built. In 1976, it set the world record for fastest air-breathing manned aircraft, flying at **3,529.6 kilometers per hour**, or just under **Mach 3.2**, and it still holds this record today. The Blackbird escaped discovery and avoided threats by simply accelerating and climbing higher, up to a service ceiling of **25 kilometers**. Flying across the entire continental U.S. took roughly **70 minutes**.

But just as revolutionary as the aircraft design were the materials used in it. The airframe consisted of **85 percent titanium**; the rest was made up of a variety of materials, including polymer



composites. While the aircraft's unusual form provided camouflage, adding cesium to the fuel also helped mask it by changing the radar echo from the exhaust fumes.

The SR-71 was powered by two **JT11D-20 turbojet engines** from Pratt & Whitney (military designation **J58**) with ram jet function. Channeling part of the inflowing air

through six tubes directly into the afterburner and bypassing the compressor increased efficiency.

Only **86 carefully selected pilots** were permitted to fly the two-seater; the second person on board was a reconnaissance officer whose job entailed photographing and filming, preferably behind the Iron Curtain. The last SR-71 flight—then on a mission for NASA—took place on **October 9, 1999**. Now the futuristic-looking aircraft can be admired in various aviation museums, including the Imperial War Museum in Duxford, England, and the Smithsonian Institute in Washington, D.C.

Aviation in figures

3.5 billion The number of passengers the world's airlines will have transported in 2015.

9.6 million The number of passengers transported in one day—that's more than in all of 1945, the year the civil aviation organization IATA was founded.

More than a third How much of the global trade volume by value is transported by air freight.

58 million The number of jobs civil aviation accounts for worldwide if we include those created by air tourism.

Heights of luxury



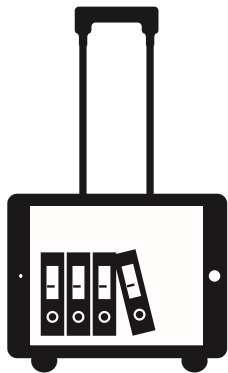
Widebody jets with customized interiors

That well-off customers travel in privately owned luxury jets is no secret—but the details of their luxurious interiors are usually kept hidden. Understandably, it's a topic that manufacturers treat with utmost discretion. Despite this, we've uncovered a few trends from a world that even first-class passengers can only dream of. We're not talking about small private aircraft, here—VVIPs are choosing to fit out widebody jets such as the Airbus A380. Standard features have long included **gilded washbasins**, **sauna facilities** and **Jacuzzis** with overflow channels to ensure that the water stays in the tub during turbulent flights. Another popular addition is a **private prayer room with an electrically adjustable prayer mat** that turns to point toward Mecca in flight. In 2007, Airbus was commissioned to build an A380 featuring an onboard **concert hall** and a **glass elevator** leading from the tarmac straight into the **330 m²** suite of rooms. Although this particular order proved no more than a flight of fancy, the market for luxury fittings is very real indeed, with the price of such customized cabin interiors reaching into the **hundreds of millions U.S. dollars**.



Work faster, travel lighter

Tablet PCs replace flight bags



1 tablet PC instead of **1 flight bag**

354g instead of **15kg**

A leather pilot case with wheels can weigh up to 5 kg when empty; once filled with manuals, tables and maps, its weight may be up to 15 kg.

64 GB instead of **4,267,000 pages**

New iPads come with up to 64 GB of memory, which is equivalent to the amount of data contained in somewhat more than four million pages in Word.

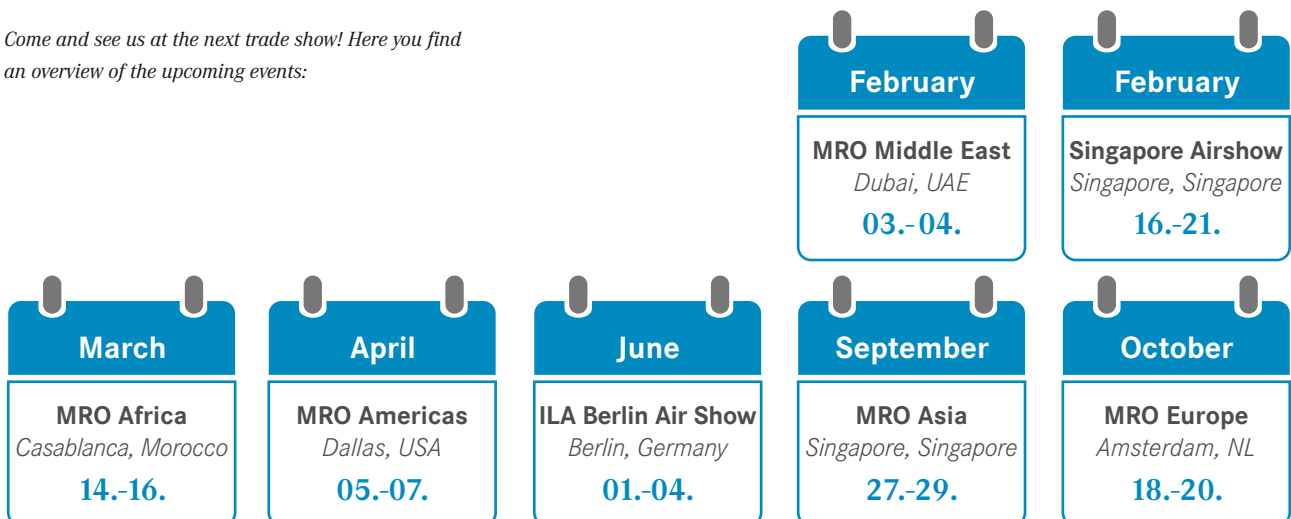


For decades, the large, dark-colored cases used by pilots to carry their in-flight documentation were a familiar sight in the aviation world. Filled with performance-calculation tables, countless navigational charts, aircraft operating manuals and other important documents, these cases contained more or less everything the pilot needed to have close at hand in the cockpit to fly the plane. But pilot cases are becoming increasingly rare as more and more airlines

replace them with the electronic equivalent: a tablet PC. These electronic flight bags (EFBs) range from modified versions of commercially available tablet devices to custom-made specialist equipment. Although they were introduced primarily to improve information quality and processing speed, EFBs provide a welcome secondary benefit: they are lighter. Without all those manuals, maps and flight documents, the weight can quickly be reduced by several kilos.

Trade show calendar 2016

Come and see us at the next trade show! Here you find an overview of the upcoming events:



Yesterday & today: Cockpit

These photos are separated by only about three decades, and yet it's plain to see how the design of the pilot's workplace has changed in this short time. The A310's cockpit (above) was state of the art in its day, but now appears hopelessly old-fashioned compared to that of the A350 (below).

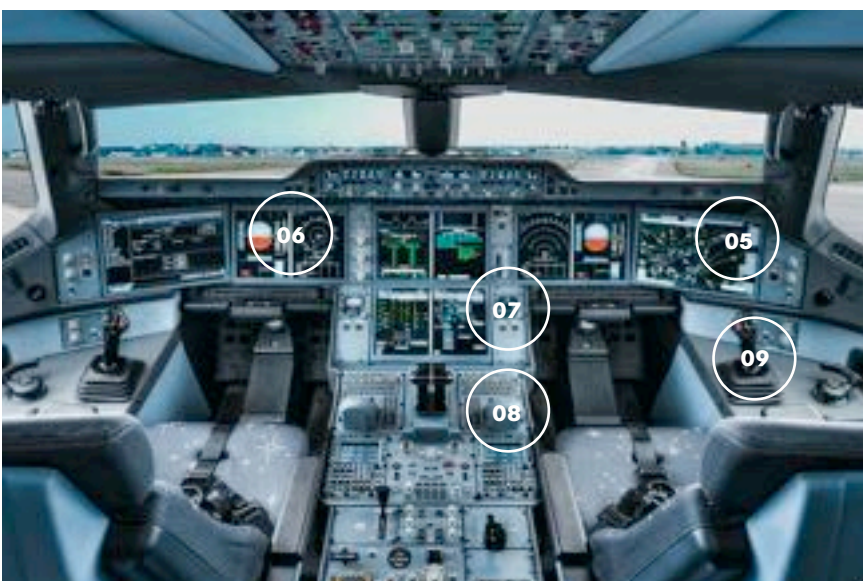
yesterday



A310 COCKPIT, CA. 1985

- 01** ____ Comparatively small, square cathode ray tube (CRT) monitors for displaying flight condition (primary flight display) and flight path (navigation display).
- 02** ____ Conventional analog instruments for displaying key parameters and serving as backup for the monitors.
- 03** ____ Conventional yoke connected directly to elevators and ailerons.
- 04** ____ "Flight management system" (FMS): small, keyboard-operated monochrome monitor.

today



A350 COCKPIT, 2015

- 05** ____ "Onboard information system" (OIS): electronic display of aeronautical charts and checklists.
- 06** ____ PFD and ND have been combined side by side into one large liquid crystal display (LCD) screen and contain a wealth of additional information (e.g. a vertical profile along the flight path).
- 07** ____ Electronic backup systems (also on monitors) for displaying essential notifications.
- 08** ____ "Flight management system" (FMS): large color monitor operated by means of a graphical user interface using a mouse.
- 09** ____ Side-stick, whose inputs are transmitted electronically to the rudders after being checked by the onboard computer.

Nonstop

The five longest commercial flights in the world



More than 16 hours nonstop in the air, covering a distance of 10,000 kilometers—roughly one-quarter of the earth's circumference. Those on board need plenty of patience! We've put together a list of today's top five ultra-long-haul flights:

	<i>Departure/arrival</i>	<i>distance</i>	<i>flight time</i>	<i>aircraft</i>	<i>airline</i>
1	<ul style="list-style-type: none"> ✈️ Dubai ✈️ Panama City 	13,821 km	17:35 hours	Boeing 777-200LR	Emirates (starting February 2016)
2	<ul style="list-style-type: none"> ✈️ Johannesburg ✈️ Atlanta 	13,582 km	16:52 hours	Boeing 777-200LR	Delta Airlines
3	<ul style="list-style-type: none"> ✈️ Dallas ✈️ Hongkong 	13,073 km	16:50 hours	Boeing 777-300ER	American Airlines
4	<ul style="list-style-type: none"> ✈️ Jeddah ✈️ Los Angeles 	13,409 km	16:40 hours	Boeing 777-300ER	Saudia
5	<ul style="list-style-type: none"> ✈️ Abu Dhabi ✈️ Los Angeles 	13,502 km	16:35 hours	Boeing 777-200LR	Ethihad Airways

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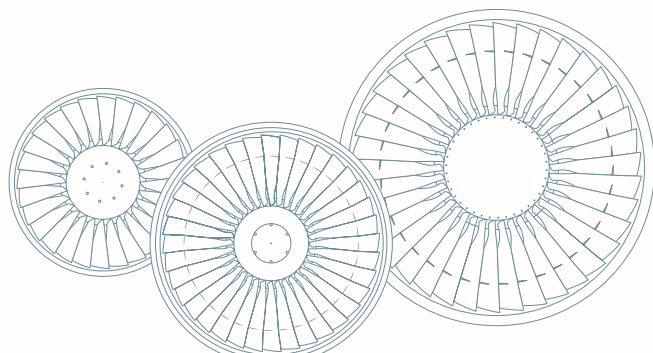


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