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EYES IN THE SKY SEE THE WORLD CHANGING

FLYING AT THE EDGE – Atmospheric research with HALO

TO SPACE – ROCKETS ALIGHT: future launchers are to be ignited by lasers

OTTO LILIENTHAL – The man who brought order to aerodynamics

DLRmagazine 150

Image: DLR/Gesine Born

Dear readers,

I was recently asked whether I believe in climate change. But I do not consider climate change to be a question of belief. Carbon dioxide concentration in the atmosphere has increased from 280 ppm (parts per million) to a dramatic 400 ppm since human beings started large-scale burning of fossil fuels. Average global temperatures have risen by 0.8 degrees Celsius within one century. This phenomenon can no longer be explained by natural changes. The World Climate Council is equally certain: human behaviour is involved in the gradual warming of our climate. The repercussions are tangible. Extreme weather conditions, such as droughts, torrential rain and flooding are becoming increasingly frequent. Climate zones will shift in the future. Rising sea levels will flood entire coastal regions. Viewed simply from the perspective of security policies, the implications of scarce drinking water and people seeking new homes are already apparent around us.

What can we do? Germany has already accepted a pioneering role through its initiation of the energy transition. The National Climate Action Programme has also defined ambitious goals. The scientific community can and must indicate suitable solutions. DLR is already making valuable contributions to contain the consequences of human actions for the environment. Among other things, it is developing lightweight concepts for aircraft and motor vehicles, has joined with industrial partners to research green aircraft engines, and is collaborating with other climate researchers to decode the processes unfolding across the atmosphere. Remote sensing data help confirm environmental changes.

You will be able to view the results – such as eco-efficient flying, for instance – at the international aerospace exhibition, ILA Berlin Air Show 2016. We would be delighted to have you there, so you can see for yourself. Our magazine is also available to inform anyone unable to make it to the German capital.

Sabine Hoffmann
Head, DLR Corporate Communications Department

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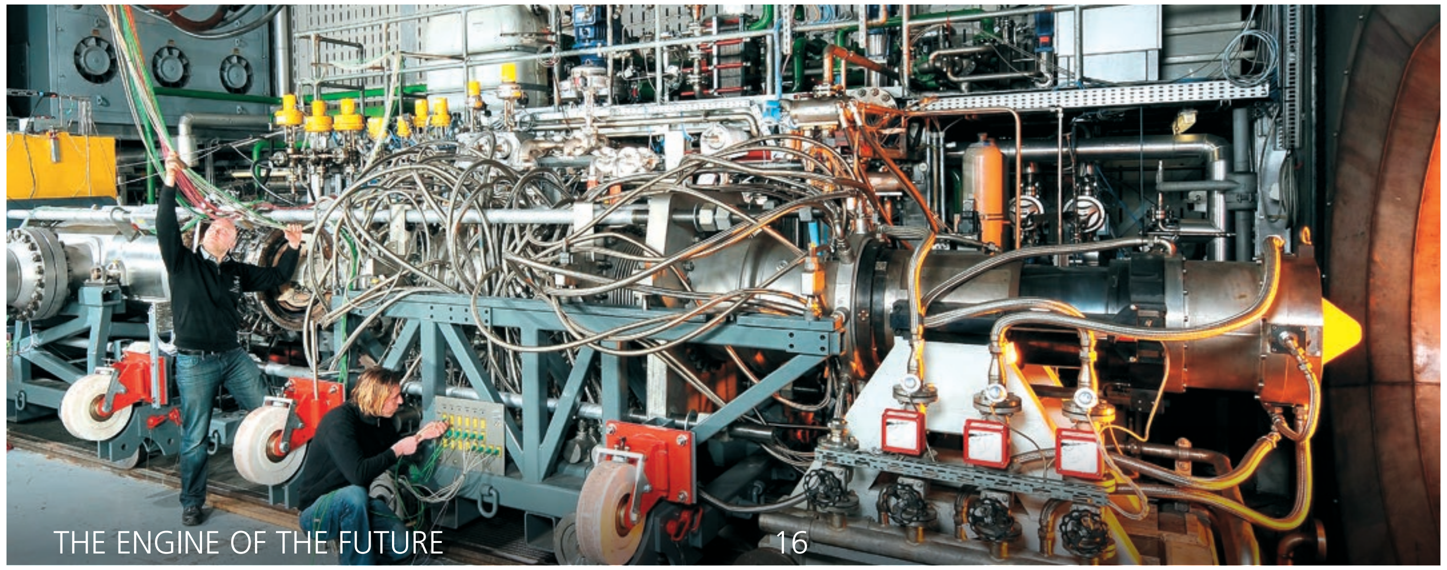

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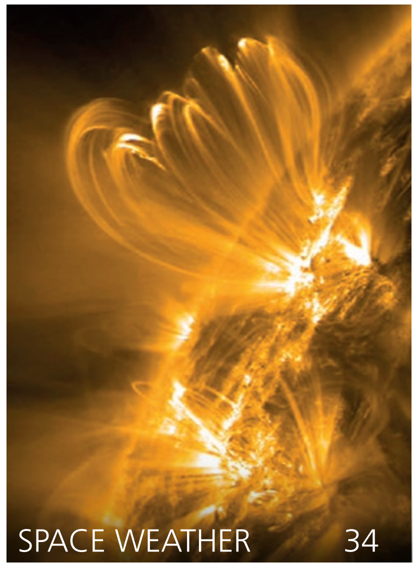

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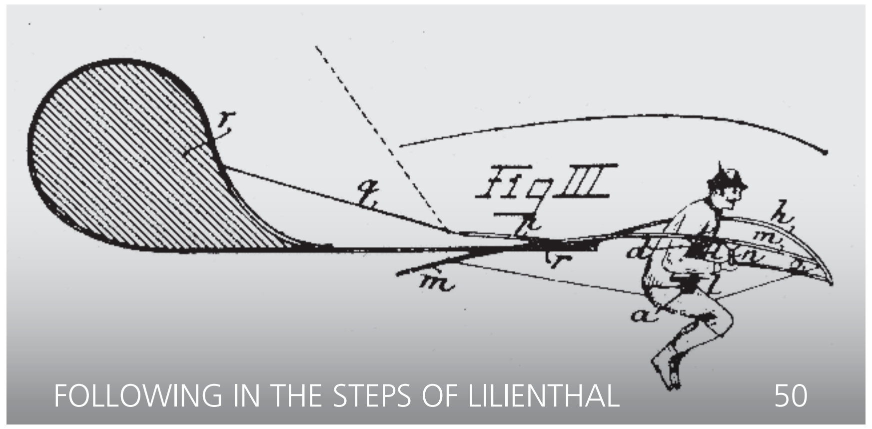

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GERMANY – AN AEROSPACE LOCATION IN A CHANGING WORLD

A commentary by Sigmar Gabriel, German Federal Minister for Economic Affairs and Energy

Image: BMWi

Sigmar Gabriel was appointed as Federal Minister of Economic Affairs and Energy and Vice Chancellor of the Federal Republic of Germany in 2013. He has been Chairman of the Social Democratic Party of Germany since 2009.

Germany is well positioned in aerospace – in research and science, as well as in industry. With a recent turnover of 32 billion euro and over 105,000 employees, this sector guarantees state-of-the-art technology, added value and good employment in Germany.

We also owe this success to DLR, as a strong research partner for industry. With its 33 institutes and departments such as the Space Administration or the Project Management Agency, DLR is highly respected – at home and abroad. In addition to DLR, German aerospace relies on a tight network of research institutions with excellent staff and outstanding facilities. To me, this research strength is a substantial positional advantage.

But the world does not stand still. Alongside the established aerospace nations, more and more new players are becoming internationally recognised with their own industry and rapidly developing research. In addition, numerous societal challenges must be overcome in the interest of the next generation – environmental and climate protection, the shaping of demographic change, sustainable mobility and the global battle against poverty and for development, to name a few.

I am sure of this – every single one of these challenges also presents an opportunity, especially for German aerospace. In times of great tasks, a unique opportunity arises to, once again, demonstrate its position as a driver of innovation.

The aviation industry is already working on its contribution to the transport system of the future – one that facilitates global mobility while conserving natural resources. In this way, it is possible not only to develop new markets for innovative solutions and products, but also to generate real social value.

In space exploration, it is our declared priority to develop applications for use on Earth. In the space strategy of the German Federal Government, this is referred to as 'Space for Earth'.

Collaborative work is necessary for the tasks of the future. I have already referred to the partnership between research and industry, but in times of digitisation and Industry 4.0, successful cooperation is affected less and less by rigid boundaries between disciplines and sectors. Interdisciplinary work has become increasingly important to tackle the problems of our time and combine strengths as we are doing, for example, with our partners in the Alliance for Industry.

The ILA Berlin Air Show is once again a good opportunity to network, especially in the field of aerospace. After all, ILA has become much more than a trade fair; it is a marketplace for ideas and a showroom for innovation. This is an outstanding approach.

This year at ILA we will celebrate the 125th anniversary of the first human flight by Otto Lilienthal. Of this I am sure – Otto Lilienthal set in motion an unparalleled history of innovation, which is not only far from over, but has truly just begun.

TRAILING EDGES THAT SNAP LIKE A FLYTRAP

DLR has initiated a project designed to create a morphing wing trailing edge that can be smoothly transformed into any shape and will make conventional flaps redundant. The new and flexible moving mechanism is inspired by the Venus Flytrap's trapping structure, which is among the fastest in the plant kingdom. To ensure that no insect can escape, it uses changes in pressure exerted on the cells of its leaves and a leaf-shape geometry optimised through evolution to capture prey between trapping fronds. The mechanism snaps shut as soon as the sensitive bristles on the inside detect suspicious movement. Researchers from the DLR Institute of Composite Structures and Adaptive Systems have exploited this principle of a dynamic cellular system, able to assume certain forms when exposed to changes in pressure, in order to develop a new trailing edge.

Image: J.W. Webb (CC BY-SA 2.0)

The leaf structure in the capture mechanism of a Venus Flytrap inspired the innovative, gapless flap technology.

The scientists designed a hitherto unseen flap demonstrator made of polymer cells driven by compressed air, which are able to flexibly assume aerodynamic shapes for cruising or landing. The benefit of this kind of wing technology is that – unlike the landing flaps on current commercial airliners – extending the flaps does not produce any gaps that impair aerodynamic characteristics. In addition, conventional landing flaps require sophisticated mechanical components and panelling that – together with the resulting gap – lead to an increase in fuel consumption and aircraft noise, which are additional drawbacks. Researchers will soon begin conducting wind tunnel tests on this new flap technology.

s.DLR.de/3b98

FLYING ROBOTS INSPECT SERVICE ROBOTS

Mobile inspection robots crawl over pipelines and use special sensors to identify critical points. What sounds like science fiction is in fact already reality. But human beings will need to get involved in the event that these robots require maintenance. DLR scientists from the Robotics and Mechatronics Center have found a way to place even maintenance in the hands of robots. The EU project ARCAS (Aerial Robotics Cooperative Assembly System) fitted a robotic gripper arm with seven degrees of freedom to a self-piloting helicopter to replace the human hand when conducting work on inaccessible points. This way, the robots can inspect and even service the pipelines, avoiding risks to humans.

Autonomous Flettner helicopter with integrated robotic arm

The system uses GPS to navigate on its own to the desired position. Upon arrival at its destination, it activates several fitted cameras to switch to a precise image processing system that allows pinpoint localisation of the inspection robot. It also enables exact positioning of the robotic arm to grab the inspection robot and transport it to a secure location. In the future, the airborne robot will be able to conduct repairs while hovering directly above defective parts. This kind of system will also be capable of servicing satellites or man-made habitats on other planets.

s.DLR.de/uy8k

SELF-PARKING CARS

Engineers have developed an application that assigns cars an active role and therefore takes them another step closer to automatic parking. Here, the vehicle parks by itself in front of the supermarket and can even be summoned back to the disembarking point once the owner has finished shopping. In 'Connected Valet Parking', developed by experts from DLR and T-Systems, the car uses a smartphone to communicate with a data platform that manages and networks information and services in the background and enables it to navigate the barrier and to park by itself. The parking fee is debited automatically by mobile phone. Authorised supermarket staff can even use electronic keys to open the vehicle and deposit groceries.

NEXT STOP: THE RED PLANET

On 14 March 2016, ExoMars set off on its quest to find biological life on Mars. A joint mission between Europe and Russia, it is scheduled to reach the Red Planet in October 2016. On board the spacecraft are the Trace Gas Orbiter (TGO) and Schiaparelli. Schiaparelli will touch down on the surface of Mars to gather data while TGO will remain in an orbit 400 kilometres above the planet to analyse the atmosphere. Work will focus especially on the trace gas methane, which is produced by biological and geological processes alike, and may therefore indicate the presence of life. Schiaparelli will test various technologies in preparation for the difficult touchdown on Mars – among these, thermal protection materials, a parachute, a Doppler radar altimeter and a propulsion system for the final phase of the landing manoeuvre.

Image: DLR/Ernsting

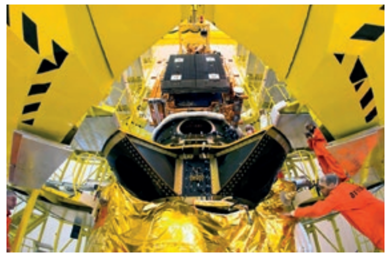
IMPROVING THE USE OF AIRSPACE

DLR and the National Aerospace Laboratory of the Netherlands (NLR) have become members of the Single European Sky ATM (Air Traffic Management) Research programme, or SESAR 2020EU. It aims to develop a new system to standardise European airspace. At present, the air traffic control system in Europe looks after 1.6 billion passengers on roughly 10 million flights per year. The current predictions assume there will be 14.4 million flights in 2035. This will prove an immense challenge for air traffic management, especially if one considers the partial fragmentation of European aerospace and the large number of organisations involved in aviation. It will therefore be vital to introduce innovative procedures and technologies alongside closer cooperation.

SENTINEL-1B IN ORBIT

Two eyes are better than one; this principle is also true for the two radar satellites that make up the Sentinel-1 mission. On 25 April 2016 at 23:02 CEST, the Sentinel-1B Earth observation satellite lifted off from Europe's spaceport in French Guiana on board a Soyuz launch vehicle. Together with its twin satellite, Sentinel-1A, it will monitor landmasses and oceans, registering even small changes in the environment.

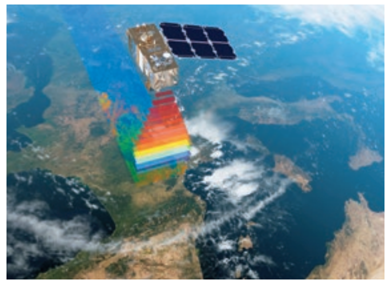
Working together with its identical twin, Sentinel-1A, which was launched in April 2014, it will monitor Earth's terrestrial and marine ecosystems with millimetric precision. The satellites will document the melting of glaciers, changes in land use or the condition of rain forests over an extended period. Each of the satellites will collect data for at least seven years.



COLLABORATING WITH JAPAN

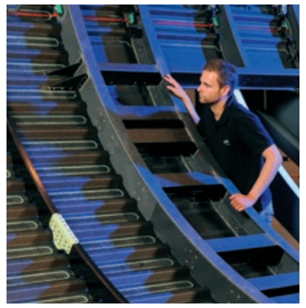
DLR and JAXA (Japan Aerospace Exploration Agency) have agreed on a strategic partnership that will serve as a framework within which the signatories will cooperate in space exploitation as well as in research and development (for instance using L- and X-band technologies in radar-assisted Earth observation) or in disaster management. There are also plans to research reusable launch vehicles and to conduct joint projects to explore the Solar System: DLR's MASCOT lander is currently making its way through space on JAXA's Hayabusa2 mission, during which it will touch down on asteroid Ryugu. In addition, Germany and Japan make intensive use of the International Space Station (ISS) to investigate issues in the areas of medicine, material development, and basic research.

Image: German Embassy Tokyo



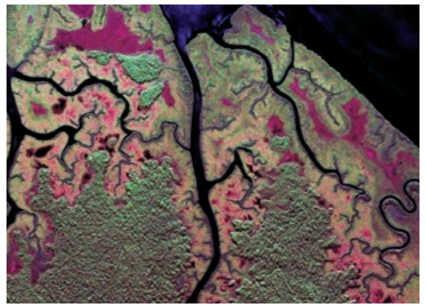
SATELLITE DATA FOR RENEWABLE ENERGIES

Supported by the DLR Space Administration, the COP4EE project involves methods and services to process satellite image data for use by energy planners. To do so, the methods and services provide information on the exploitation of renewable energy sources. Here, users have particular access to data from the Sentinel satellites within the European Copernicus programme. Sentinels 1 and 2 fly over special planning areas every six days, taking high-resolution images of the Earth's surface. This permits the creation of information sequences on wind conditions, changes in biomass or terrain erosion. In addition, data from the German RapidEye programme is also available for use. The data acquired by TerraSAR-X is particularly interesting, as its radar beams are able to penetrate through cloud cover.



COMPONENT NERVE SYSTEMS

DLR has developed and built an aircraft component made of carbon-fibre reinforced polymers (CRP). Its purpose is to make this material even safer for use in aircraft. It is able to provide information on the extent and location of damage, so that it is no longer necessary to dismantle and laboriously analyse the defective part. This in turn simplifies maintenance and repair, and ensures that damage is not left undetected. The CRP component was fitted with a kind of nerve network. 584 sensors are integrated within a five by seven metre fuselage section. In the future, it will no longer be necessary to call a technician to track down any defects if an aircraft is damaged, for instance if a section is chipped during loading procedures. With the press of a button, the aircraft structure is able to provide information on precisely which section is damaged.



RADAR IMAGING OF THE RAINFOREST

DLR scientists took to the skies on board the DO228-212, a twin-engine research aircraft fitted with high-end radar technology, to conduct numerous measurement flights across Gabon in central Africa. In this way, they were able to determine the condition of the rainforest. The data helps to improve climate models and to understand global warming. The Earth's climate system is extremely intricate and dependent on many factors. Forests cover approximately one third of its landmass. The implications of windthrow or forest clearing and other factors are particularly serious, as forest biomass stores half of the Earth's total carbon. Moreover, it is not yet possible to predict precisely the effects of reforestation on the carbon cycle. This makes global inventories of forest surfaces and their changes such an immensely important task.

ROCKET SCIENCE FOR STUDENTS

Rocket experiments are frequently conducted at the Esrange Space Center in north Sweden. A double campaign – REXUS 10 and 20 – took to the skies once again in March 2016. Hailing from five countries, 45 students in eight teams developed, built and conducted their own experiments, which featured flights to an altitude of over 70 kilometres. The six-metre research rockets each experienced two minutes of near weightlessness while airborne. Among other things, the experiments were designed to investigate thermal protection, communication systems, simulation of tumbling motions in uncontrolled satellites, the spreading of flames in a microgravity environment, acquisition and transmission of atmospheric data, cell membrane testing, and the study of boiling processes.

Image: ZARM

MEET DLR AT …

WONDERS OF NATURE
11 March – 30 December 2016 • Oberhausen
The 'Wonders of nature' exhibit at the Gasometer in Oberhausen follows growth and development on our planet, and celebrates its intelligence and diversity. The highlight of the exhibit is Earth, which is brought to life, glowing in the immense interior of the Gasometer.

A NEW PERSPECTIVE ON MARS
1 April – 1 July 2016 • Colorado Springs, USA
The 3D exhibit 'A New Perspective on Mars' at the Space Foundation World Headquarters and Discovery Center, showcases high-resolution images acquired by the DLR-operated HRSC camera on board Mars Express. Orbiting Mars for more than 10 years now, the mission is providing fascinating insights into the geology of our neighbour, not to mention jaw-dropping images.

ONERA-DLR AEROSPACE SYMPOSIUM
21 – 23 June 2016 • Weßling, Germany
ODAS is an annual event bringing young doctoral candidates and scientists from ONERA and DLR together to enhance scientific exchange between the two institutes. This year the main topic will be 'Remote Sensing', focusing on the German-French cooperation regarding carbon dioxide and methane detection/monitoring.

AUTOMATICA – 7TH INTERNATIONAL TRADE FAIR FOR AUTOMATION AND MECHATRONICS
21 – 24 June 2016 • Munich, Germany
The leading trade fair for industrial automation and mechatronics, AUTOMATICA features six halls focusing on topics ranging from sensors and drive technology to service robots. DLR is presenting the latest from its Robotics and Mechatronics Center in Oberpfaffenhofen at this year's fair in Munich.

GERMANY AEROSPACE CONGRESS
13 – 15 September 2016 • Braunschweig, Germany
The 65th Congress of the German Society for Aeronautics and Astronautics (DGLR) brings together experts from the aviation and aerospace industries to present the latest on a wide range of topics in the sector through conferences and symposia.

INNOTRANS
20 – 23 September 2016 • Berlin, Germany
The leading international trade fair for transport technology returns to Berlin this year, and DLR is taking part via its current research projects. The fair is divided into five different segments covering rail and transport technology and infrastructure and includes 3500 metres of rails in the track and outdoor area.

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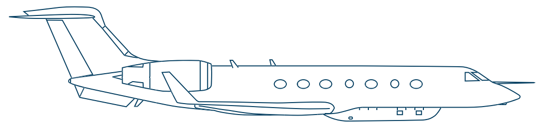
HALO on the landing strip at Kiruna in northern Sweden. This aircraft is the ideal all-purpose tool for climate research in the North Polar region. The research aircraft is flexible; it has a range of 8000 kilometres, extensive space for scientific instruments and can fly at altitudes of up to 15 kilometres. With these capabilities, HALO is one of the few research aircraft that can fly to the North Pole.

Image: DLR/Andreas Minikin

FLYING AT THE EDGE



HALO – the ideal platform for climate scientists. In the three most recent measurement campaigns, this atmospheric research aircraft revealed its performance capabilities.

By Fabian Locher

DLR researchers have explored climate change above the Arctic Circle and its effects on the polar atmosphere in close cooperation with other German research institutions. During three measurement campaigns (POLSTRACC, SALSA, GW LCYCLE) with HALO (High Altitude and LOng Range Research Aircraft) and the DLR Falcon, departing from Kiruna in northern Sweden, they investigated changes in the composition of the atmosphere throughout the polar winter.

One goal of the POLSTRACC (Polar Stratosphere in a Changing Climate) campaign is to examine polar ozone chemistry. The Earth's ozone layer is recovering since the late 1990s. This is due, above all, to the stringent regulations on the emission of climate-damaging chlorofluorocarbons (CFC). Ozone not only protects Earth from dangerous solar radiation; it is also a greenhouse gas. Ozone has a strong effect on the climate – especially in the tropopause region, the transition layer between the troposphere and the stratosphere at an altitude of eight to 16 kilometres. Due to the increasing concentration of carbon dioxide in the atmosphere, the temperatures at ground level and in the troposphere are increasing, and decreasing in the stratosphere. In the polar winter, this can lead to the formation of more polar stratospheric clouds – especially in the Arctic. These clouds promote the degradation of the protective ozone layer. While an extensive hole forms over Antarctica in the southern hemisphere spring, the ozone depletion above the Arctic is usually less pronounced. During the winter of 2015-16, this was not the case. "In 2015-2016, we had an extremely cold period in the Arctic stratosphere, with temperatures falling as low as minus 90 degrees Celsius. This allowed us to observe extensive fields of polar stratospheric clouds for several weeks and examine their effect on the ozone layer," explains Christiane Voigt, scientific coordinator of DLR's activities during the POLSTRACC campaign. The increase in stratospheric cloud cover contributed to the fact that, by the beginning of March 2015, the ozone layer in the polar vortex was reduced by almost 50 percent.

No trend can be deduced from measurements over a single winter. However, DLR researchers estimate that if there is further cooling of the stratosphere, the number of cold winters in the Arctic will increase, thus intensifying ozone depletion. Since ozone absorbs a part of solar radiation, this might lead – particularly in spring – to increased ultraviolet exposure for the inhabitants of northern and central latitudes.

For the measurement campaigns, researchers from the DLR Institute of Atmospheric Physics equipped HALO with a laser spectrometer to measure the stratospheric clouds, a nitric oxide instrument for determining the nitric acid content of the clouds, and a mass spectrometer to measure chlorine compounds in the air. The POLSTRACC measurement campaign led by the Karlsruhe Institute of Technology (KIT) was conducted jointly with the SALSA (Seasonality of Air mass transport and origin in the Lowermost Stratosphere using the HALO Aircraft) mission, under the leadership of the University of Frankfurt.

The focus of GW-LCYCLE (Gravity Wave Life Cycle Experiment) was to study the propagation of gravity waves. These gravity-driven oscillations of air masses are excited in the lower levels of the atmosphere – for instance, by airflows over mountains. The resulting turbulence transports energy and momentum to the higher levels of the atmosphere, where they become unstable and dissipate above an altitude of 50 kilometres (stratosphere or mesosphere). This causes wind speed and temperature fluctuations, and has an effect on the energy balance and – over the long-term – the climate. However, how exactly gravity waves affect global warming has not yet been sufficiently explored. Studies on the phenomenon of gravity waves have been conducted, but they were mainly studied in either the lower or upper layers of the atmosphere.

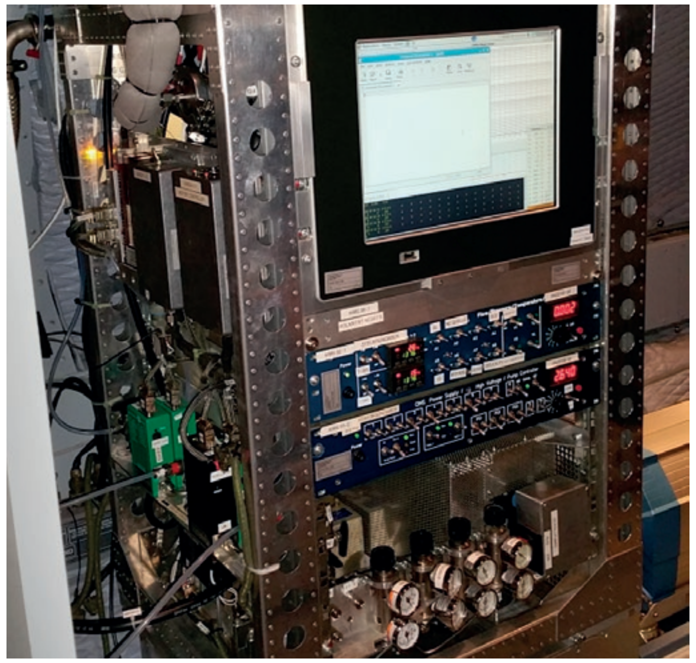
The individual layers of the atmosphere are, however, in a situation of constant interchange. This is why the researchers used a second aircraft from the DLR fleet – the Falcon. In several combined flight experiments, Falcon and HALO flew one above the other in formation. HALO directed its measuring instruments in the direction of the upper atmosphere, while the Falcon observed the lower atmospheric layers. "HALO flew in the transition region between the atmospheric layers. The Falcon, on the other hand, flew much lower, and directed its measuring instruments partly downwards and partly upwards, observing altitudes of up to 85 kilometres," explains Oliver Brieger, Head of Flight Operations at the DLR Flight Experiments Facility.

Various instruments were used for measuring the gravity waves – laser devices for the detection of wind, trace gases and aerosols; an imaging infrared spectrometer for remote sensing of the 3D distribution of temperature and trace gases; and instruments for the in situ measurement of the concentration of trace gases in the atmosphere. Since gravity waves are very small-scale phenomena and are extremely difficult to measure, DLR took a creative approach. In order to study this weather phenomenon, the researchers used a special camera to image the appearance of gravity waves in the 'airglow' at an altitude of 85 kilometres (ionosphere), which are caused by chemical reactions in this atmospheric layer.

"Previously, it was only possible to measure gravity waves in the lower or upper atmosphere. Now, we are able to measure them throughout the atmosphere," enthuses Markus Rapp, Director of the Institute of Atmospheric Physics. "This is an important step in climate research, to understand atmospheric flow patterns and make predictions."

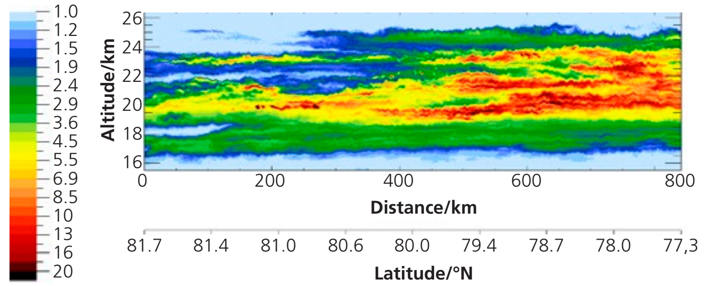
HALO shortly before take-off. The atmospheric research aircraft is based on a Gulfstream G550 long-range business jet. The combination of long range performance, the ability to operate at high altitudes, an extensive payload capacity and comprehensive instrumentation makes it a globally unique research platform.

A view of the flight deck. The transition region between the troposphere and stratosphere at an altitude of up to 16 kilometres is technically difficult to explore. However, this region has a large influence on the atmospheric energy balance, the oxidation capacity and the vertical transport of momentum and trace gases. In addition, the effect of high-altitude ice clouds (cirrus) on climate disturbances is of enormous importance. The climatic impact can be strengthened or weakened as a result.

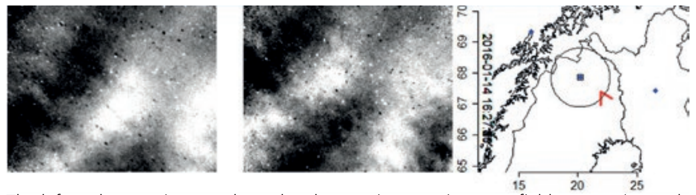


AIMS mass spectrometer. To better understand the processes leading to polar ozone loss, it is important to characterise the evolution of the chlorine species throughout the winter. Using the airborne mass spectrometer (AIMS), scientists can analyse chlorine compounds in the polar stratosphere.

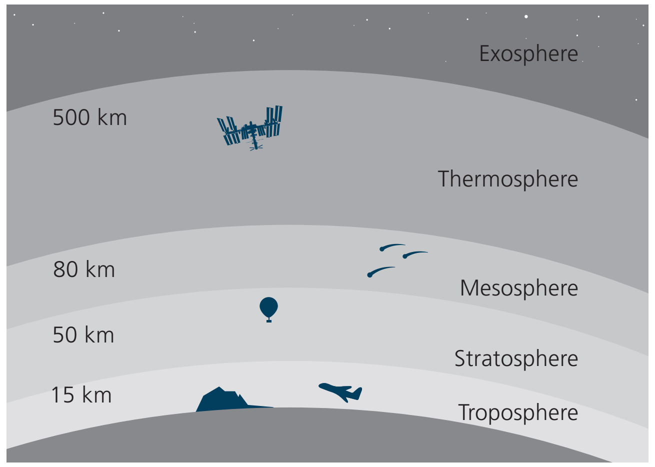
The interior of HALO. There are up to 15 racks for scientific instruments in the cabin. At the front right of the image are two instruments; one for measuring humidity (hygrometer) and ozone. In the background is the airborne mass spectrometer AIMS. It measures halogen and nitrogen oxide compounds that promote polar ozone depletion.



As part of the POLSTRACC campaign, DLR researchers measured polar stratospheric clouds (PSC) in the North Polar region using a LiDAR (Light Detection And Ranging) instrument. The image shows a horizontally extended PSC at an altitude of 17 to 25 kilometres. At the core is an ice cloud embedded in cloud layers of supercooled droplets and solid particles containing nitric acid. On the surface of the cloud particles, halogen-containing compounds are processed. During the polar spring, these compounds are activated and lead to polar ozone loss. The red areas indicate strong backscattering from the ice clouds, which accelerates polar ozone depletion.



The left and centre images show the changes in a gravity wave field over an interval of a few seconds. The black and white dots are stars that have not been entirely eliminated and are amplified by the differential image. The right-hand image shows northern Scandinavia. The red arrow marks the position of the DLR Falcon; the blue dots are ground stations.



The most recent measurement campaigns were carried out in the fascinating transition region between the troposphere and stratosphere

ON MISSION TO THE ARCTIC CIRCLE

During the latest mission, scientists from DLR, in close cooperation with other German research institutions, examined the complex processes of climate change and their effects on the polar atmosphere. On board HALO (High Altitude and LOng Range Research Aircraft), changes in the composition of the upper troposphere and lower stratosphere during the polar winter were studied over the course of three measurement campaigns.

HALO – FLAGSHIP OF GERMAN CLIMATE RESEARCH

HALO Is a joint project of German environmental and climate research institutions, and is supported by grants from the Federal Ministry for Education and Research (BMBF), the Deutsche Forschungsgemeinschaft (DFG), the Helmholtz Association, the Max Planck Society (MPG), the Leibniz Association, the state of Bavaria, the Karlsruhe Institute of Technology (KIT), the German Research Centre for Geosciences (GFZ), the Forschungszentrum Jülich and DLR.

UNDERSTANDING WHAT HAPPENS IN THE SKY

Interview with DLR test pilot Steffen Gemsa, by Fabian Locher

Mr Gemsa, as a test pilot at DLR Oberpfaffenhofen, the aircraft you fly include Falcon and HALO. How long have you been flying?
: Next year, it will be 30 years.

How many flight hours?
Altogether, I have completed around 7000 flight hours.

How did you get into flying?
: Flying has captivated me as far back as I can remember. I always thought it was fascinating. Naturally, you don't directly become a test pilot. There is a small airfield near where I grew up. I started there as a 15-year-old, flying gliders. Since then, I have never stopped flying. After graduating from secondary school, I went to Stuttgart to study aerospace engineering. There, I then worked as a scientist and researched adaptive wing systems. Eventually, I missed actual flying, so I obtained my pilot's license and worked for a while as a flying instructor.

And how did you become a test pilot?
: I started working at DLR as a technical pilot and, in 2004, I began training as a test pilot.

Now, you fly all the research aircraft that are stationed at DLR Oberpfaffenhofen – HALO, Falcon, the Do 228 and the Cessna 208B Grand Caravan. Do you have a favourite?
: Quite honestly, they are all great aircraft. Each one is the best for the tasks assigned to it. For example, HALO is a long-distance aircraft and ideal for climate research missions. The Do 228, the other hand, is used principally for remote sensing missions. With this aircraft, you can land on a gravel landing strip or take off from very short runways. That has its appeal. The Dornier, on the other hand, cannot fly 12,000 kilometres at a time, as can HALO, which is a rebuilt Gulfstream 550 especially suited for high altitude and long flights for German environmental and climate research institutions. Every platform has its own special charm, and I really cannot talk about a 'favourite aircraft'. The variety makes things exciting.

HALO flies on behalf various research groups. Do you sometimes feel pressured by the scientist's expectations?
: Expectations are always high. The projects are very expensive and the scientists expect good measurements. However, safety always comes first. At the end of the day, all those on board must make it home safely. For me, as a pilot, that is the central focus of every mission. If I manage to do this, and good scientific results have been achieved at the end of the day, then it was a great flight.

So you concentrate on flying and block out the scientific tasks while you are in the air?
: (Thinks it over) I would not exactly agree with that. After all, the aircraft is in the air for science – that is what it was built for, and that is what it is being paid for. My job as a pilot is to fly the aircraft so that the mission objectives can be best achieved without compromising safety.

That is certainly a topic for lively discussions…
: Definitely! The scientists would not say what is possible in terms of flying – which they certainly should not do. They do not know what is acceptable, and where the aircraft reaches its limits. The scientists always have big ideas and all kinds of wishes. I think that this is the way a scientist should also approach the topic of research flights. Our task, on the other hand, is to filter the scientist's ideas to the point where we can ensure a safe flight while allowing them to collect the maximum amount of data. There is always some tension with this, and you have to be able to withstand that. Luckily, scientists are intelligent human beings, who understand sensible arguments and can comprehend what is going on (laughs).

To what extent do you get involved with the scientific background of a mission in advance?
: Obviously, I cannot interact extensively with all the topics; they are too complex and too varied. I cannot and should not do that. However, the better the scientists make us pilots understand what they are looking to achieve, the better the results that we can get out of each measurement flight. I have flown measurement campaigns where I had no idea what the scientists were doing; in those cases, I was just the 'driver'. But on the most recent HALO mission in Kiruna, we obtained some great results, simply because we knew what the scientists really wanted to study. With us in the cockpit, there is, so to say, another data source available – our experience. Most scientists know how to take advantage of this, and many see their pilots as additional scientific instruments.

An experienced pilot as an additional measuring instrument?
: Yes, because if nobody talks to the pilots ahead of time, then we simply fly the predetermined route. But if we have an understanding of what is going on, during the flight we can give advice, based on our experience, that may prove valuable for the mission. Sometimes we can even know what will happen in the next few moments even before the measuring instruments. If disturbances occur in the flight, or if the temperature changes, or if we fly into different cloud formations, then it is us pilots who notice it, feel it and see it first. So we also know if we are at the best place for a particular task or if it would be better to fly somewhere else.

What was the most exceptional thing about the most recent mission to the Arctic Circle?
: This was the first time that we flew with HALO into such an icy climate. The temperatures were sometimes below minus 30 degrees Celsius. The runway was completely covered with ice. Our local colleagues spread hot sand on the landing strip, which melted the ice and left the surface behaving like asphalt. Otherwise, we would not have been able to take off and land safely – for me that was a new and exciting experience.

You sometimes fly to some very remote areas of the Earth. Are there times where you are in awe of nature?
: Every single time. During the polar night, for example, there is no stray light. There, the night is not grey, nor is there even a small amount of light anywhere; the sky is pitch black and you can see countless stars. We saw many aurorae, and it was a true spectacle each and every time.

When you are out in the uninhabited vastness, do you miss civilisation?
: You forget the normal frenzy of civilisation very quickly and you do not miss it at all. That is why you are in quite a state of shock when you return home. (Laughs)

It will soon be your 30th anniversary working in or above the clouds. How long do you want to continue flying for?
: As long as I still enjoy it!


The DLR Falcon about to take off from Kiruna, in northern Sweden.

40 YEARS OF FALCON

Congratulations, Falcon! On 16 July 2016, the research aircraft with the registration D CMET will have been in service for 40 years, primarily conducting atmospheric research. The still modern aircraft has long enjoyed a leading position among European research aircraft. The twin-engine jet can fly at altitudes of up to 12,800 metres. Its extremely robust and versatile design allows measurements to be performed even in the vicinity of thunderstorms or just 30 metres behind the engines of an airliner. After the eruption of the Icelandic volcano Eyjafjallajökull in 2010, the Falcon became an international celebrity as the 'Volcano Ash Hunter'.

A WIN-WIN SITUATION FOR THE ENGINES OF THE FUTURE

For 20 years, DLR and Rolls-Royce have been cooperating on research and development for environment-friendly aircraft engines

By Patrick Hoeveler

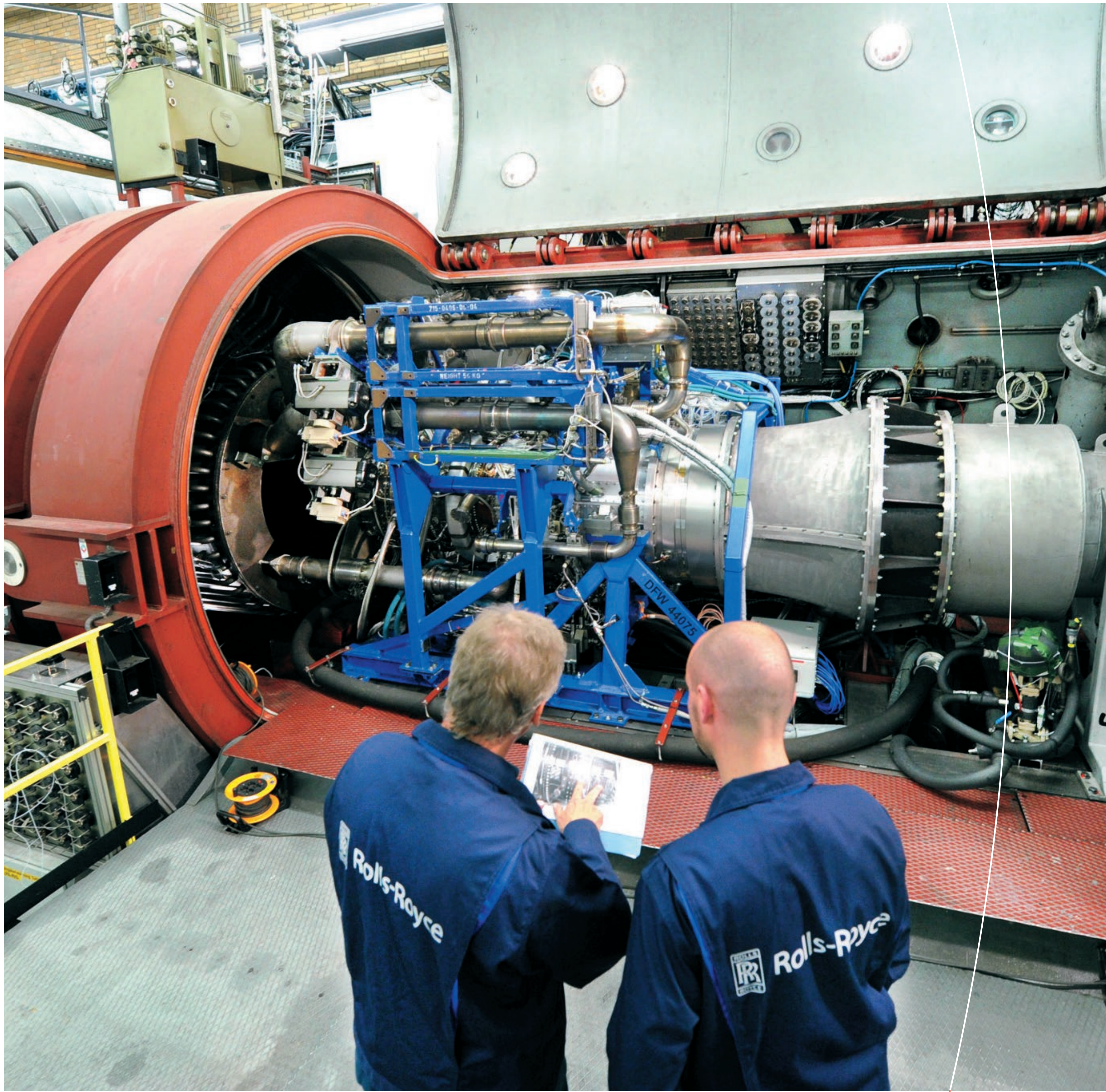
What will commercial aviation look like in the coming decades? What developments will there be in the aircraft engines of the future? To find answers to these questions, DLR specialists are working closely with experts in industry and academia; one of their most important partners is the aircraft engine manufacturer Rolls-Royce. Last November, DLR and Rolls-Royce signed a cooperation agreement with the goal of conducting more intensive research. The joint activities will eventually encompass the entire engine – from the integration of components through to the compressor, combustion chamber and turbine.

Despite all the progress made with the current generation of civil aircraft engines, development engineers will have to overcome a number of challenges for future designs. "One very important topic continues to be the issue of climate change. That is, we must reduce carbon dioxide emissions," says Manfred Aigner, Head of the DLR Institute of Combustion Technology in Stuttgart. And this must be done to a great extent; by 2050, carbon dioxide emissions per passenger kilometre must be reduced by 75 percent to comply with the European Commission requirements for future air transport. The baseline for the 'Flightpath 2050' initiative is a standard commercial airliner from 2000.

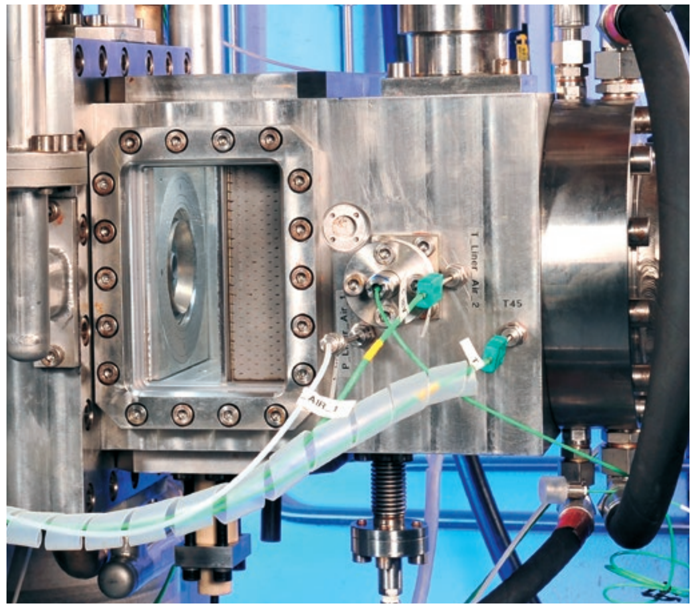
Understanding what happens in the combustion chamber

To reach this target, researchers will have to increase the efficiency of future engines. But the higher pressures and temperatures required to achieve this make life difficult for the engineers responsible for the combustion chamber. "The chemical processes that occur during higher-temperature combustion processes lead to more pollutants, and at higher pressures this occurs at a higher rate," explains Christoph Hassa of the DLR Institute of Propulsion Technology in Cologne. Nevertheless, nitrogen oxide emissions must be reduced by 90 percent according to the goals set by the EU. To accommodate these conflicting needs, what are referred to as 'lean-burn' combustion chambers have been implemented in new large engines. "Here, combustion takes place in the presence of excess air in order to reduce the local combustion temperatures and thus suppress the formation of nitrogen oxides."

Image: Rolls-Royce



Test of an engine core with a lean-burn combustion chamber in the High Altitude Test Facility at the University of Stuttgart



With modern test facilities of all sizes, DLR and its partners are able to conduct a variety of combustion tests. Here, one component of an optically accessible combustion chamber is being tested on the HBK1 test stand in Cologne.

Image: Rolls-Royce

The results of the research will enhance the latest engine developments by Rolls Royce

According to Hassa, Rolls Royce and DLR have been working together on this for quite some time. "With regard to our participation, the paths to a solution lie in recording the flow and the reactions in the combustion chamber. With an understanding of the processes gained in this way, we want to create the basis for improvements." The development of combustion technology and the respective combustion chambers has, in the meantime, made significant progress. However, the complexity of the fuel system continues to be a major challenge. In addition, the design of complex components such as the injectors must be adapted for use in smaller engines.

With all these innovations, the designers must continue to maintain the reliability achieved by current combustion chambers over the past few decades. At altitudes of up to nine kilometres there should be no problems when restarting the engine – should this be necessary. In addition, the emissions of unburned hydrocarbons and carbon monoxide, which are already well controlled, must not be disregarded. At the same time, the noise generated by the combustion chamber is increasingly becoming a focus for the developers. Other sources of noise in the engine are being reduced more and more, so the engineers have now turned their attention to the combustion process. Thermoacoustics is a fundamental and important issue for low-emission combustion. Progress here requires striking a balance between the various requirements because noise reduction in combustion chambers is difficult; any dampening measures have an adverse effect on complexity and total weight.

Realistic tests in combustion chamber test stands

In their projects, DLR's partners benefit from being able to use the existing test stands – most notably the high-pressure combustion chamber test facility HBK5 at the DLR site in Cologne, which was opened in 2015. Here, complete aircraft engine combustion chambers with a diameter of up to one metre can be tested under realistic conditions. The test stand can generate a thermal output of 125 megawatts, corresponding to the output of about 1000 medium-size cars. Rolls-Royce has secured use of this exclusive test facility for the next 30 years. "The possibilities offered by the HBK5 are unique. For us, the final test takes place in a full annular segment – that is, with a complete combustion chamber – before we implement a new technology in engines under development," explains Thomas Dörr, Combustion Group Leader at Rolls-Royce Deutschland. Dörr considers the new test facility to be a further milestone in the cooperation between the partners: "We have been working with DLR since the first aviation research programme of the German Federal Government in 1995, and as part of this we developed and studied a special low-emission combustor. This formed the technical basis for other programmes, in which we have continued to develop the technology. In this way, we have been able to continue our progress on lean-burn combustion technology." Towards the end of 2016, Rolls-Royce plans to conduct a flight test of this combustion chamber technology in a demonstrator based on a Trent 1000, the engine used on the Boeing 787 Dreamliner.

DLR has benefited from this collaboration as well, as Hassa explains: "It is through industrial cooperation that we gain first-hand knowledge about current problem areas – something that helps us better align our research to relevant topics." Manfred Aigner adds: "We also get an insight into modern engine technology. In addition, there are issues that we cannot solve alone. Here, each of the partners brings their own expertise – only a combination of this leads to solutions." The partnership began in the 90s with the development of the BR700 family of engines – designed to power regional and corporate aircraft – by what was then BMW Rolls-Royce AeroEngines in Dahlewitz, in the southern outskirts of Berlin. Since then, it has expanded to encompass combustion chambers for the engines of long-haul aircraft. Currently, specialists are studying the exact distribution of the exhaust gas temperatures and speeds at the combustor exit, since a number of factors for turbine development may change during the transition from rich-lean to lean-burn combustion chambers.

Interactions with turbines

This is another facet to the successful cooperation between Rolls-Royce and DLR. As part of another aviation research programme, the partners are testing a new two-stage turbine. "Here, we are strongly concerned with the areas of cooling and gas flow, in order to create efficient turbines," says Frank Kocian of the Institute of Propulsion Technology's Turbine Department at DLR Göttingen. "The clear challenge here lies in the interaction between the components; on the one hand, between the combustion chamber and the high-pressure turbine, and on the other hand between the high-pressure and low-pressure turbines. Here, phenomena are occurring in forms not previously of great interest to scientists, and which they are now researching to learn more and exploit any remaining possibilities for optimisation." The focus is now on new technologies, particularly materials and production methods; for example, additive manufacturing processes for components with complex geometries that provide internal cooling. For this, a computer-controlled laser melts metal into a powder bed and, layer by layer, builds up components. This method was used at Rolls-Royce to create turbine blades, while the test turbine was constructed and manufactured by DLR. Integration and commissioning were conducted by joint teams. Trials are being carried out using the ultramodern NG-Turb turbine test facility at DLR Göttingen, which was completed in 2015. It enables the researchers to conduct tests under realistic conditions.

Collaboration does not only focus on application-oriented research; the fundamental principles are also examined intensively. The DLR Institute of Combustion Technology is frequently consulted, in particular with regard to pollutant emissions. "At the moment, one major issue is soot particles and their effect on the atmosphere," says Aigner. When dealing with soot particles, in the words of the Head of the Institute, one is dealing with: "a very complex process that is correspondingly difficult to evaluate and prevent." The soot particles always form in a fuel-rich zone. The fuel takes the form of gas molecules – these meet, combine and eventually form solid particles. This occurs extremely fast – in around a millisecond – and gives rise to particles with sizes in the nanometre region in an environment where the temperature is at least 2000 degrees Celsius. "This is why the first analyses were very difficult. To conduct the basic observations of these processes, we first had to develop a measuring technology with very high spatial and temporal resolution. The second challenge was to reproduce these processes in a numerical simulation."

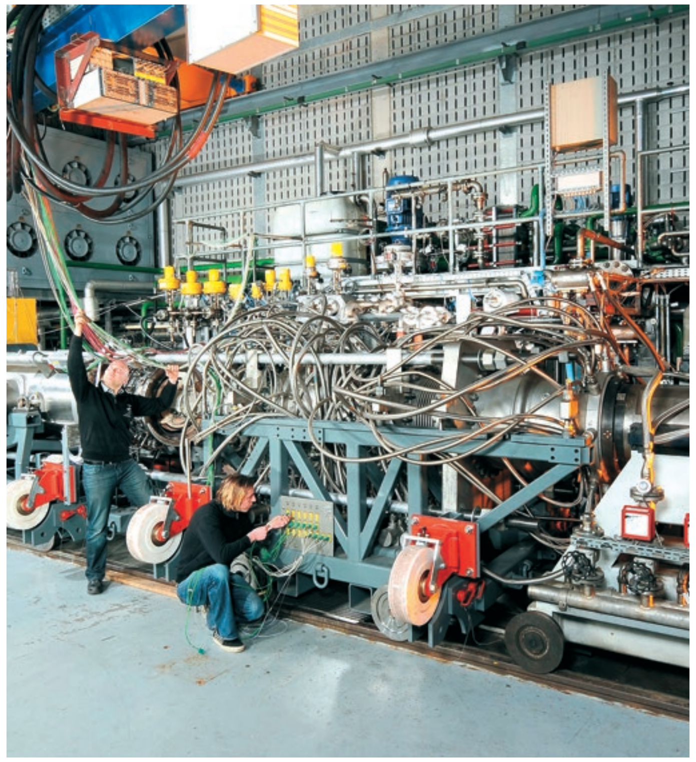
Diagnosing flames for the use of new fuels

Rolls-Royce also benefits from the expertise of DLR specialists in this area of combustion, as Thomas Dörr from the Dahlewitz-based engine manufacturer explains: "DLR has advanced, highly sophisticated flame diagnostics employing laser spectroscopy techniques that encompass both measurement technology and analysis." The methods are almost all laser-based, since optical systems can perform contactless measurements at extreme temperatures and pressures, and no physical probe disturbs the process being observed. For example, the method known as Laser-Induced Incandescence (LII) illuminates the tiny particles in a particular region and heats them. The radiation emitted by the soot particles then gives information about their number and size. Other measurement technologies allow conclusions to be drawn about the distribution of the fuel, the velocity of the gas flows and their temperature. "The combination of expertise, measurement techniques and our high pressure test facilities is quite unique in Europe," says Aigner. This knowledge is essential to deal with another important topic – the issue of fuels. "Fuels based on petroleum must be replaced at least in part in order to improve the carbon footprint and to reduce our dependence on oil."

The reduction of pollutant emissions could be achieved, for example, using what are referred to as 'designer fuels', an alternative energy source that, in contrast to kerosene, has a smaller proportion of aromatic hydrocarbons or even no aromatics at all. These chemical compounds are instrumental in soot production. The extent to which the use of lean-burn combustion chambers is appropriate for this application is a question on which DLR's scientists and engineers are hard at work. "This is truly fundamental research. Deciding on which fuel should be selected, how to appropriately control the temperature profile in the combustion process and adjust the direction of air flows are topics that will move seamlessly from fundamental research to applications," says Aigner. "This is a very exciting area that will have a great impact on the environment, as well as on the commercial viability of the resulting products."

Patrick Hoeveler is a journalist specialising in aviation and has worked for many years at, among other places, the magazine 'Flug Revue'.

In the high-pressure combustion chamber test facility HBK5 at DLR Cologne, complete combustion chambers can be tested under realistic conditions.



DLR has extensive expertise in combustion metrology

FLYING SAFELY – EVEN IN THE EVENT OF A MALFUNCTION

A new in-flight pilot assistance system has undergone extensive testing in a moving base simulator at NASA Ames Research Center. It was jointly developed by Thomas Lombaerts and a team of NASA researchers. In this interview with the DLR Magazine, he tells us more about it.

Image: DLR/Wolfgang Maria Weber

About Thomas Lombaerts

Thomas Lombaerts worked at the DLR Institute of System Dynamics and Control in Oberpfaffenhofen, where he conducted research into how aircraft can be safely controlled, even in difficult situations. He has done so by developing assistance systems to support pilots in unexpected situations as part of his thesis and in subsequent projects. He is currently working at NASA again. There, he has been testing such systems in the flight simulator at the Ames Research Center in California. The commercial pilots in the test were impressed.

Dr Lombaerts, you have been looking at how an in-flight pilot assistance system can be used in extraordinary flight situations. How safely can pilots control an aircraft nowadays – even under exceptional circumstances?

: First of all, it is important to note that we have achieved an enormously high standard of safety in air transport, and many safety improvements have been achieved in the past decades. A simple engine failure, for example – assuming this even happens – will rarely cause any major difficulties for pilots nowadays. There is a routine procedure for this scenario that pilots can regularly practise in the simulator. Well-practised procedures in the cockpit have already been established for a vast range of malfunctions during flight. They make an indispensable contribution to today's high safety standards. Now, unforeseeable events – though rare – have become the biggest challenge faced by pilots. If an aircraft stops performing as the pilots are used to – or as they have been trained to react to in a wide range of circumstances – they may unintentionally push the aircraft beyond the limits of its flight envelope.

So, how often are pilots suddenly unable to control their aircraft correctly?

: An investigation by the ICAO (International Civil Aviation Organization) and the Commercial Aviation Safety Team (CAST) has shown that loss of control of the aircraft during flight has been the main cause of serious accidents in civil aviation since the turn of the millennium. The study in question meticulously analysed aircraft accidents between 2002 and 2011. Twenty-three percent of all accidents during this period were attributed to a loss of control during flight, and the majority of casualties occurred in these cases.

Under what kinds of circumstances can a pilot find it hard or impossible to maintain control of the aircraft?

: There are three main causes, all three of which – individually or in combination – can make it difficult for pilots to maintain control of an aircraft. One cause is technical defects or malfunctions of the on-board systems. Another is extreme atmospheric influences, such as severe and/or unexpected turbulence or ice on the wings. Thirdly, misinterpretation of the flight condition by the flight crew – so-called loss of 'situational awareness' – can lead to difficulties.

That seems somewhat abstract – can you give an example?

: Yes – the Bijlmermeer accident in 1992. In that accident, a Boeing 747 cargo aircraft lost both engines on the starboard wing shortly after taking off from Schiphol Airport in Amsterdam. The cause was metal fatigue in the fuse pins that form part of the engine mounting. The flight crew reacted immediately and tried to manoeuvre the aircraft to return to the airport. During this process, the aircraft went into a rolling nosedive at low speed. The pilots were unable to recover and the aircraft crashed into the neighbourhood of Bijlmermeer in the Netherlands. Investigation of the accident revealed that, in theory, it could have been possible to prevent the uncontrolled rolling nosedive.

Image: NASA

Flight deck of the NASA Advanced Concepts Flight Simulator

How can loss of control on the flight deck be prevented, and what might have helped the pilots involved in the Bijlmermeer accident?

: When problems suddenly occur, an aircraft should remain capable of normal flight for the pilots as much as possible within its range of physical capabilities, and it should not enter dangerous flying conditions. To this end, problems and irregularities with the aircraft need to be detected using appropriate sensors, and the resulting new flight envelope limits need to be determined quickly. If this information can be calculated, it is technically possible to adjust the flight control algorithms automatically. Previous research has already demonstrated this. The flight crew needs to be informed as quickly and reliably as possible of the effects that the restriction of the flight envelope will have. This is what an in-flight pilot assistance system is needed for.

How are changes in the flight performance of an aircraft detected? An unexpected malfunction during flight can have a vast range of causes. Are the aerodynamics of an aircraft calculated in advance for different scenarios, such as flying without flaps, a defective empennage and the like?

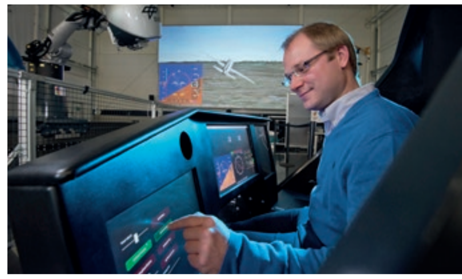
: This is an interesting question that is currently being discussed in expert circles. There are two research strategies. Firstly, scientists are looking to develop an entire library of pre-calculated aerodynamic configurations. This might be helpful, but it cannot be used to cover every single unexpected incident. So we have taken a different approach.

What are you doing that is different?

: We are focusing on being better prepared for the unforeseeable. Our computer programs do this by calculating how the aerodynamics change in the event of an incident – depending on the situation. Hence, in the event of a problem, we compute the changes to the aerodynamics and the new limits for safe aircraft operation in near real-time. Various sensors for determining location, attitude, acceleration and airflow provide the data required for this.

How is this meant to work?

: If control units on the tail section or on the wings malfunction, for example, the aircraft accelerates differently; the mathematical models calculate the new behaviour of the aircraft in general terms and transfer this change in flight behaviour to the flight control system, which adapts automatically. The pilot can then continue flying in a controlled manner, using the customary control inputs, instead of having to improvise – with uncertain results.



How advanced is the development of such an assistance system for pilots? What tests have already taken place?

: In Project ADFLICO, which stands for Adaptive Flight Control for Advanced Aircraft Concepts, I have been working at the NASA Ames Research Center as part of a two-and-a-half-year research visit. There, I investigated the problem of restricted flight envelopes of a damaged aircraft, as well as how changes to the envelope limits can be determined in real time. During my stay, I had the opportunity, together with NASA colleagues, to test the new technology in sophisticated simulator experiments with airline pilots.

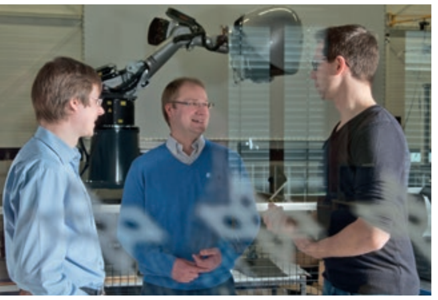
What exactly did you investigate with your colleagues at NASA?

: We tested various extraordinary scenarios with 20 pilots from the major US air carriers. For example, they had to fly an aircraft in the simulator during icy conditions or with a defective tailplane. They did so with and without the assistance system. The results showed that, once they became familiar with the assistance system, the pilots' capacity to remain inside the safe flight envelope was greatly improved and dangerous losses of control were prevented.

Is this because, on the display, the pilots can simply see what they are allowed to do in flight and what is no longer permitted in an unexpected situation?

: Exactly. The updated limits of safe flight operation are shown to the pilots in an intuitive way using yellow and red markings on an enhanced primary flight data display. If information about the changed flight envelope is known, it can also be used for early warning systems, to achieve automatic compliance with the flight envelope by the flight controller, or for optimising the flightpath under the new conditions.

How did the test pilots react to the new system?
: Entirely positively. One even said to us that he had witnessed unstable approaches where no lives were actually lost, but in which the aircraft suffered damage amounting to millions of dollars. Evaluation of the flight data recorders (also commonly known as black boxes) showed that the pilots were actually running into difficulties much earlier in the flight, without being aware of it. The pilots appreciated the significant improvement in awareness of the situation provided by the new system, which will ultimately prevent danger and avoid expensive repairs.



One response to the increasing technical complexity on the flight deck, which reduces much of the workload for the pilots but also takes away much of the flight routine, is to let pilots go back to more manual flying. How does your new assistance system fit in with this trend?
: The two are not mutually exclusive. Rather, they complement one another. With the new system, pilots should get better support in difficult flight situations that they are not accustomed to. In this regard, both developments can be seen as complementary.

What is still needed in terms of research for an assistance system that is ready for operational use?
: In addition to a very fast determination of the safe flight envelope and supportive displays for the pilots, an adaptive flight control system needs to be developed. This should adjust the pilot's control input to the control surfaces during manoeuvres in such a way that a damaged aircraft ideally cannot exceed its flight envelope or, if it does, it automatically reverts to safe flying conditions. It is also possible that the flight deck controls could provide a mechanical counter-force, meaning that the pilot can feel the flight envelope boundaries in the actual controls. This type of sensory feedback is currently being investigated at the Delft University of Technology. More robust sensors and sensor error detection are other important research areas.

When will we be able to fly on board an aircraft equipped with the new flight control system?
: Unfortunately, it will still take time. We want to develop the technology even further and integrate it, then carry out further simulator tests and ultimately test flights. In the meantime, industry must also be convinced about the innovations. And, as ever with aviation, no new system will make it into passenger aircraft without extensive certification by the various aviation authorities. But our method has an important advantage in this regard – the technology is based on physical models, which makes interpretation of the signals significantly easier. This could be beneficial in achieving certification.

Interview conducted by Fabian Locher

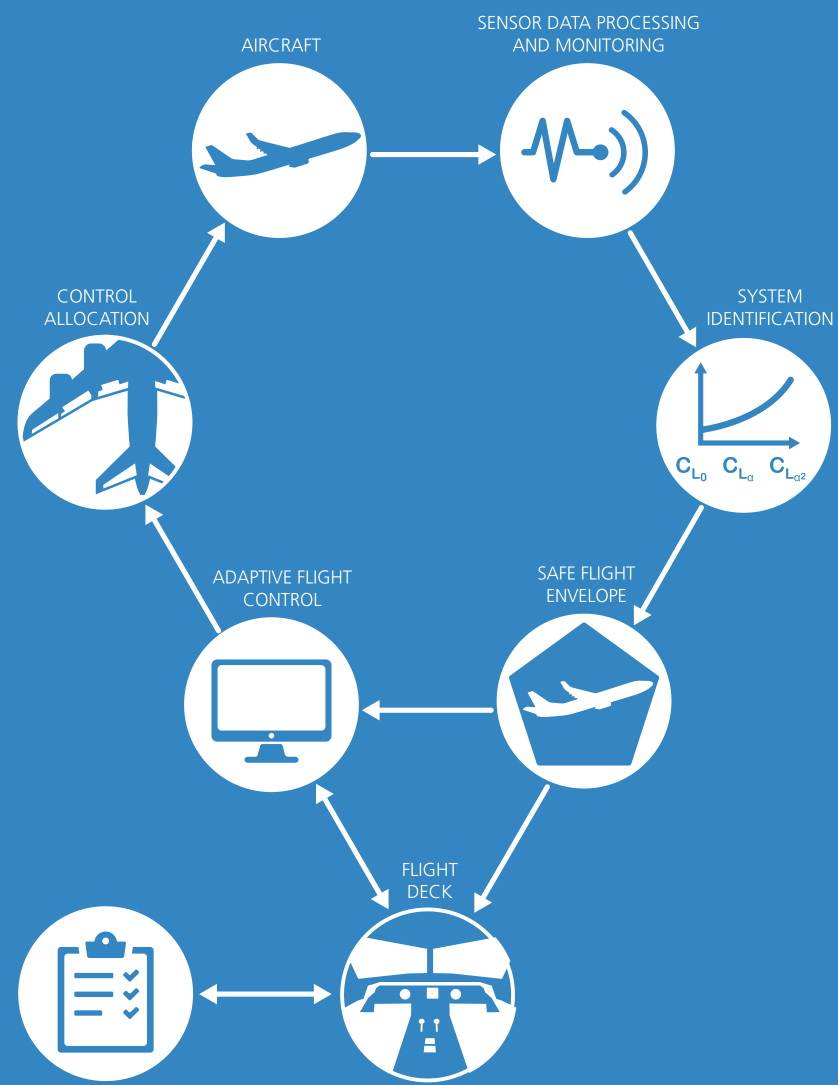
Boeing 747 belonging to American airfreight company Southern Air

THE ADFLICO PROJECT

In Project ADFLICO (Adaptive Flight Control for Advanced Aircraft Concepts), Thomas Lombaerts, from the DLR Institute of System Dynamics and Control, worked with researchers at the NASA Ames Research Center from April 2012 to November 2014. The objective was to investigate a new assistance system for pilots that displays updated flight envelope limits in exceptional situations, helping them to continue flying – even in the event of unforeseeable malfunctions. Twenty commercial pilots tested the new system in the flight simulator in various exceptional scenarios. The results showed that the pilots were more successful to remain in the safe flight zone and prevent dangerous loss of control using the assistance system. The joint work conducted by DLR and NASA in ADFLICO was financially supported by a Marie Curie International Outgoing Fellowship (IOF) under the European Union's seventh Framework Programme and by the Vehicle Systems Safety Technologies (VSST) project under NASA's Aviation Safety Programme. In September 2015, the DLR/NASA research team was awarded a Group Achievement Award for its contribution to promoting safety in civil aviation.

The most important technological subjects in the area of fault-tolerant flight

Six aspects need to be considered: Firstly, sensor data processing and monitoring, which supplies the data for system identification. It is used to determine how the aircraft is behaving aerodynamically. The safe flight envelope is calculated from this, in relation to the speed, rate of climb or sink rate and the attitude. This safe flight operation range needs to be displayed as intuitively and comprehensibly as possible for the pilots in the flight deck. Adaptive controls should take this updated information into account and should also enable the pilots to feel the flight envelope limits. The (adaptively optimised) distribution of the total control effort over the different available control effectors (control surfaces and engines) is called control allocation. These components have an effect on one another and together form the fault-tolerant flight control system that is under development.



EYES IN THE SKY SEE THE WORLD CHANGING

From Paris to Marrakesh – a contribution to the World Climate Conference

By Martin Fleischmann

The Maldives and Marshall Islands have become underwater landscapes. Seventy percent of the rain forest has withered away. 250 million people have been forced to leave their homes due to hunger and thirst. That is what 2100 might look like, because the growing emissions of carbon dioxide will cause a global rise in temperature of two to six degrees by the end of the century. With every degree of warming, the amount of tropical storms increases by 30 percent, while at the same time the average thickness of the ice sheet in the Arctic recedes; in 20 to 30 years the Arctic may be completely ice free during the summer. The smaller the ice coverage, the lower the amount of solar radiation reflected back to space. Earth is getting warmer, causing the sea level to rise by 3.42 millimetres every year. By the turn of the century, it could be between half a metre to two metres higher than it is at present. A rise of only half a metre would already put 136 coastal cities at risk and endanger assets worth over 18 trillion euro.

To prevent these scenarios from becoming reality, 195 countries adopted the world climate treaty in Paris on 12 December 2015. It is set out to hold the increase in the global average temperature to well below two degrees Celsius related to pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius. To achieve this, all countries would have to reduce their greenhouse gas emissions. DLR is studying how this can be made possible, what scientific basis is needed, and how changes can be monitored. The research conducted by DLR on transport, aeronautics and space can make valuable contributions to this.

Global inventory from the perspective of satellites

Achievement of the climate goals will be evaluated every five years, starting in 2023, whereby the individual countries will be held accountable to 'the best available science' – a global stocktake of climate change. Earth observation will play a role in this monitoring – greenhouse gases, ocean currents and land clearing can be observed using satellites. The 'Guardians' Sentinel-1 and, above all, Sentinel-2 of the European Copernicus programme form a suitable set of 'eyes in the sky' with the capability of providing information with the necessary temporal and spatial coverage. 3D images acquired by the future radar satellite Tandem-L mission could also be used to monitor forests. From the changes in tree heights over time it is possible to acquire information on the loss or gain in overall biomass, and subsequently on the amount of stored carbon dioxide.

From 2020, the greenhouse gas methane will be monitored with a LiDAR instrument on board the Franco-German MERLIN satellite. Thus far, carbon dioxide data have been gathered only by a United States and a Japanese satellite. However, they only have one spectrometer on board – passive instruments with low resolution that can measure the concentrations only through reflection of solar radiation from Earth's surface. Clouds and aerosols in the atmosphere disturb and distort their measurement results. LiDAR could also be used to measure carbon dioxide in a future satellite mission.

ABILITIES OF EARTH OBSERVATION SATELLITES

The pioneer: In 2008, using data from the SCIAMACHY instrument on board Envisat, researchers were able to, for the first time, distinguish between natural and man-made sources of carbon dioxide; as such, it became a pioneer for a new European carbon dioxide satellite.

The guardians: Sentinel-1 and -2 and Sentinel-5 and -5P will measure greenhouse gases from space, and starting in 2016 will, over a 20-year period, provide a long-time series of measurements.

The radar eyes: The satellite duo TerraSAR-X and TanDEM-X can be used to monitor large ice sheets and glaciers, and document their melting over time.

The wizard: with its LiDAR instrument, MERLIN will trace sources of methane and distinguish between natural and man-made sources.

According to a recent study conducted by NASA, the sea level is rising 3.42 millimetres every year. Sixty percent of the increase is attributed to ocean warming, and 40 percent to the melting of ice. The TanDEM-X digital elevation model shows glaciers in Spitsbergen. The colours represent different elevations. The changes can be clearly shown by repeating the data acquisition with the DLR radar satellites at certain time intervals.

The damage caused by climate change and the related natural catastrophes can also be observed from space. In the event of a catastrophe, satellites can provide a quick overview of the situation – which places are flooded? Which roads are still open to traffic? Where is evacuation needed? Where is air support necessary? The European Space Agency and the DLR Space Administration are involved in the International Charter 'Space and Major Disasters'. If necessary, satellite data can be delivered worldwide, quickly and without cost. For example, the DLR scientists are able to re-schedule the TerraSAR-X and TanDEM-X satellites at short notice if needed in order to rapidly provide images of an affected region.

Seeing how the world changes – and acting upon it

"What once seemed unthinkable is now unstoppable. History will remember this day," said UN General Secretary Ban Ki Moon after the COP 21 in Paris, attesting to the success of the world climate conference. The follow-up COP 22 conference will take place between 7 and 18 November 2016 in Marrakesh (Morocco). The focus points of this conference have yet to be defined. Science can provide information about how Earth is changing – and DLR, through its research, can make valuable contributions to achieving the climate goals adopted in Paris.

www.marrakech-cop22.com

EXAMPLES OF DLR CLIMATE RESEARCH

Renewable energy:
Wind turbines and solar power plants – where to construct which system? DLR provides a freeware simulation programme for the assessment of renewable power plant projects.

s.DLR.de/lvf1

Eco-efficient flying:
How can flight be climate friendly? – DLR is studying the impact of air traffic on climate, and is developing strategies for new aircraft configurations and modes of operation.

Electromobility:
Electric drives reduce the burden on the environment related to car exhaust fumes. DLR researchers conduct research into vehicles and components, and analyse the traffic system to strengthen this path in the future.

s.DLR.de/fev6

The Bel Temple in Palmyra before its destruction. It is considered one of the most important religious buildings of the first century in the Middle East. The special construction and design made this temple unique.

LEGACIES FROM THE PAST – FOR THE FUTURE

World heritage through the eyes of satellites

by Bernadette Jung, Gunter Schreier and Günter Strunz

In September 2015, satellite images confirmed the suspicions of local observers in Syria: the Bel Temple, the centrepiece of the 2000-year-old UNESCO World Heritage Site at Palmyra, as well as the nearby row of columns and the Baalshamin Temple had been destroyed, evidently blown up by the terrorist organisation 'Islamic State.' It was possible to document these destructions by comparing local changes to older satellite images. A few years earlier, archaeologists had made spectacular discoveries in Palmyra with the help of satellite images.

Thanks to a spring of water in the middle of the Syrian Desert and its central location along the caravan road between Asia and Europe, Palmyra went from being a small oasis to a global centre of trade during the Roman Empire. It had long been assumed that the city had been settled as early as the third century B.C. and was carrying out trade relations around the world. Andreas Schmidt-Colinet of the Institut für Klassische Archäologie der Universität Wien (University of Vienna Institute for Classical Archaeology) was able to prove it in his 2008 work. Magnetometer studies of the soil and targeted excavations led his team to a settlement hidden under the sand outside of the known city area. Data acquired by the German radar satellite TerraSAR-X supplemented the analysis. The DLR Microwaves and Radar Institute and the DLR Earth Observation Center prepared those high-resolution radar images. In this way, the archaeologists were able to recognise ground structures that are not visible to the naked eye or discernible from terrestrial surveys.

Schmidt-Colinet is currently preparing a publication on the ancient quarries of Palmyra. Once again, the latest satellite images will be used to evaluate research results. "This will be even more important since even these quarries are directly threatened by destruction from the war in Syria," noted Schmidt-Colinet.

Cultural mandate

The culture identity of a community – whether regional, national or international – is tied to its cultural heritage. Ancient monuments give society a historical context and, with it, a reference for current challenges. Testimonies from ancient civilisations should therefore be maintained – through monitoring, documentation, evaluation and interpretation of archaeological sites. DLR is driving appropriate technologies forward in Oberpfaffenhofen. The German Remote Sensing Data Center and the Remote Sensing Technology Institute make up DLR's Earth Observation Center (EOC), and combine their expertise to acquire, evaluate, process and manage Earth observation data.

Support for archaeological research began 13 years ago with the mapping of the ancient Iraqi city of Uruk. Only DLR was in a position to deliver satellite data to the German Archaeological Institute to assess the threat to the oldest settlement in the world during the Iraqi conflict of that time. Since 2004, the EOC has been making an outstanding cultural contribution – it has been providing remote sensing data from DLR missions for scientific work to preserve World Heritage Sites designated by UNESCO, the organisation of the United Nations with a mandate in the area of culture. A task with huge dimensions – more than 1000 natural and cultural sites in 163 countries are currently listed as UNESCO World Heritage Sites. In Germany alone, 40 sites have 'Outstanding Universal Value', including the Cologne Cathedral, the Museumsinsel in Berlin, the border facilities of the Roman Empire (Limes), the Wadden Sea and the opera house in Bayreuth.

The pyramids of Giza in Egypt, Museuminsel in Berlin (bottom left) and the sites of the Holy See in Rome (below right) are three of the 802 cultural monuments listed as UNESCO World Heritage Sites. There are 197 natural sites and 31 transboundary sites; they are regarded as exceptional and must therefore be considered as part of the world heritage of all humankind. The General Conference of UNESCO adopted on 16 November 1972 the Recommendation concerning the Protection at National Level, of the Cultural and Natural Heritage, which was implemented in 1975. To date, 191 member states are devoted to the protection and preservation of the World Heritage located in their territory. The United Nations Educational, Scientific and Cultural Organization (UNESCO) has a special UN agency that sanctions for non-compliance. Often, the only remaining option is to bring threats or damage to world public attention, as in the case of Palmyra example with images from remote sensing satellites.

The historic centre of Sana'a, Yemen.

Image: Space Imaging Middle East/DLR

Tailor-made satellite data

Archaeology and remote sensing have one thing in common: attention to detail while maintaining a view of the whole. The success of combining the capabilities of these research areas and the new possibilities that result from it are particularly evident in large projects, such as Palmyra. Documenting a historical site, perhaps through excavation work, involves great expenditure of personnel, time and money. Such sites are therefore generally analysed using aerial images and photographs. Monument conservationists and archaeologists can particularly benefit from satellite images. From an altitude of over 500 kilometres, Earth observation satellites have an unobstructed view of areas, which are hard to reach or are too dangerous for reconnaissance flights and on site work. They deliver current and high-resolution images of areas extending over many square kilometres. Large surface overview images help archaeologists in the field to discover a 'find' more quickly, and then to piece together individual finds to reconstruct the historical picture.

Radar satellite data takes are possible regardless of cloud cover or time of day. The Tandem-L mission developed by the DLR Microwaves and Radar Institute will, in future, use radar tomography to see through treetops and vegetation down to the ground and under the surface. Satellites are able to acquire images of archaeological sites on a regular basis with exactly the same settings, making them perfect for monitoring. The DLR German satellite data archive contains readily available data spanning more than 30 years – with new data added daily. Comparative images and images over time show each change, whether it be sudden destruction, the slow deterioration of an antique structure or a threat to a nature reserve. By operating the data archive, the EOC ensures the availability of remote sensing treasures for future generations as well.

Remote sensing in detail

When UNESCO or an archaeological research facility submits a request, the Earth Observation Center can react promptly. First, the required satellite data are retrieved. New data can be created in near real-time. Receiving systems on the EOC building secure direct access to high-resolution data from the WorldView-2 and WorldView-3 optical satellites. Radar data are provided as part of the DLR TerraSAR-X and TanDEM-X radar satellite mission, operated from Oberpfaffenhofen. In addition, the EOC can activate its cooperation network and request satellite data, including that of its partner, European Space Imaging. This also applies to archive data to compare images.

In the next step, DLR scientists evaluate and process the raw data. If there is a special need, non-scientific data are also drawn from many sources, such as videos and photographs from the Internet. In order to obtain a comprehensible picture from this data pool, certain tweaks and adjustments are required – angular distortions are removed, the terrain information is adjusted according to the location, and the spatial resolution is sharpened. Analyses of change are also requested. Highly precise images, taken before and after an event can help conservationists and UNESCO to develop measures to protect a World Heritage Site or to evaluate their efficacy.

For data analysis, the EOC benefits in particular from the work and experience gained in the Center for Satellite Based Crisis Information (ZKI). In the event of natural disasters or emergencies, satellite image maps and situation analyses are created on demand at the ZKI for national, European and international authorities and institutions for civil protection. This is how Palmyra satellite data were evaluated by the ZKI. The Center is on-call around the clock and complements the unique infrastructure of the EOC in Oberpfaffenhofen. Remote sensing specialists at EOC are thus able to attend to all requests reliably and consistently.

Image: European Space Imaging

This recording, acquired by the WorldView-2 satellite on 27 August 2015 shows the Bel Temple in Palmyra, a unique World Heritage Site.

Image: European Space Imaging

A few days later, on 2 September 2015 the satellite image confirmed the worst fears: the 2000-year-old temple had been destroyed.

Global perspective

It has been nearly 60 years since man was able to see his world from space for the first time. These images altered humankind's perspective forever. Satellite-based remote sensing has broadened this perspective, and the UNESCO World Heritage programme has embraced it. However, these heritage sites not only have a cultural value. Many regions and countries get significant income from tourism affecting World Heritage Sites. Earth observation data can provide the necessary overview required for planning purposes, as is the case with the pyramids of Giza. Analyses of change clearly show how settlements have drawn in ever more tightly around the 4500-year-old structures. The increased stress and changing environmental demands are closing in on the colossal structures at the gates of Cairo. Elsewhere, in Peru, landslides endanger the Machu Picchu World Heritage Site. Whether it be the erosion of soil by ever more frequent flooding or by drought, the retreat of glaciers or rising sea levels, the effects of global climate change pose ever greater challenges to archaeologists and conservationists.

To monitor all the sites and protect them is a herculean task. Only the view from space provides the necessary overview and reveals the global realities. Earth observation satellites can deliver information quickly, comprehensively and worldwide. Thus, remote sensing creates completely new databases for researchers and decision-makers. The European Copernicus Earth observation programme is already driving forward the development of a basic geo-information service, particularly for environmental monitoring and for civil security. The Tandem-L satellite radar mission could, in future, map Earth's surface on a weekly basis, as well as provide unique information products. Through the large number of missions, targeted research and new evaluation technologies, remote sensing is destined to take on this global challenge. This includes acquiring important information about the world's cultural heritage, and helping to preserve it.

Günter Strunz is head of the Geo-Risks and Civil Security department at the DLR German Remote Sensing Data Center.
Gunter Schreier coordinates business development matters, in particular for Copernicus at the DLR German Remote Sensing Data Center.
Bernadette Jung is an editor in DLR communications.

Image: European Space Imaging

Ancient Palmyra is located in an oasis in the modern Syrian city of Tadmur in the centre of the Aleppo highlands

PRECIOUS SATELLITE VIEW OF THE WORLD'S CULTURAL HERITAGE

Three questions for Margarete van Ess, scientific director at the German Archaeological Institute (DAI).

Dr van Ess, how widespread is the use of remote sensing techniques in archaeology?

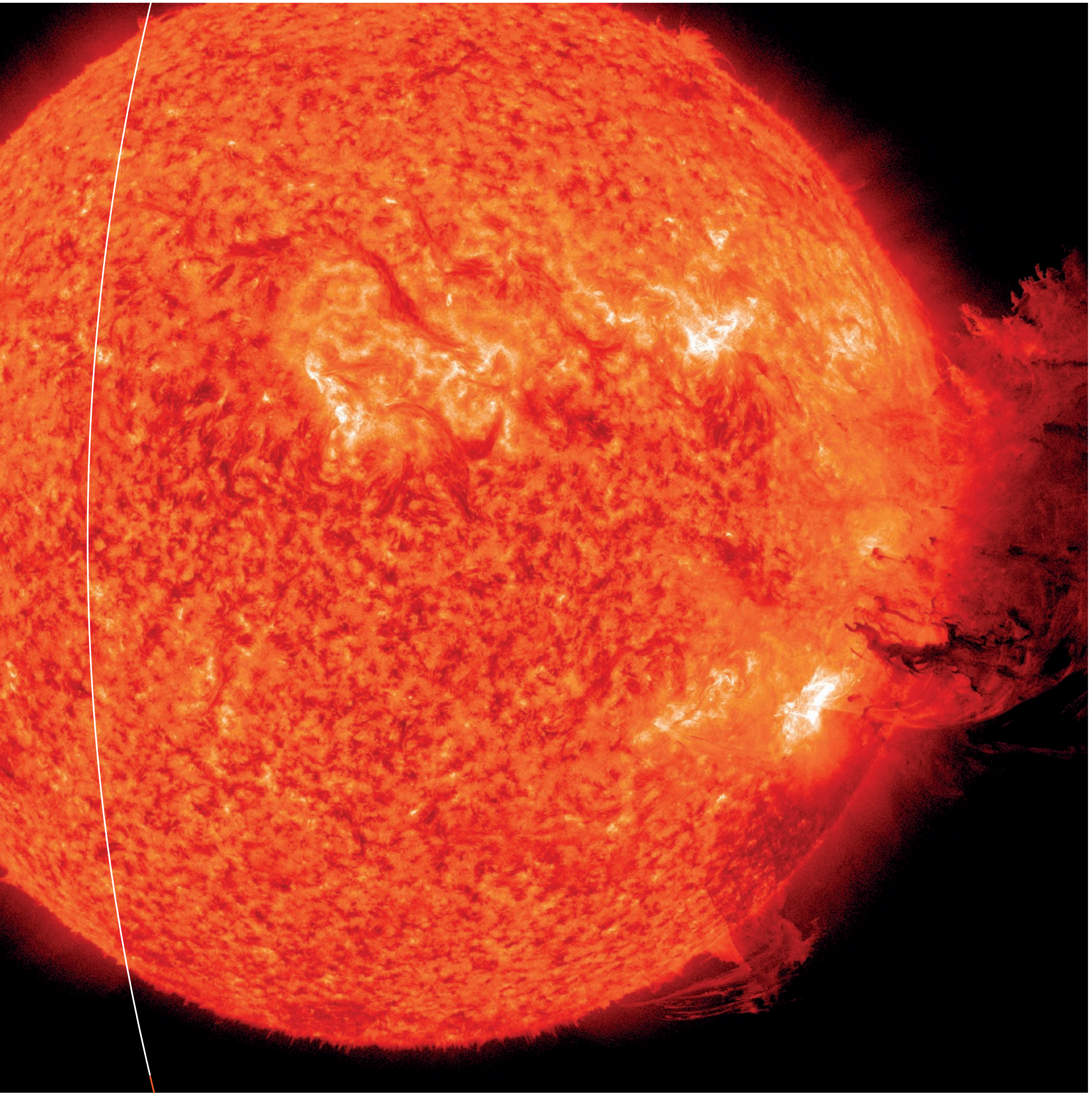
: Remote sensing techniques have been an important topic in archaeology for many years now. However, they are used with great hesitation, mainly because acquiring these high-resolution images is expensive and requires special knowledge for their evaluation. The images are used to learn about still unexcavated ancient settlements and to trace long buried overland routes and canals, but also to recognise destruction through illicit excavations or infrastructure activities. At the same time, the analysis methods are becoming refined and, in this way, are being developed into routine procedures in archaeology. Remote sensing is therefore of ever increasing importance for us.

What is special about the cooperation between the German Archaeological Institute and DLR?

: Because it is their daily work, scientists at DLR can provide assessments of remote sensing data based on their expertise, while archaeologists do not have this special knowledge. On the other hand, archaeologists consider details that would not occur to persons with a different kind of training. The constant availability of experts and the experience of both institutions allow the evaluation of data in short order and permit a timely, informed delivery to responsible institutions. It is only in this way that we can protect endangered sites.

What do you expect from remote sensing for your future research?

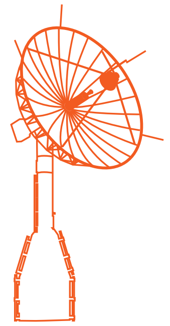
: We would like for the remote sensing techniques to become routine in archaeology – both from the viewpoint of science and in the area of cultural preservation. For this purpose, regular analyses of satellite images are very meaningful – analyses that until now have not been sufficiently available. Regular analyses would be an important preventive measure – not only for the protection of cultural heritage, but also for evaluating the archaeological potential of a landscape or a place.



A medium-sized solar flare. The image shows a spectacular coronal mass ejection that occurred on 7 June 2011 in the extreme ultraviolet.

Image: NASA/SDO and the AIA, EVE, and HMI science teams

WEATHERING THE SOLAR STORM



Researchers in Neustrelitz work on predicting space weather

By Fabian Locher

The Universe – endless, silent, peaceful… or is it? Massive solar eruptions can cause extreme solar winds. Energetic particles from the Sun's corona are hurled into space. Solar storms can trigger ionospheric disturbances in the atmosphere, and thus endanger the sensitive infrastructure of our modern, high-tech society. After all, our daily communication and navigation relies on satellites. DLR scientists are studying the causes and effects of space weather. Researchers from the DLR Institute of Communications and Navigation and the German Remote Sensing Data Center are working on establishing the Ionosphere Monitoring and Prediction Center (IMPC) at DLR's Neustrelitz site. The IMPC is a space weather monitoring, prediction and warning centre for industry, government, academia and interested laypersons.

Highly active central star

Over 4.5 billion years ago, the Solar System was formed from a cloud of gas and dust. Even today, the Sun is a very active star. Not only does it emit warming light, but also sends out a stream of electrically charged particles – the solar wind. Without any warning, explosive eruptions can take place on its scorching surface, which has a temperature of 5500 degrees Celsius. At that point, the particle stream that is hurled into space can be much stronger than usual for a short time and in a limited area – researchers refer to this as a solar storm. If these highly charged particles hit the Earth's atmosphere, they can damage the technical systems in our orbit. But an accurate prediction of such eruptions is not yet possible, and the mechanisms underlying the ejection of solar storms are not fully understood.

DLR researchers are using data from solar observatories to determine whether a solar storm will hit the Earth, how strong it will be and how to mitigate this effect. These 'warning sensors' are 1.5 million kilometres away from the Earth. Three satellites – SOHO, ACE and DSCOVER (see glossary, page 37) – keep watch in this hostile environment. Here, the Lagrange point L1 serves as a base. L1 is a stable point in the Earth-Sun system, where the satellites can remain with a low expenditure of energy.

In this way, the satellites fulfil special observation tasks: SOHO, among other things, photographs the Sun in the UV range. ACE has been active since 1997, and was supplemented by DSCOVR in 2015. The latter two satellites measure the interplanetary magnetic field and the velocity of the solar wind, in addition to temperature and proton density.

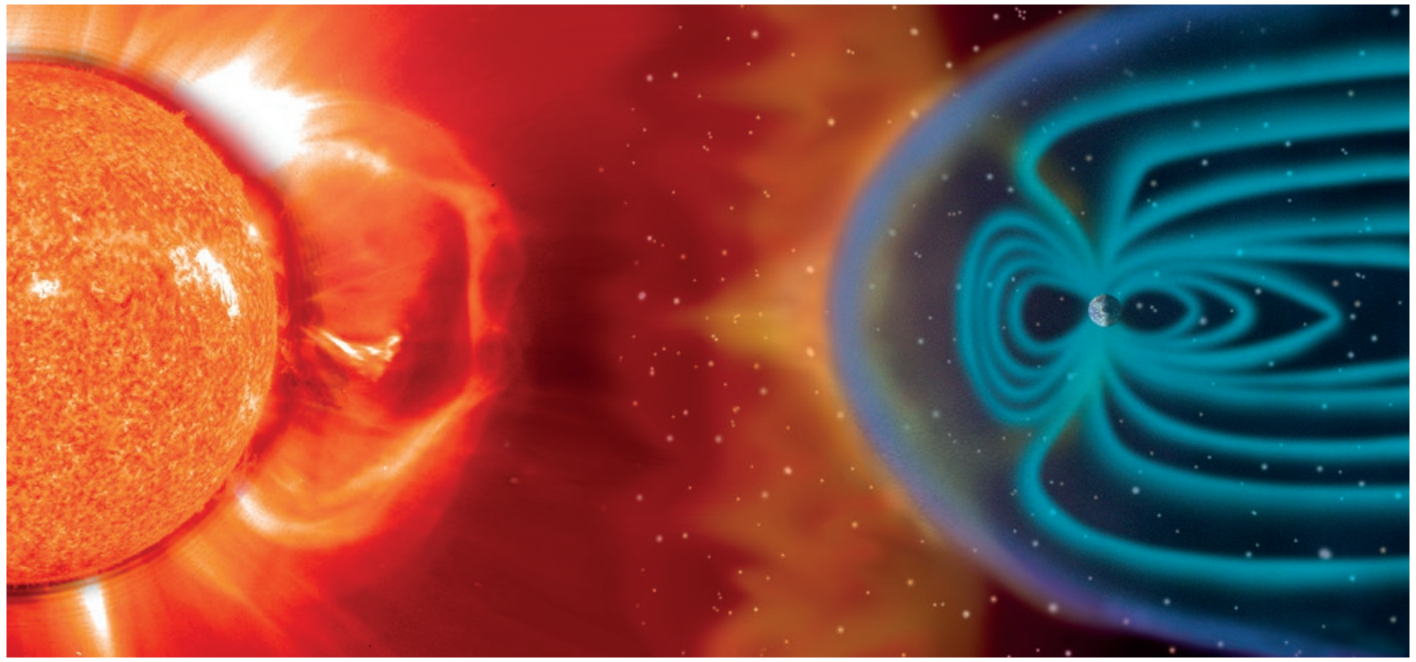


Image: NASA/SDO and the AIA, EVE, and HMI science teams

Illustration of a coronal mass ejection of the Sun and its consequences for the Earth

Clouds of high-energy particles

When a particle storm is forming, charged particles are flung into the expanse of space as a plasma cloud. As soon as the extreme solar wind passes Lagrange point L1, the ACE and DSCOVR satellites measure the changed parameters. The signal is sent to the receiving station at the speed of light. The storm, however, moves appreciably slower. It makes its way as a gigantic plasma cloud at 800 to 2000 kilometres per second through the heliosphere. The signals from the satellites are received by the powerful antennas in Neustrelitz. This DLR site in Mecklenburg-Vorpommern is the only European receiving station in the real-time solar wind observation network. Other stations are located in the United States, South Korea and Japan.

DLR scientists evaluate the data and can quickly react to sudden changes in solar wind parameters. Researchers analyse the interplanetary magnetic field and calculate the dynamic pressure of the solar wind at Lagrange point L1. At this point, there is some certainty: Yes, it is a solar storm; Yes, it is moving towards the Earth; And yes, it will reach our planet. Space weather experts call this 'effective injection of plasma particles into the Earth's atmosphere'.

From this moment, researchers have a lead time of 30 to 60 minutes, depending on how fast the solar wind is moving. And the calculation begins. How strong will the effects of the solar storm be? How efficiently will the penetration in the Earth's atmosphere be? With this information, scientists can make forecasts and predict possible disturbances to communication and navigation technical systems.

Aurora and communication disturbances

Earth is – to a great extent – protected from weak solar storms by the atmosphere and its magnetic field. The incoming charged particles travel at a distance of about 10 earth radii (approximately 70,000 kilometres) along the magnetic field lines around the Earth. At high altitudes and in the polar regions, this protection is weaker. There, the magnetic field lines are more inclined towards the Earth's surface. Due to this, these regions are more vulnerable to the effects of solar storms.

The reflection of shortwaves on the bottom side ionosphere allows global radio communications. The ionosphere consists of free electrons and ions. This makes it a charged layer, thereby susceptible to currents of charged solar wind particles or changes in the magnetic field. Short, yet intense disturbances are caused by so-called flares, or intensive bursts of radiation. It is common for charged particles to be ejected during one of these flares – a phenomenon known as a coronal mass ejection. These particles in the form of a giant plasma cloud travel 150 million kilometres from the Sun to the Earth. The consequences of this are not just wonderful aurorae; the particles also affect spacecraft, technical systems in space and on the Earth, as well as the lives and health of human beings. They change the number of free electrons and thereby the thickness of the ionosphere. The ionospheric plasma causes refraction, diffraction, scattering and absorption of radio signals and is the largest source of errors in the single frequency positioning systems that are integrated into navigation devices and smartphones.

In order to accurately determine the position – even during extreme solar storms – it is very important to correct for the ionospheric propagation error. This error (known as 'range error') occurs in the dispersion of the signal from the satellite to the ground station and is caused by delays in signal travel time in the ionosphere. During strong geomagnetic storms, however, not only navigation, but also high-frequency radio communication is disturbed. This affects civilian air transport. Space Based Augmentation Systems (SBAS) play a decisive role in modern, rapidly scheduled series of take-offs and landings. They complement existing satellite navigation systems, and thus compensate for certain disadvantages of GNSS in terms of accuracy, integrity, continuity and availability. If the precision that is required for safety can no longer be ensured, these support systems can no longer be used. This causes delays in air traffic.

Consequences for agriculture and the power supply

Air traffic is not the only sector affected by space weather. For example, snowploughs in Norway require highly exact positioning data in order to manoeuvre through the dense snow. Farmers involved in 'precision farming' use automated fertilising vehicles, which can significantly reduce the excessive use of fertilisers thanks to GPS data. In maritime transport, precise navigation data are used to achieve exact positioning within harbours or to calculate the best route over the water. If the geomagnetic storms are very strong, operators of electrical networks must also take into account the induced currents, which may lead to technical problems or electrical current outages. In addition, high-energy particle radiation in an extreme solar storm can destroy the electronics of TV or mobile communication satellites, which will result in signal interruptions. For astronauts, the increased quantities of radiation present a life-threatening hazard. Outside of the Earth's protective atmosphere, space travellers are directly exposed to the hazardous high-energy particle radiation.

In general, the atmosphere protects 'normal' air passengers – at typical flight altitudes of 11 kilometres – from heavy doses of radiation. However, since this natural protection is weaker in the polar regions, polar routes are avoided during strong solar storms and aircraft fly at lower altitudes to stay within the protective zone of the atmosphere.

Observe, warn, protect

Even if the strength and course of a solar storm is not exactly predictable, one can prepare for this event (similarly to a predicted hurricane). Space weather experts are able to use the altered numbers of electrons in the ionosphere to estimate which disturbances are to be expected in the information exchange between ground station and satellite and vice versa. "A reliable and accurate prediction of space weather is crucial to be able to take appropriate precautionary measures," says Jens Berdermann of the DLR Institute of Communications and Navigation. The corrections calculated on the basis of ionospheric models can also serve as early warning systems for users. The information from ACE/DSCOVR allows satellite operators to orient the sensitive measurement and communication systems away from the solar wind or to turn it off completely when a severe event is predicted. In this way, the electrical charging of sensitive electronic systems due to the solar wind can be avoided.

Thus, through improved predictions of space weather effects on our highly technical society, DLR scientists are working to build and expand an observation and prediction centre called the Ionosphere Monitoring and Prediction Center (IMPC). With the Space Weather Application Center (SWACI), DLR researchers at Neustrelitz have already demonstrated that it is possible to analyse and evaluate Earth- and space-based ionospheric data in real time. The next step is the construction of the IMPC. "With the IMPC, we want to extend and improve the existing automatic warning system to the needs of various users," explains Berdermann, Team Leader at the DLR site in Neustrelitz. The warning system is interesting to both scientists and systems operators in the area of satellite communication and navigation.

Service adapted to different users

Depending on needs and requirements, users will be able to register for one or more services ('stages').

Stage one – early recognition, using real-time observation data from the Royal Observatory of Belgium (ROB) and data from the recently developed Global Flare Detection System (GIFDS). Flares and coronal mass ejections are detected and arrival probabilities are calculated. Thus, an approximate prediction can be made (two to three days ahead), although the exact time cannot yet be determined. This stage is mainly of interest to scientists rather than industrial users.

Stage two – Lagrange point L1 is involved. If the ACE and DSCOVR satellites are able to measure a solar storm, it will also reach the Earth. The

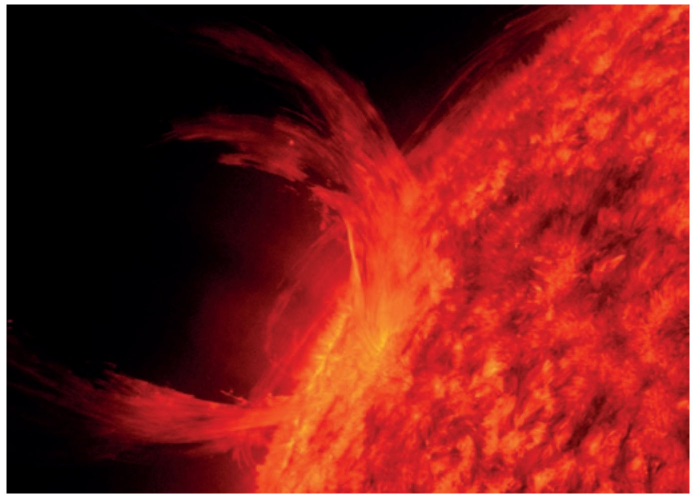


Image: NASA/SDO and the AIA, EVE, and HMI science teams

SHORT HISTORY OF SPACE WEATHER

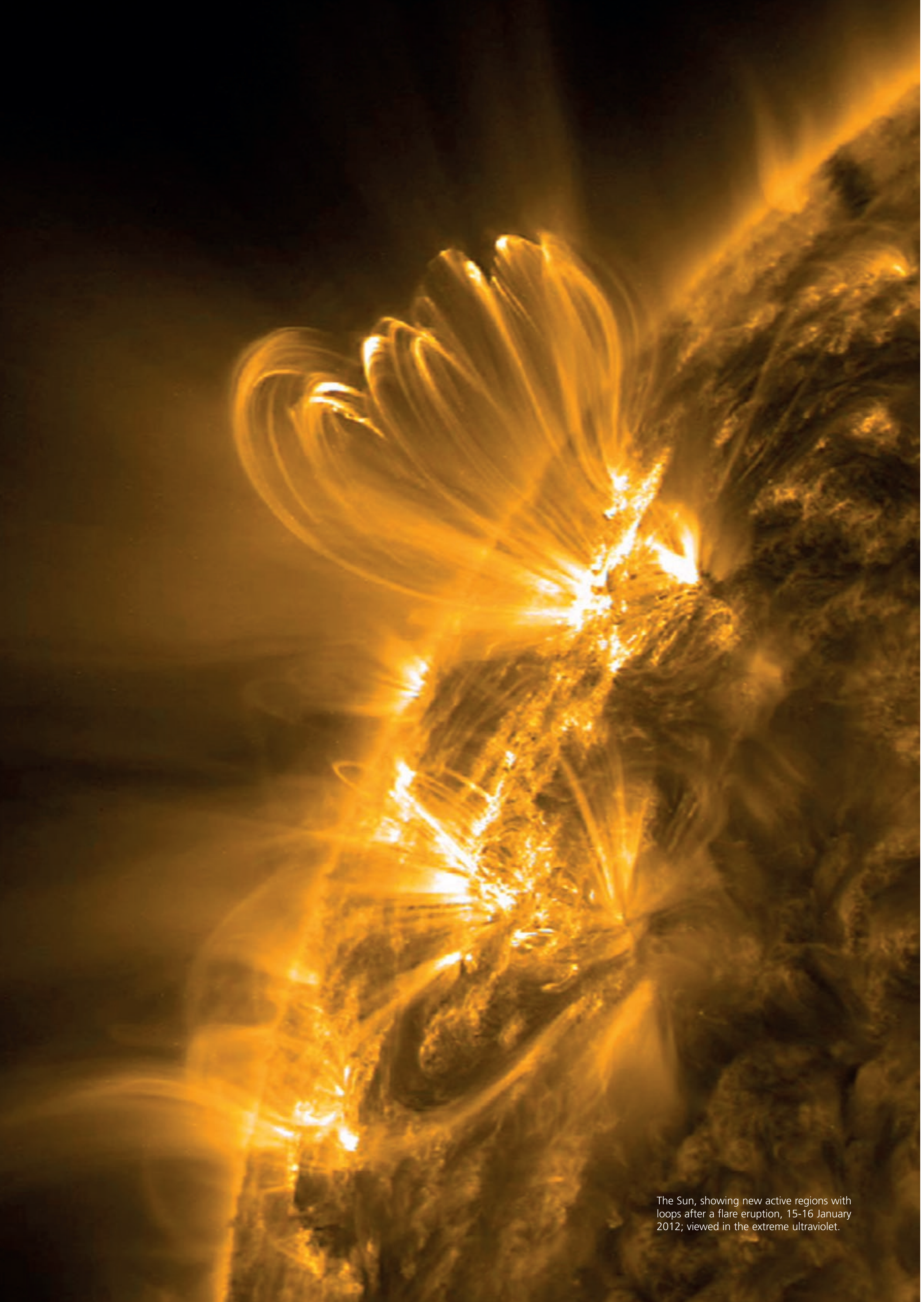
1859 – Carrington event: When sketching sunspots, the amateur astronomer Richard Carrington discovered a massive eruption on the Sun. This event is the largest scientifically observed magnetic storm ever observed and marks the beginning of space weather research. Employees at telegraph stations are said to have suffered electric shocks. Today, such a strong event would have catastrophic consequences.

1921 – storm in May: One of the greatest solar storms of the 20th century generated extremely high currents in transmission lines. The northern hemisphere was affected as far as Mexico and Puerto Rico, while the southern hemisphere was affected down to the latitude of Samoa. A similar storm today would cause the collapse of half of the electrical grids in North America.

1989 – Quebec, Canada: A mighty geomagnetic storm led to a nine-hour power outage in the Montreal region. Traffic control systems, airports and district heating supply centres failed. Some six million people were affected.

2003 – Halloween storm: Seventeen large flares were observed within two weeks. There were very strong, but short-lived disturbances of radio communication. In Malmö, Sweden, a part of the electrical grid failed. Air corridors in northern Canada were closed to passenger flights. Signals from satellite and navigation systems were temporarily out of order. The particle cloud was up to 13 times as large as the Earth and was moving at 1.6 million kilometres per hour. One satellite was completely destroyed and 27 others displayed anomalies in their functioning.

Outlook: Destroyed communication and positioning systems, restriction of air and ship traffic and economic damages in the billions – an extreme geomagnetic storm is a rare but very consequential event. A space weather forecast would give satellite operators time to react and to reduce the costs of damage resulting from solar storms. Since the beginning of 2000, DLR has been running workshops to bring together decision makers in order to make them aware of the topic. The group called 'Ionospheric Effects and Corrections' of the Institute of Communications and Navigation has been working at DLR Neustrelitz to set up a permanent space weather service, the Ionosphere Monitoring and Prediction Service (IMPC).



The Sun, showing new active regions with loops after a flare eruption, 15-16 January 2012; viewed in the extreme ultraviolet.

Image: NASA/SDO and the AIA, EVE, and HMI science teams

Antenna system at DLR Neustrelitz that is used to receive space weather data

Image: DLR/Manuel Tennert

Jens Berdermann, theoretical physicist. He obtained a doctorate in astroparticle physics on 'Equation of state and neutrino transport for superconducting quark matter in neutron stars'. He has been working at the DLR Institute of Communications and Navigation in Neustrelitz since 2011; there, he leads the Ionospheric Effects and Corrections Group and is working toward the establishment of the Ionosphere Monitoring and Prediction Centre (IMPC).

strength of the storm will depend on a number of factors, particularly the interplanetary magnetic field and whether solar storm particles can penetrate well into the Earth's atmosphere. At this time it is already possible to make an accurate prediction and to issue a warning. From the time of measurement at L1 and depending on the speed of the solar wind, the solar storm will reach the Earth's atmosphere within 30-60 minutes. Disturbances in the ionosphere will then spread from the polar regions to the lower latitudes (Germany) within another two to three hours. This time frame is very helpful for industry. It gives enough warning time for many applications, so that technical systems can be promptly adjusted or switched off.

Stage three – prediction. Using empirical models and, in the future, physical models, a prediction of when and where any such disturbance is expected can be made.

Stage four – real-time tracking. The calculation models are constantly compared to and adjusted on the basis of real-time measurements of the ionosphere. In this way, scientists on site can accurately determine if the storm has passed and give the corresponding all-clear signal.

DLR's space weather expertise

Since the turn of the millennium, DLR has been running national space weather workshops and has thus created a platform for this important topic. In the 4th workshop, in 2015, a joint position paper was proposed that is still under development. This document should help national decision-makers to adequately consider current aspects of complex space weather issues in their decisions and to use existing national resources appropriately.

The silent, vibrant energy of the Sun makes life on the Earth possible. In our daily lives we are generally not aware of the destructive energy of the gigantic eruptions on its surface. But these charged solar wind energy particles are real and affect our society at its most sensitive point: its networks.

When will there be a large solar storm? No one can say precisely. That it will come, however, is certain. DLR is working so that society will be as ready as possible to weather the solar storm.

Five questions for Jens Berdermann

1. "To me, my job means …"
: … new daily challenges and interesting research, but also application-oriented science.

2. "If I could obtain the answer to a scientific question, my question would be…"
: Hmm, difficult. (thinks) General, perhaps – what is the Universe made of? What existed before the Big Bang? It is hard to find a limit to this question. From my work point of view, I wonder how large the maximum solar storm could be so we know what to prepare for in the extreme case.

3. "When I look up at the sky, I see…"
: … clouds? (Laughs) No, I move around normally in everyday life, without directing my gaze constantly at the sky …

4. "If I was not working on space weather, then I would…"
: … be studying another exciting field in physics.

5. "In 30 years, space weather research will have progressed to the point that…"
: … space weather is as well understood as weather on the Earth. The greatest progress that I foresee is in the field of physical modelling with data assimilation and forecasts. I hope that we will have more direct observation data from satellites, but can also integrate ground-based data into a physical model. This will make it possible to improve the temporal and spatial precision of the forecasts concerning the state of the ionosphere and more accurately predicting disturbances.

GLOSSARY

SOHO – SOlar and Heliospheric Observatory – European-US solar observatory, delivers data about the solar interior, the solar atmosphere, the corona and the solar wind.

ACE – Advanced Composition Explorer – NASA satellite to analyse the solar wind and solar, interplanetary and cosmic particles, which transmits the data to the US, Japan and DLR Neustrelitz.

DSCOVR – Deep Space Climate Observatory – measures the strength of the solar wind and the interplanetary magnetic field and determines its orientation. In addition, back-scattered radiation from the sunlit side of the Earth is investigated.

GPS – Global Positioning System – satellites orbiting at an altitude of 20,000 kilometres and used for positioning and navigation on Earth.

WHEN LIGHTNING STRIKES

How non-metallic airplane parts get their lightning protection

By Nicole Waibel

Aircraft are struck by lightning once every 3000 flight hours, on average. The passengers do not notice this – just like in a car, the lightning is redirected along the metallic outer skin of the aircraft, so the interior is protected from electrical discharges. The reason for this is the shielding effect of what is known as the 'Faraday cage.'

Fibre composite materials, such as carbon fibre-reinforced plastic (CFRP), are increasingly being used for airplane fuselage. But additional lightning protection is necessary for these materials to form a Faraday cage – the solution lies in a special lightning strike protection layer. Until now, this coating has been manually applied to the entire fuselage shell. But this process is too time-consuming and cost-intensive to produce the next generation of airplanes economically. The DLR Center for Lightweight Production Technology (ZLP) in Augsburg, together with partners in industry, has developed and tested a method that allows the fully automated application of the lightning strike protection material.

The goal is to make the process quicker and more cost-effective, while obtaining the same smooth, crease-free result achieved with the manual precision work. "For this, the lightning protection should be applied in an automated, robust process, with reproducible results and consistent quality. In addition, we would like to improve the utilisation of material and make tighter tolerances possible," says Marcin Malecha, Project Leader at ZLP in Augsburg. "To achieve this, we have worked with our industrial partners to develop a holistic automated solution that, in addition to the laying and draping process, also includes strategies for optimised robot paths and process planning."

A robot-guided laying head consolidates the process steps

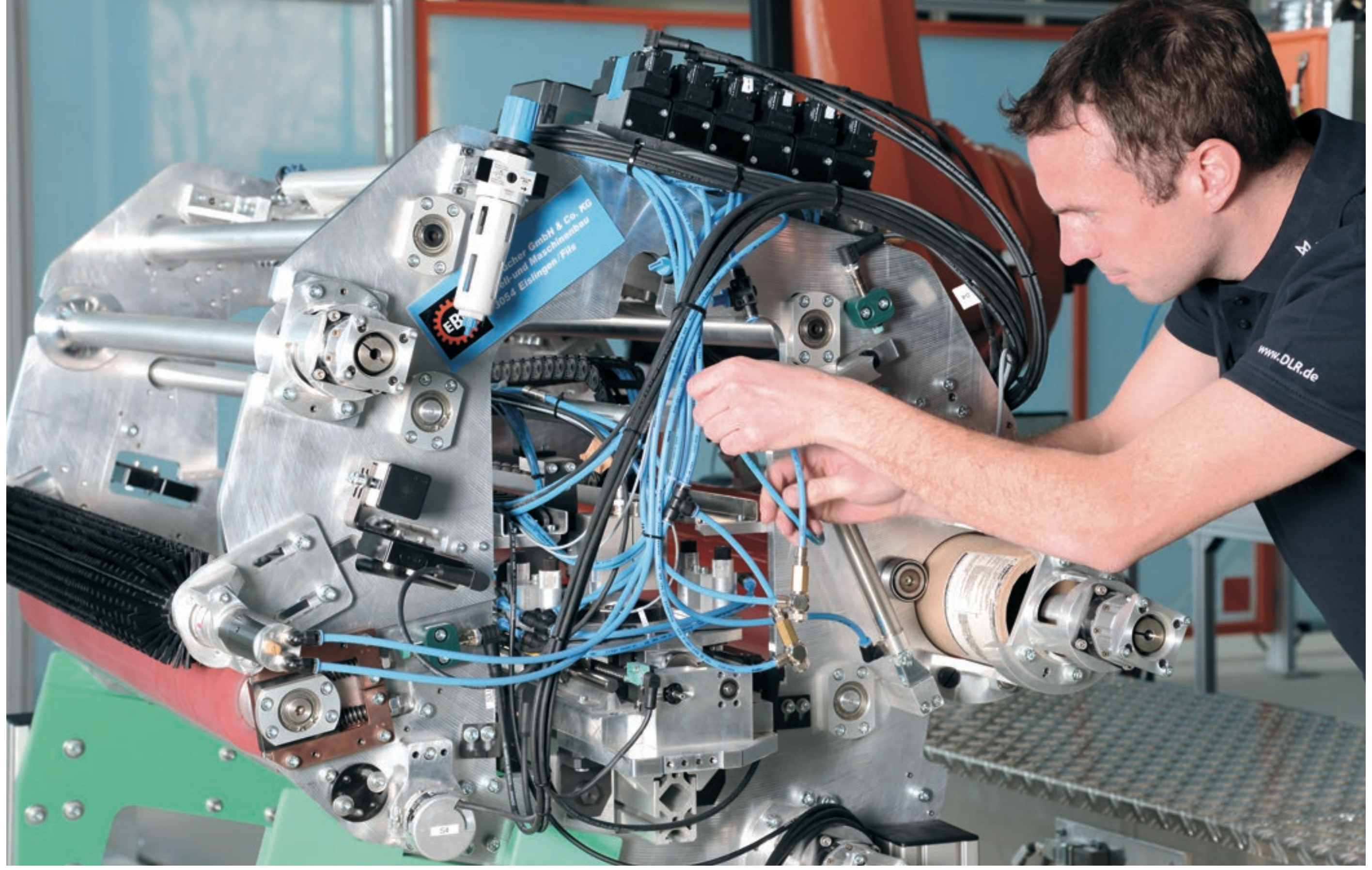
An automated laying head was designed, developed and implemented in collaboration with the company Emil Bucher GmbH & Co. KG. The application of the lightning strike protection coating is especially complicated towards the rear of the aircraft, where the fuselage surfaces become double-curved. "You can easily imagine the problems encountered when trying to glue a piece of paper to a ball," says Patrick Kaufmann, a research associate at ZLP in Augsburg, describing the complex process of applying the coating on the curved fuselage shell. The material must be carefully cut, pressed and smoothed out evenly to avoid the formation of creases. "We took into account all the necessary functions in the particular process steps," Kaufmann says, explaining the procedure for developing the automated application system. "During the first phase, it was particularly helpful to use an experimental trolley, with which we reproduced the material flow and improved the individual function modules, such as the cutting unit, the pressure roller and the draping unit.

"Then, everything was integrated into a compact overall system. The laying head performed the depositing process automatically until the 90-centimetre-wide roll of material was exhausted. It prepares the material, cuts it, places it, drapes it and then collects the protective foil, backing paper and waste material – all in one step." A robot guides the position and orientation of the laying head and controls all the driving gear.

The attempts to optimally drape the metal mesh in the full size are carried out on a double-curved tool surface. The lightning strike protection coating always forms the outermost layer of the aircraft. It is however possible, depending on the sequence in which the individual layers are applied, to initiate the lightning protection process with a concave shell as the first layer, or to complete the lightning strike protection on a convex shell. "Initially, we were able to lay the material on a convex tool surface. Then we expanded the laying head for a concave geometry. Since these differ in shape and power distribution, we had to change the geometry of the pressure roller," Kaufmann explains. Another important measure led to an optimised process control. In a final series of trials, the required depositing quality for three paths was successfully verified for concave geometry in full size.

FARADAY CAGE

The 'Faraday cage' is named after English physicist Michael Faraday (1791-1867). He found out experimentally that the interior of a space enclosed by metal is protected from external electrical fields and electromagnetic waves, as though in a cage. The cage conducts current around the outside. Automobiles, trains and airplanes form such 'Faraday cages'. If they are struck by lightning, the metal redirects the energy on the outside and protects the occupants of the vehicle. Lightning rods also use the effect discovered by Faraday.



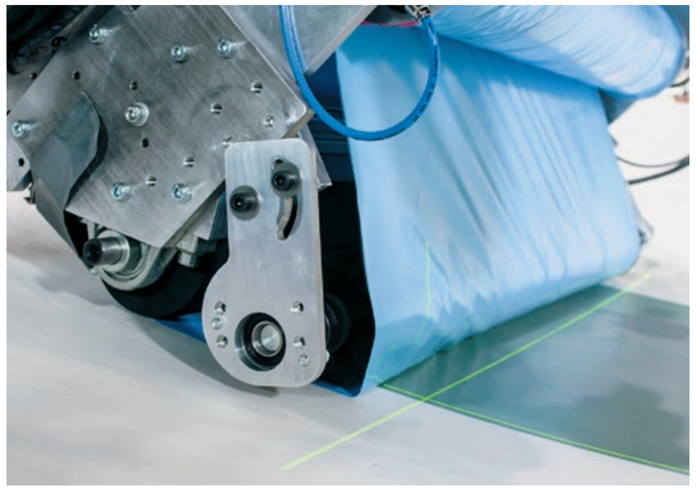
The developed laying head conducts the deposition process completely automatically. Only the loading of the material must be carried out manually.

Crease-free placement and better utilisation of material

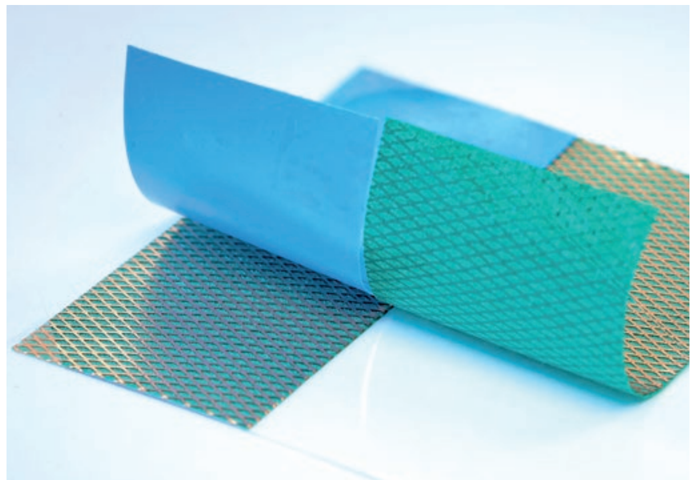
"In addition to the crease-free placement of a material that is almost without distortion, another difficulty lies in finding the best placement path," adds Malecha. The path planning for the robot describes the course of movement of the laying head as it is positioned and oriented by the robotic equipment. "In the manual process, the aircraft tailpiece is divided into parallel slices to make the placement simpler for the worker. In this way, for paths with strong curvature material cuts resembling the shape of a banana are created. As a result, only part of the material can be utilised."

The path planning that has now been developed uses significantly less material, since almost the entire width of the roll of material can be placed. With the use of an algorithm developed by the scientists, the robotic paths can be optimally adjusted to the various curvatures of the surface. "We can lay down broader paths, in which overlaps are narrow and the waste material is reduced. In addition, more material can be placed in a shorter time," Malecha says, listing several advantages of the automated solution. This has been implemented and successfully validated together with the industrial partners Premium AEROTEC GmbH and Emil Bucher GmbH & Co. KG. Malecha says in summary: "We have, for the first time ever, succeeded in transferring the placement of lightning strike protective material onto large-surface, curved airplane parts through a completely automated process."

Nicole Waibel is responsible for Public Relations at the Institute of Structures and Design**.**



Precise placement and crease-free results are two important criteria for the automated application of lightning strike protection



An additional copper lattice ensures that even fuselages made of composite materials easily conduct electricity, and thus the aircraft is protected from lightning.

A SMOOTH MOVE TO MASS PRODUCTION

The factory of the future – lighter cars with functionally integrated components.

By Nicole Waibel

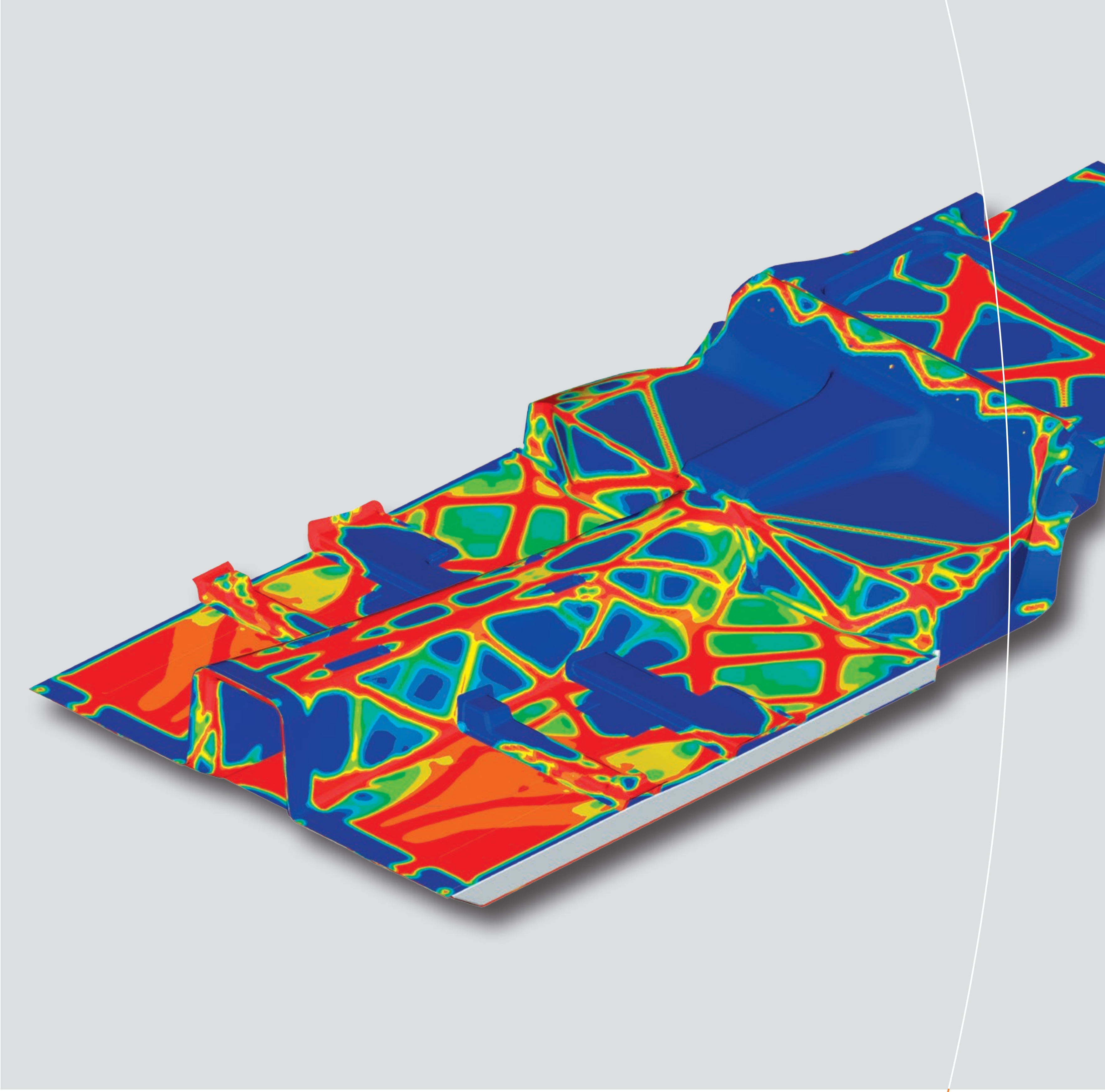
The evolution of the horse-drawn carriage to the automobile was revolutionary. However, this was not the case with materials. They were mainly made out of wood, leather and iron. With time, forged and hot rolled steel came into play. Until the middle of the 20th century, wood frames and sheet metal were the most frequently used components for a car chassis. Wood was varnished or covered with leather. Despite the use of the 'fibre composite' wood, the major focus of chassis development was not lightweight design.

Today, the secret of successful automobile manufacturers is the targeted and economic use of materials. The goal is to build an automobile that is as light as possible, because the less it weighs, the lower the fuel consumption and exhaust emissions from internal combustion engines. Carbon fibre-reinforced plastic (CFRP) is therefore being used more and more frequently in lightweight auto design. These materials do not rust, exhibit greater stiffness and stability at a lower weight than steel or aluminium, and are thus suitable for crash-relevant components.

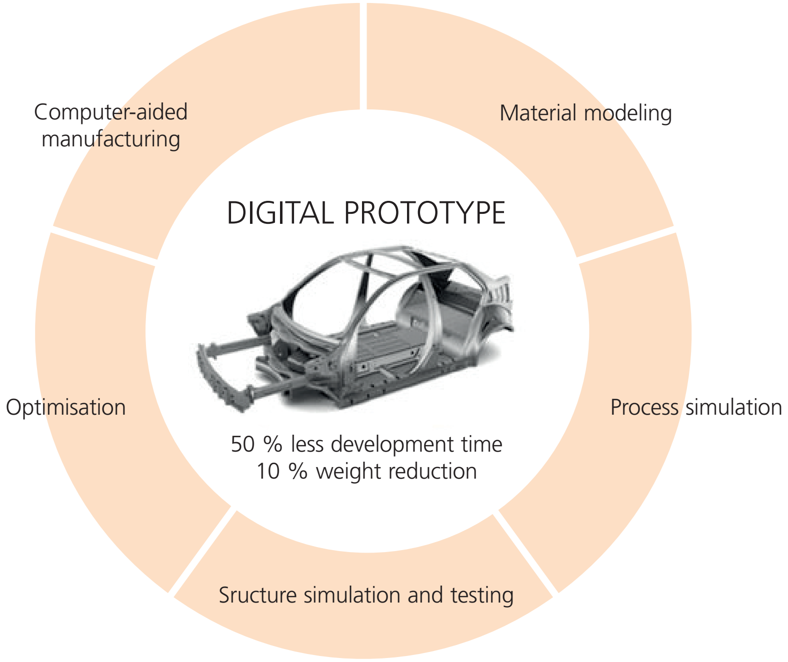
In addition to the introduction of modern lightweight design materials, weight can also be reduced by integrating as many technical functions as possible into one structure. Here, once again, fibre-composite materials present outstanding possibilities. Nonetheless, so-called functionally integrated structures are still seldom used in the mass production of automobiles. In order to support their introduction into mass production, DLR, together with partners, is working in the ARENA2036 research campus on new methods of lightweight design with the integrated functions, and on the development of digital prototypes.

ARENA2036

In the research campus ARENA2036 (Active Research Environment for the Next Generation of Automobiles), experts from industry and academia are working together on lightweight technologies and production models for the automobile of the future. As a founding member, DLR – together with two of its Stuttgart-based institutes, the Institute of Vehicle Concepts and the Institute of Structures and Design – is applying its expertise in the areas of vehicle design, lightweight vehicle design, as well as crash simulation and testing.



DLR researchers investigate the stresses in a floor module during normal operation and also in the event of a collision. By knowing where the structure must absorb the highest loads, in order to keep the assembly as light as possible, they selectively strengthen these areas (shown in red). The result is an overall structure that remains stable while minimising use of materials.



Lighter panels with several functions

"The weight can be reduced through components made of high-strength steels, aluminium or even CFRP. Further possibilities result from the correct combination in multi-material design. The goal is to get the most out of the material and the lightweight design method. A functionally integrated component normally weighs less than the sum of all the individual functional components. "With the right combination of materials and functional integration, the weight can be reduced by 20 to 30 percent. This is known thanks to transport projects," says Gundolf Kopp, Head of the Lightweight and Hybrid Design Methods research area at the DLR Institute of Vehicle Concepts in Stuttgart. "With greater functional integration and fewer individual components, we can also reduce future expenditure for assembly and logistics."

In the project LeiFu (a German abbreviation for lightweight design based on functional integration), the ARENA2036 partners are exploring the foundations for the integration of selected individual functions. A multifunctional floor module for high-end vehicles serves as one example of such an application. Instead of making the floor structure primarily out of metal, as done until now, the researchers are using fibre-composite materials and are integrating additional functions directly into the subfloor. The vehicle floor of the future will serve not only as a platform to anchor elements such as the vehicle seats, but will have additional functions as well. "The possible functionalities range from sensory or electrical to thermal functions, and through to sound and heat insulation. In the project, we are developing assessment and design rules for highly integrated components," explains Kopp. The goal is to further develop the concepts, designs and manufacturing methods of functionally integrated composite structures so that they can be easily introduced into the mass production of automobiles.

Image: ARENA2036

The factory of the future is networked and flexible – new developments can be incorporated into ongoing production immediately.

Digital prototype supports virtual product development

How can the behaviour of fibre-composite materials be predicted? And can fibre-composite components be calculated on a computer for a closed process chain, from basic design through to manufacture? These are the questions that are engaging the ARENA2036 partners in the second subproject, 'DigitPro' (digital prototype).

"The challenge lies in developing realistic material models in order to be able to simulate material and structure behaviour on a computer," explains Nathalie Toso, Head of the Structural Integrity department at the Institute of Structures and Design in Stuttgart. "In that way, we can provide our partners involved in manufacturing with important information regarding, for example, the level of strength and stiffness that can be achieved, how much energy can be absorbed during a crash, or which production processes are most suitable for materials and structures."

Numerous processes are involved from the design of a component through to its automated manufacture. "The simulation tools and the data formats that are used by the various actors differ, which makes data exchange difficult," says Toso. The goal of the DigitPro subproject is to digitally simulate all the required stages in the development of a component, and subsequently transfer them virtually into a closed process chain. This is achieved by using the example of two different textile fibre architectures: braided composite and open reed weave (ORW), a completely new weaving technology.

"In this way, components can be designed quickly and in line with requirements. With the help of a complete, digital model and continuous data exchange encompassing all the steps of the process chain, the weight of the component can be reduced by 10 percent and the development time by 50 percent." In addition, development costs can be reduced, friction losses in the chain avoided, and the expense for physical tests required until now to validate and confirm component properties minimised.

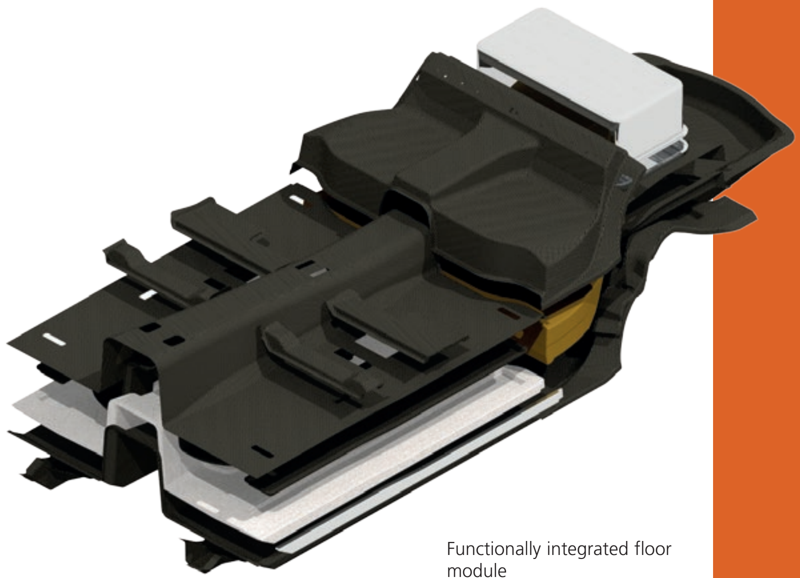
Image: ARENA2036

The research factory for the next generation of automobiles is currently being built at the Stuttgart University campus in Vaihingen

Close cooperation between industry and science

The ForschFab (Research Factory) project combines the research and development work of the LeiFu and DigitPro projects. The focus of the Research Factory is to transform the industrial production principle – that is, to replace the present conveyor-belt manufacturing with the adaptable production of the future. This is Industry 4.0, whereby the assembly line is so flexible that new developments can be integrated into ongoing production immediately, and in which network and sensor-driven robotic and assistance systems support human beings. Classical combustion engines, hybrid drives, and electric drives with batteries or fuel cells can be produced next to one another simultaneously. Peter Froeschle, Managing Director of ARENA2036, says: "The Research Factory project does not just involve a unique facility to study Industry 4.0; it also brings together experts from business and science under one roof. The goal of this interdisciplinary and interinstitutional cooperation is to accelerate the transfer of research findings to industrial production. It is here that DLR is making an important contribution."

Nicole Waibel is responsible for Public Relations at the Institute of Structures and Design.



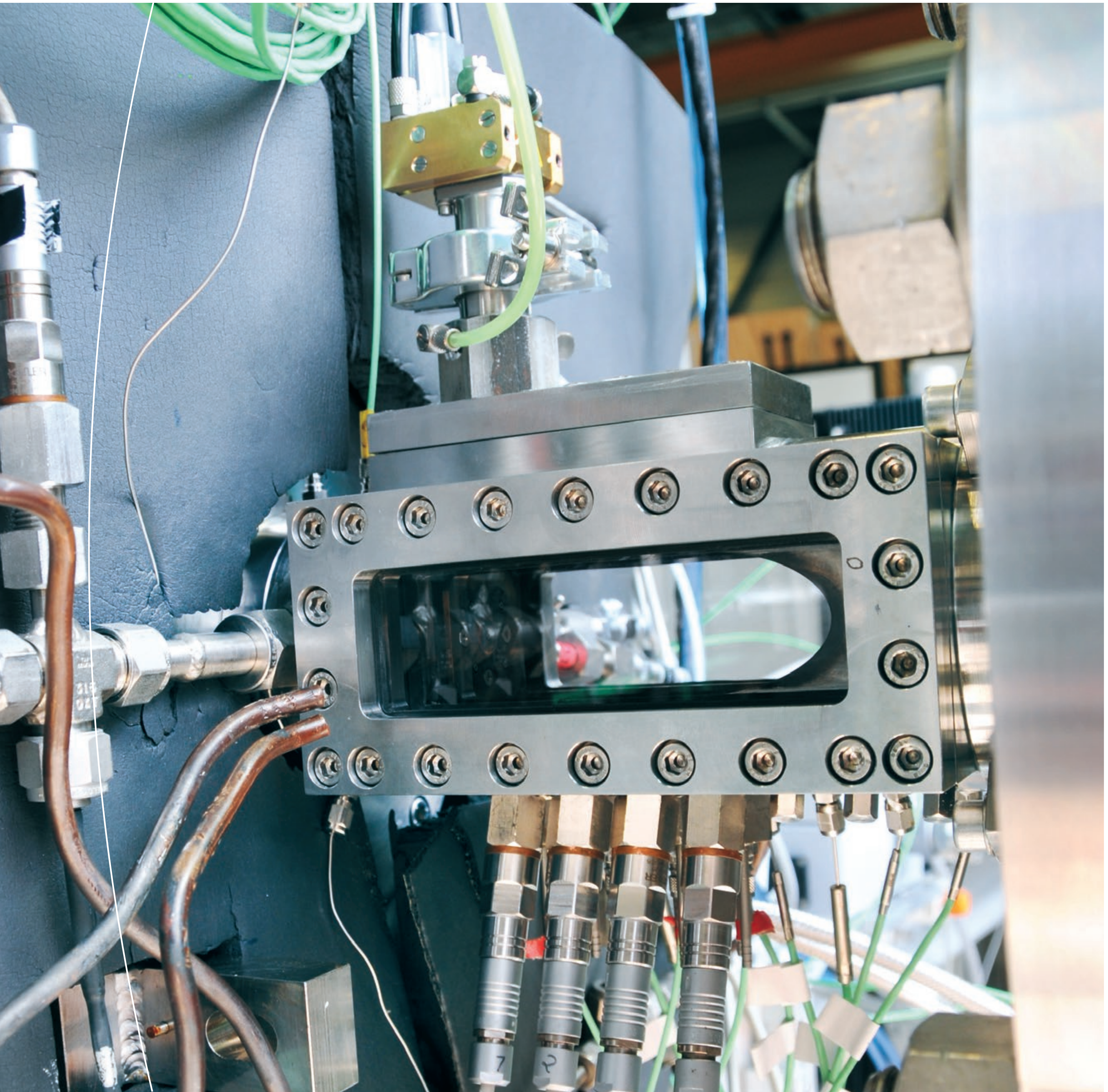
Functionally integrated floor module

ARENA2036: EUROPE'S LARGEST RESEARCH FACTORY

The ARENA2036 (Active Research Environment for the Next Generation of Automobiles) research programme is among the winners of the 'Research campus – public-private partnership for innovation' competition, which was sponsored by the German Federal Ministry of Education and Research. The year 2036 refers to the 150th anniversary of the automobile. In addition to DLR, the founding members are BASF SE, Daimler AG, the German Institutes of Textile and Fiber Research Denkendorf, the Fraunhofer-Gesellschaft, Robert Bosch GmbH and the University of Stuttgart.

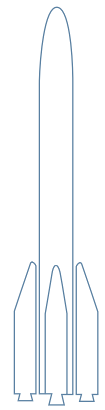
Since July 2013, ARENA2036 has been working in a temporary building on all four initial projects: LeiFu (lightweight design based on functional integration), DigitPro (Digital Prototype), ForschFab (Research Factory) and the interconnecting project Khoch3 (creativity, cooperation, competence transfer). On 8 October 2015, the foundation was laid for a new research building at the university campus in Stuttgart-Vaihingen. This 'Research Factory' brings together the activities of the research campus under one roof. It fosters close interaction of the various disciplines and enables the timely testing of results from the research into development and design as well as simulation. There will be as many as 160 employees in this new research building.

The research and development project ARENA2036 is supported with funds from the German Federal Ministry of Education and Research and managed by the Project Management Agency Karlsruhe.



Before the several hundred-ton rocket lifts off, the engine must be reliably ignited. Laser pulses could play an important role in future. The image shows the test chamber at the DLR test bench M3 with the HiPoLas laser. The glass combustion chamber and pressure and temperature sensors allow the propellant injection and the ignition behaviour to be studied in detail.

TO SPACE – ROCKETS ALIGHT



Future launchers are to be ignited with lasers

By Chiara Manfletti, Michael Börner, Gerhard Kroupa and Sebastian Soller

December 2014, Luxembourg: The European Space Agency Council Meeting at Ministerial level concludes with the decision to develop a new launcher for Europe – Ariane 6 – to guarantee Europe's independent access to space. A European launcher system, however, not limited to carrying Europe's space projects to space but to also be a worldwide competitive commercial launcher.

The new launcher is a member of the European launcher family, consisting of the large Ariane 6 and the smaller, but no less important, VEGA-C. Together, they will form the backbone of coordinated European space transportation activities. European launchers make spectacular projects possible – the Rosetta comet mission and the ATV supply flights to the International Space Station (ISS) are outstanding examples. Moreover, European launcher systems are also of great importance for large projects, such as the Galileo satellite system, to consolidate Europe's sovereignty.

This new launcher family is based on the P120C solid-rocket booster, which is being especially developed for the new generation of launchers. In addition, existing technologies, such as the Vulcain 2 engine, the workhorse of Ariane 5, are further being improved. Laser ignition will quite literally give this a boost. In laser ignition, a short laser pulse is focused using a lens, whereby hot plasma of several thousand degrees Celsius is created. The resulting flame grows into a combustion zone and ignites the combustion chamber.

But lasers were not always considered for the ignition of engines. Initial ideas in the 1970s fell through due to the necessary high energy densities of such laser pulses and the complex structural forms. At the time, lasers were complicated systems the size of a washing machine, were temperature sensitive and required intensive maintenance. In order to generate plasma in the air, the laser system must produce an intensity of one trillion watts per square centimetre. These laser pulse intensities can only be created with sufficiently compact lasers through very short laser pulses in the nanosecond range, meaning in billionths of a second.

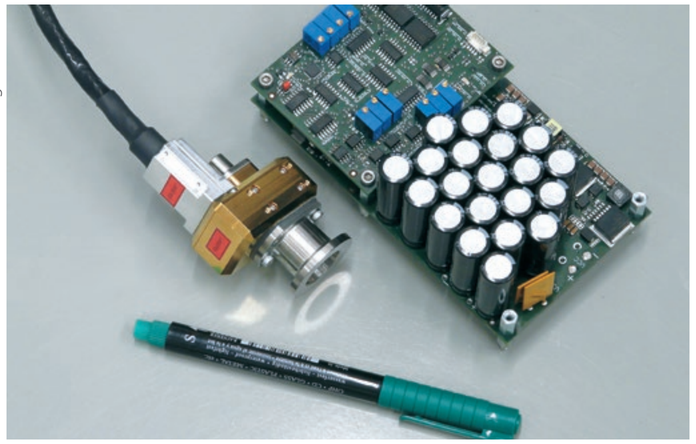


Image: CTR AG

The HiPoLas laser of Austrian Carinthian Tech Research

The laser, which is being developed today in a cooperation between DLR and ASL (Airbus Safran Launchers) especially for use in rocket engines, is the HiPoLas laser of the Austrian centre for technology Carinthian Tech Research (CTR). It is a very small and very light laser system, weighing half a kilogram.

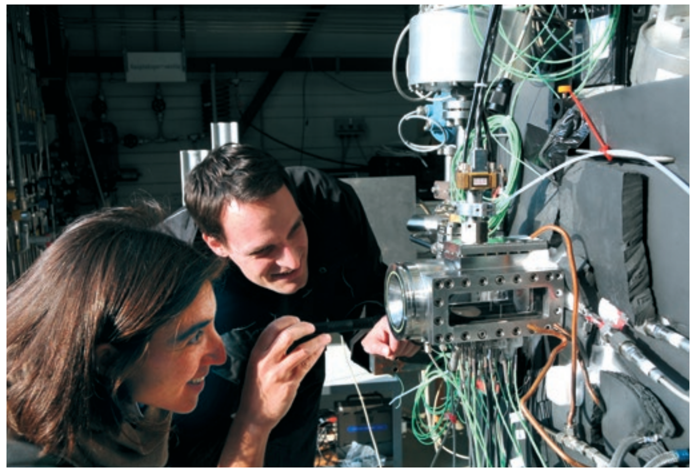
The first laser ignition tests of an experimental combustion chamber took place in the 1990s at the M3 test bench of the DLR Institute of Space Propulsion in Lampoldshausen. The goal was to obtain experimental data of the ignition process. Thanks to the precisely determinable place and time of ignition, laser ignition is perfectly suitable for numerical simulations of the ignition process allowing researchers to examine the interdependencies of propellant injection characteristics, time of ignition and the pressure evolution after ignition. In those days, the technical implementation on real engines was not yet conceivable.

The first version of a laser igniter was developed by the Austrian Centre for Technology Carinthian Tech Research (CTR) in 2004. At that time, a substitute was sought for the electrical spark plugs of cars and trucks. It soon became apparent that a very compact solid-state laser made of as few components as possible was necessary for operation under the existing vibrations and temperatures. Work was also conducted on laser igniters for large internal combustion engines and aircraft turbines. For this, the lasers had to be converted from water cooling to passive cooling and further reduced in size. A compact, technically qualified for aerospace applications electronics box was also produced. The prerequisites to implement the system in space applications were born.

It was not until 2009 that laser ignition was considered as an ignition technology for so-called attitude control thrusters. These small engines are used in both satellites and launchers in order to correct, change or maintain the position and orientation during launch, flight and in orbit. Current attitude control systems are operated with hydrazine-based propellants. These propellants have the advantage of not requiring any ignition system, but they are toxic and are considered carcinogenic. In 2007 the EU REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) rules came into effect. As such, the use of certain environmentally harmful substances was restricted or banned altogether. Hydrazine is one of these. One alternative for hydrazine in attitude control engines on launchers is the use of hydrogen and oxygen from the main tanks. The operation of such attitude control engines would however require a light-weight and reliable ignition system. For this reason, laser ignition for liquid oxygen and gaseous hydrogen or gaseous methane was studied using an experimental combustion chamber at the DLR M3 test bench.

This experimental combustion chamber, in combination with the test bench vacuum system, allows the simulation of the very low pressures that exist at very high altitudes. A six-month test campaign with over 300 test runs demonstrated that laser ignition is a suitable method both for ignition under sea-level conditions and at high altitudes. It was also the first time that the miniaturised HiPoLas laser was used in an experimental rocket combustion chamber. The success of this test campaign was the foundation for the further development of laser ignition for space propulsion applications in Europe.

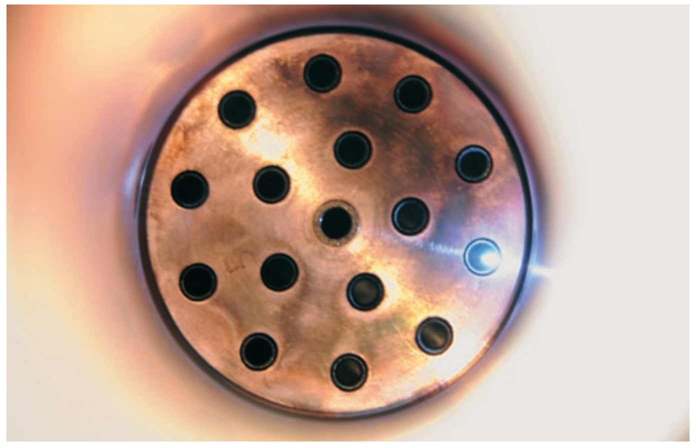
After the first basic tests in 2011, the technology which was first thought of for implementation in attitude control thruster, was also considered as a possible test bench technology to increase the test cadence per day. Furthermore, laser ignition was also identified as a possible alternative for the ignition of larger engines. In 2014, a second ESA research project followed the first one. The goal of this project was to test laser ignition of a combustion chamber with multiple propellant injection elements under high-altitude conditions. The basic tests conducted at the M3 test bench of the DLR Institute of Space Propulsion in Lampoldshausen were so promising that a test campaign at the European P8 research and technology test bench followed. This campaign aimed at testing the suitability of laser ignition in combustion chambers of high thrust ground ignited engines.



At the DLR test bench M3: The combustion chamber is inspected for damage at the end of the day.

More than 1500 ignition tests were conducted for the propellant combinations oxygen/hydrogen and oxygen/methane during the four-month test campaign at the end of 2014. This campaign boasted the most ignitions ever performed at DLR cryogenic test benches. During each of the 30-minute test runs, the combustion chamber was ignited 60 times, brought to its steady-state operating point, and shut down again. Laser ignition thereby passed its aptitude test with flying colours.

In parallel to fundamental research conducted by DLR, ASL initiated investigations into the industrial development of laser-based ignition systems for rocket engines. As an extension of the fundamental research tests conducted at DLR, ASL studies concentrated on the integration of such an ignition system into an existing engine and on demonstrating its feasibility under the operating conditions of a space mission.



View through the nozzle of the combustion chamber to the injection elements of the injector head with the thousands of degrees hot plasma generated by the laser pulse

For this, various system requirements must be considered. In a flight engine, the ignition system must fit seamlessly into the architecture of the entire stage. This includes power supply and the electromagnetic tolerance of the system with regard to the other electronic components or assemblies on the launcher. The maximum possible construction space and the accessibility for assembly and maintenance work must also be taken into account. In addition, European regulations with regard to spaceflight components must be adhered to. Components that are of limited availability due to international legislation must be avoided. Moreover, evidence of reliability under vibration and thermal loading must be provided, and must be considered as early as the design stage of the system. The ignition laser must be sufficiently thermally shielded from its surroundings and able to withstand the remaining temperature fluctuations and mechanical loads. At the same time, optical access to the combustion chamber must be designed so that thermal effects do not cause any impairment to the ignition.

Aerial image of a Vulcain 2 test on the P5 test stand at DLR Lampoldshausen

WITH CURIOSITY AS THE DRIVING FORCE

Short interview with Chiara Manfletti

When did you realise that you wanted to work with rocket engines?
: It happened shortly before the beginning of my studies in September 1997. During the evening news, a video about the ESA Huygens probe was broadcast. The video showed how the space probe would plunge into the atmosphere of Titan, one of Saturn's moons. At that moment, I knew I wanted to do something like that – to make inspiring space missions possible! I went to my parents and said, "I am moving to London; I am going to make spaceflight possible." And that is how the journey began.

What ability or skill is especially necessary to work in the field of space propulsion?
: The ability to apply all that you have ever learned both in theory and in practice, at precisely the right moment. I look at it as a little pocket of magic instruments you carry with you at all times; you use them as the occasion arises, and you know exactly what to use and when. And to be open to anything new, even to ideas that seem impossible at first.

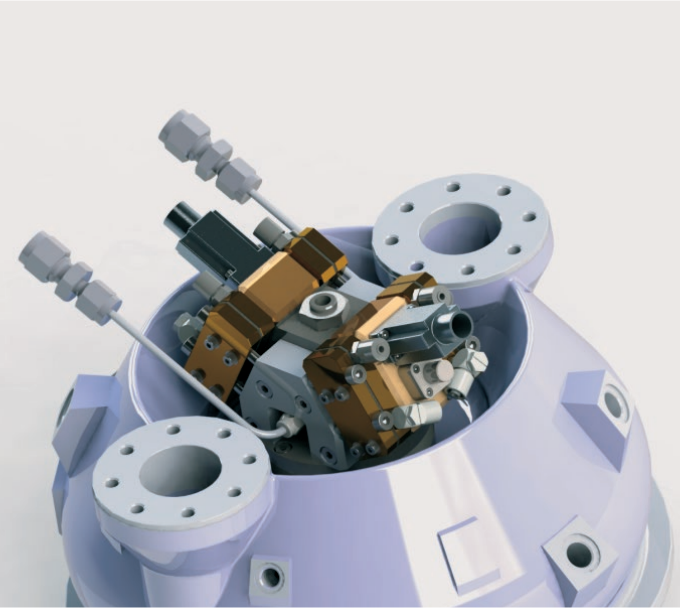
Which profession would you have taken up if you had not become an aerospace engineer?
: I am a curious person – I pondered over a lot of things, from marine biologist to lawyer, journalist, veterinarian, civil engineer… The list is long, I even wanted to join the Italian Air Force at one point and become a fighter pilot.

Would you like to fly to space?
: Oh yes! – When are we going?

Do you like New Year's Eve?
: Absolutely! Friends, family, sparkling wine, snow, lentils at midnight (…an Italian tradition)… and of course, New Year's Eve fireworks.

Questions by Cordula Tegen

Image: ASL



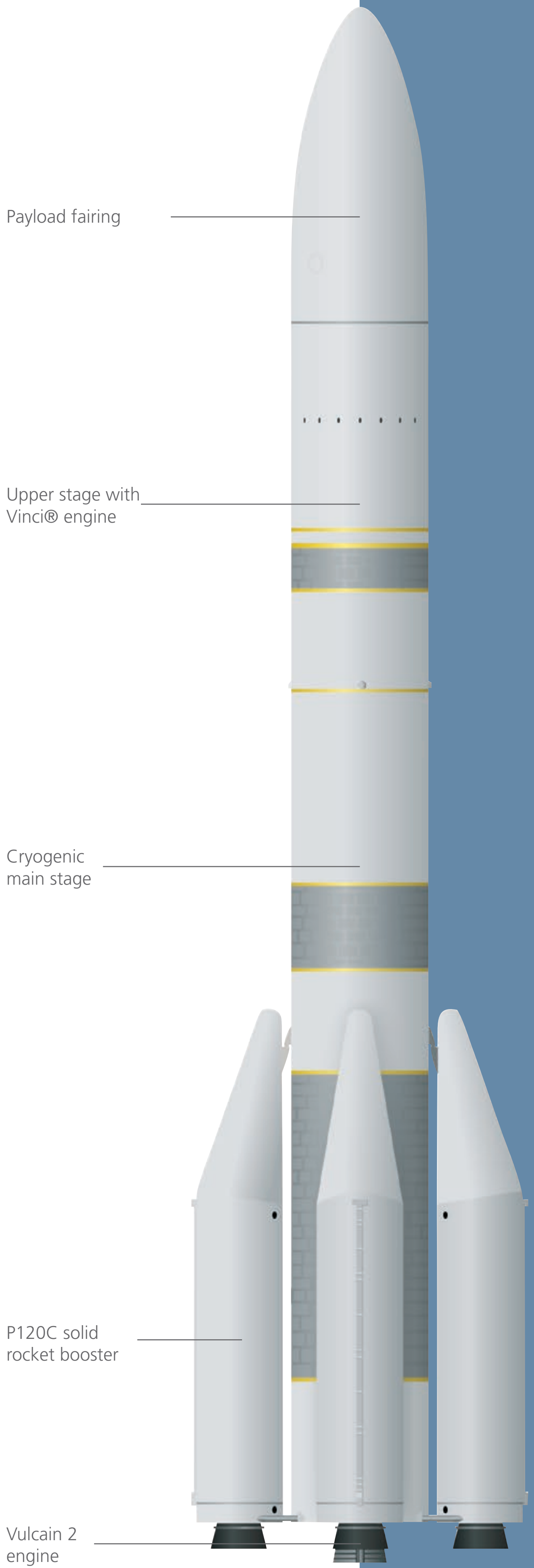
Laser ignition system integrated into the gas generator of the Vulcain 2 engine

Efforts continue to be made to move from experiments with combustion chambers on a small scale to the full-scale application. These efforts involve a technology demonstration engine at the original scale of a flight engine. This demonstrator will be tested in 2017 on the DLR P3 test bench in Lampoldshausen. The functionality of the laser ignition system built specifically for this was already demonstrated in the fall of 2015 at the P8 research test bench as part of its own ASL test campaign. During these tests, the valves were set up and the ignition sequence was performed in such a way as would be necessary for the later engine, which is dictated by the interaction of the individual system parts, such as the turbopumps, valves and cooling system. A re-ignition of the engine after an initial burning phase and a longer shut-down phase – as would be the case in a true rocket flight – could also be demonstrated. The system showed its technical readiness and paved the way to test laser ignition for use on the Vinci® upper stage engine of the Ariane 6.

The results from the test bench experiments have shown that the robustness of a laser-based ignition system significantly reduces the operating costs of the launcher system. Thanks to the work conducted in recent years, laser ignition systems have reached a state of development that allows their use in liquid rocket engines.

The first use on an Ariane 6 launcher rocket has been set for the near future. Researchers are anxiously awaiting the maiden flight in 2020 and hope that the laser ignition system will make a valuable contribution to its success.

Chiara Manfletti conducted research at the Department of rocket propulsion systems of the DLR Institute of Space Propulsion until April 2016. She is now working at ESA. **Gerhard Kroupa** is Project Manager of the high-energy laser at Carinthian Tech Research AG. **Michael Börner** works at the DLR Institute of Space Propulsion as project manager for ignition processes. **Sebastian Soller** is a systems engineer and Project Manager for research and development at Airbus Safran Launchers GmbH.



Vulcain 2 engine during a test at the DLR P5 test bench

Vinci® engine at DLR's P4.1 test bench

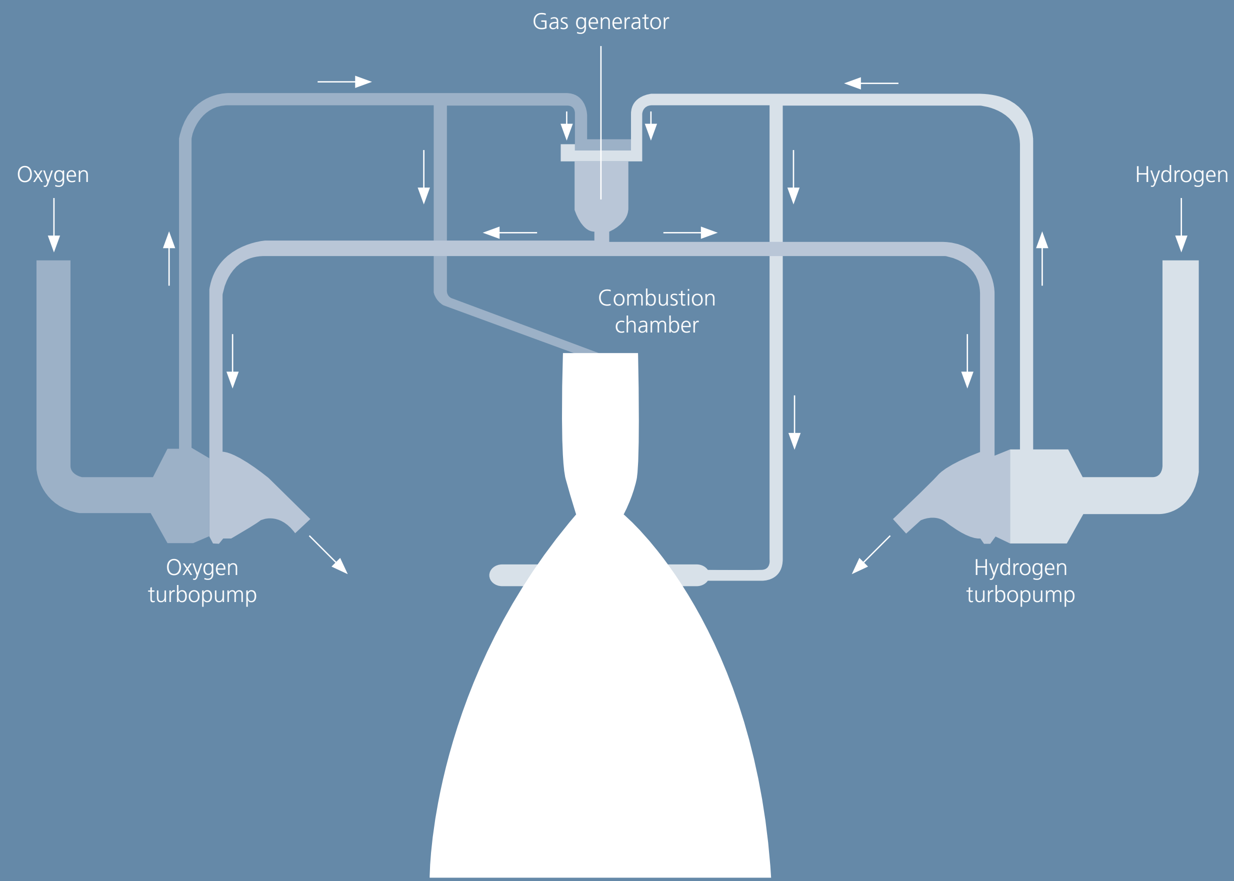
THE ENGINES OF THE ARIANE 5 AND 6

The main stage Vulcain 2 engine of today's Ariane-5 rocket works with liquid oxygen and liquid hydrogen. Its maximum thrust of 1359 kilonewtons (kN) would be sufficient to lift 100 small cars. Together with the new Vinci® upper stage engine (180 kN of thrust), the Ariane 6 can fly missions in which engine re-ignition is necessary. This may be the case when a payload must be brought to a specific orbit around Earth or to other celestial bodies, or when several payloads must be brought into orbits of varying altitudes with a single launcher. Upon separation from the payload, the upper stage of the rocket can re-enter Earth's atmosphere using its engine for orbital correction manoeuvres, and avoid contributing to space debris in Earth orbit.

There are various technical solutions for single ignition systems. At present, pyrotechnical elements are used to ignite the Vulcain 2 engine. They function in a similar way to the propellants in fireworks. Such elements ignite both the combustion chamber and the gas generator of the Vulcain 2. The advantages of pyrotechnic igniters include their simple design, their low weight and compact volume. One of the disadvantages is that pyrotechnic elements can only be used once, which rules out re-ignition. Secondly, they are subject to regulations on explosives materials, which makes the assembly of the rockets more complex.

Torch igniters are an alternative to pyrotechnical igniters. These use spark plugs to ignite and burn a gaseous oxidiser (e.g., oxygen) and a gaseous fuel (e.g., hydrogen) in a smaller, separate combustion chamber. The resulting hot gas is then fed into the main combustion chamber to ignite the injected fuel. The advantage of electrical igniters is that the engine can be re-ignited. The disadvantage is the need for additional components such as the small ignition chamber, the additional propellant lines, valves and, depending on the design, a separate high-pressure propellant supply system. As such, they make the engine heavier, and more complex as the order in which the igniter and propellant valves are activated must be set up very precisely.

If instead, a laser igniter is attached directly to the main combustion chamber, these additional components and steps are no longer necessary. This makes ignition by laser a very promising alternative which is therefore being studied not only for the Vulcain 2, but also for the Vinci® engine of the Ariane 6.



About Andreas Dillmann

Andreas Dillmann (born 1961) studied mechanical engineering at the University of Karlsruhe. He then went on to become a researcher at the Max Planck Institute for Flow Research in Göttingen, and obtained his doctorate in 1989 at the local University. In 1990 he began working at the DLR Institute of Flow Technology. In 1995, he completed his habilitation in Göttingen and at the University of Hannover in the subject of high-speed aerodynamics. From 1998 to 2003, he was Professor of Theoretical Fluid Mechanics at the Technical University Berlin. Since 2003, he has been Director of the DLR Institute of Aerodynamics and Flow Technology in Göttingen and Professor of Aerodynamics at Göttingen University.

OTTO LILIENTHAL – THE MAN WHO BROUGHT ORDER TO AERODYNAMICS

An interview with Andreas Dillmann about 125 years of flight and the Lilienthal Glider

Why is a cutting-edge research institution like the German Aerospace Center building a full-sized replica of an historic aircraft?

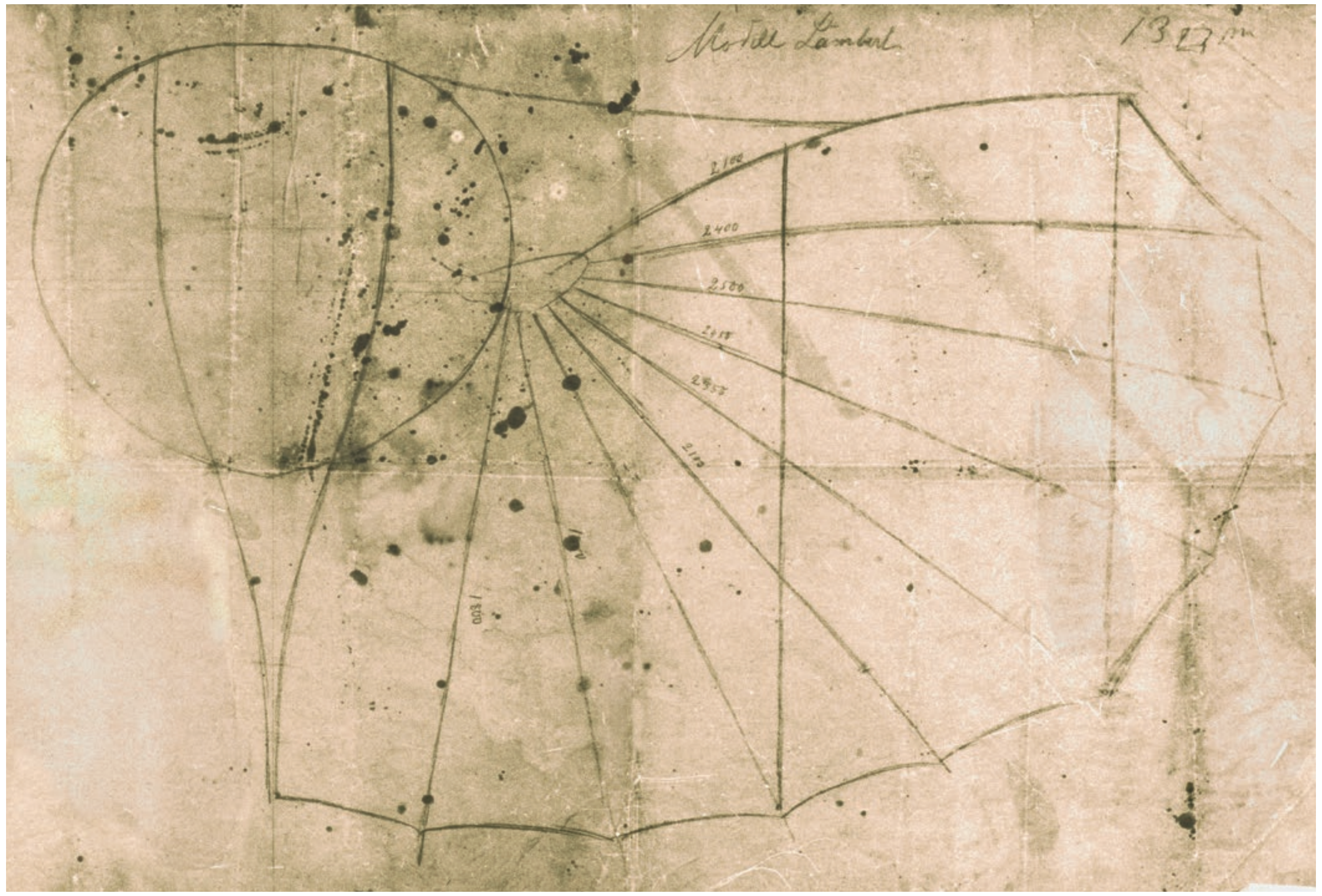
: We want to acknowledge the accomplishments of Otto Lilienthal. Lilienthal was the first person to realise that a curved wing can generate more than twice as much lift as a flat one. He documented this well in his book. But going from wing to airplane is not trivial. For an aircraft to fly, it must be stable around all three axes. Whether or not Lilienthal built such an inherently stable airplane continues to be the subject of debate in research. In my opinion, it is very likely that Lilienthal was indeed the first person to achieve this. Our research will help us to determine this.

What do we owe Otto Lilienthal as a pioneer of air transport?

: From a scientific point of view, Lilienthal brought order at the beginning of aerodynamics. He recognised what forces had to be measured and how to meaningfully present them to allow for the transition from the model to the full-sized version. So he invented the 'Lilienthal polars' – a standardised graphical representation for assessing lift and drag, that is, the aerodynamic properties of aircraft and aircraft wings. You could say that it is practically the aerodynamic business card of an aircraft. Lilienthal was the first person to apply scientific methods to solve the issue of flight. Before that, it had been mainly hobbyists that built flying machines that could lift into the air for a short time; they only made short hops. Lilienthal really flew – the day on which he conducted his first flight is rightfully marked as the day on which humankind learned to fly.

How did Otto Lilienthal go about constructing his aircraft?

: Essentially in the same way as aviation researchers today. He systematically researched wing profiles from this point of view: Could the wing support the weight of the aircraft and the pilot with the least possible resistance? He used dimensionless coefficients for aerodynamic drag and lift – the same values that, in principle, we use even today. Apparently, he already understood that an aircraft is basically a rigid body that needs, in addition to the wings, an empennage to maintain a stable equilibrium between the weight and aerodynamic forces at any flight position.



Sketch of 'normal glider': The first series produced commercial aircraft in the world, which is now being replicated by DLR, in cooperation with the Otto Lilienthal Museum Anklam. The drawing was once made for a glider for Charles de Lambert, one of the nine known buyers of the series aircraft from Lilienthal.

Lilienthal's book 'Bird flight as the basis of aviation' is now regarded as the most important aeronautical publication of the 19th century and one of the great books of art history

Image: Archiv Otto-Lilienthal-Museum

In 1893, Lilienthal constructed a 'flight station' on the Maihöhe in Steglitz, which served as a jumping station and glider hangar. The picture was acquired by Ottomar Anschütz, a pioneer of photography.

Otto Lilienthal designed and built a whole series of flying machines. Why was the so-called 'Normalsegelapparat' chosen for the replica?

: There are several reasons for that. To begin with, the 'Normalsegelapparat', or Normal Glider, was the first series-produced aircraft in the world. Lilienthal sold nine of them, and in doing so he had built the first commercially successful aircraft. It is also the most popular Lilienthal flying machine, of which there are many photographs and one that has also been very well documented. The Normal Glider was also the one that Lilienthal was flying when he crashed and died. We hope to gain some insight into the cause of the accident.

So how do we know what Lilienthal's aircraft looked like, exactly?

: Lilienthal left behind his original construction plans, and there are numerous excellent photographs that show many details. The Otto Lilienthal Museum in Anklam, Germany, owns templates of the wing profiles – a particularly important aspect that allows a precise reconstruction. What we cannot see exactly from his documents – for example, the air permeability of the covering fabric or whether there was waterproofing – we have commissioned to be studied by a specialised institute, based on original swatches of material that have been preserved. Regarding the wood construction, we are relying on the many years of expertise at the Museum. In addition to keeping the wing and tail geometry as close to the original as possible, the reconstruction of the covering fabric is especially important. If the weave density does not match that of the original material, the aerodynamic properties will vary. Since the original covering fabric is no longer available, we are having it woven by a speciality weaving company, based on the results of our studies.

Lilienthal flying machines have already been replicated several times in the past. What is special about the one being constructed by DLR?

: Generally, these have been decorative pieces more than true replicas. There were also a few that were tried to be flown. But most of these did not work, since they were not apparently replicated correctly. For example, Lilienthal's original templates were not used – this is something that we are doing. We are concerned with building a machine that will fly and that has the same characteristics as Lilienthal's glider. And that it is capable of flying is something that we can demonstrate through wind tunnel tests.

Why don't you demonstrate this via an actual flight attempt?

: That would not be a scientific study. The conditions for that would always be different, and as such would not be reproducible. We want to know how far he got with his control methods – what wind gusts was he able to fly through? We are also interested in the aerodynamic performance parameters, such as the glide ratio. How far could he actually glide from a given altitude? The data in the literature is quite contradictory here. Only one study attempt has been conducted until now. In the 1990s, a replica was loaded onto a measurement car of the DHV (Deutscher Hängegleiterverband; German Hang Glider Association) in order to determine the longitudinal stability of the glider during a drive. In that case, the glider completely fell apart. We must not forget about safety either. The only person who frequently flew the Normal Glider was ultimately killed in one when it crashed. Perhaps our studies will show that Lilienthal's flying machine was not stable after all and could never have received certification. Ultimately, we do not want to put any lives at risk.

What studies are going to be conducted with the replica?

: The measurements will be similar to those that we would make on a modern commercial airliner. The focus will be the tests in the German-Dutch LLF wind tunnel in the Netherlands – one of the largest wind tunnels in Europe. The glider, with its six-metre wingspan, fits right in. There, the replica will be attached to a six-component scale, where by measuring the three forces and the three rotation moments, all effects of air currents on the flying device can be measured. In that way, we collect information about all the flight characteristics, and can make the Lilienthal glider fly virtually on the computer. A problem for a modern wind tunnel will be the slow speed with which we have to measure – a little too fast, and Lilienthal's fragile construction could fall apart, as it did in the trial with the measurement car.

What knowledge can be gained from the studies?

: If we understand the complete flight characteristics of the 'Normalsegelapparat', we can answer many questions. How far could Lilienthal fly from a specific jump height? Is it true that he always had to fly from a high inclination angle, which would have been really dangerous due to the risk of a stall? Is the suspected cause of the crash, a heat eddy, correct, or did other factors come into play? And last but not least, we would like to clarify the historical question: How good an aircraft manufacturer was Lilienthal in reality?

Otto Lilienthal is a role model for aerodynamics researchers throughout the world. As a researcher and an aviation enthusiast, one could say that you are practically 'related' to Lilienthal. What does the project mean to you, personally?

: It is great, for sure. We are following in Lilienthal's footsteps – this is one of the most exciting projects of my professional career. Some of my colleagues are envious. In addition, as a German aeronautics researcher, I feel an obligation to acknowledge Lilienthal's accomplishments, just as my US colleagues did in 2003 by studying the Wright brothers' aircraft in a wind tunnel. By the way, at that time it became clear that the Wrights' flying machine was unstable at any flight speed. From this point of view, Lilienthal was possibly more of a pioneer and inspiration for the Wright brothers than his successors.

The interview was conducted by Jens Wucherpfennig

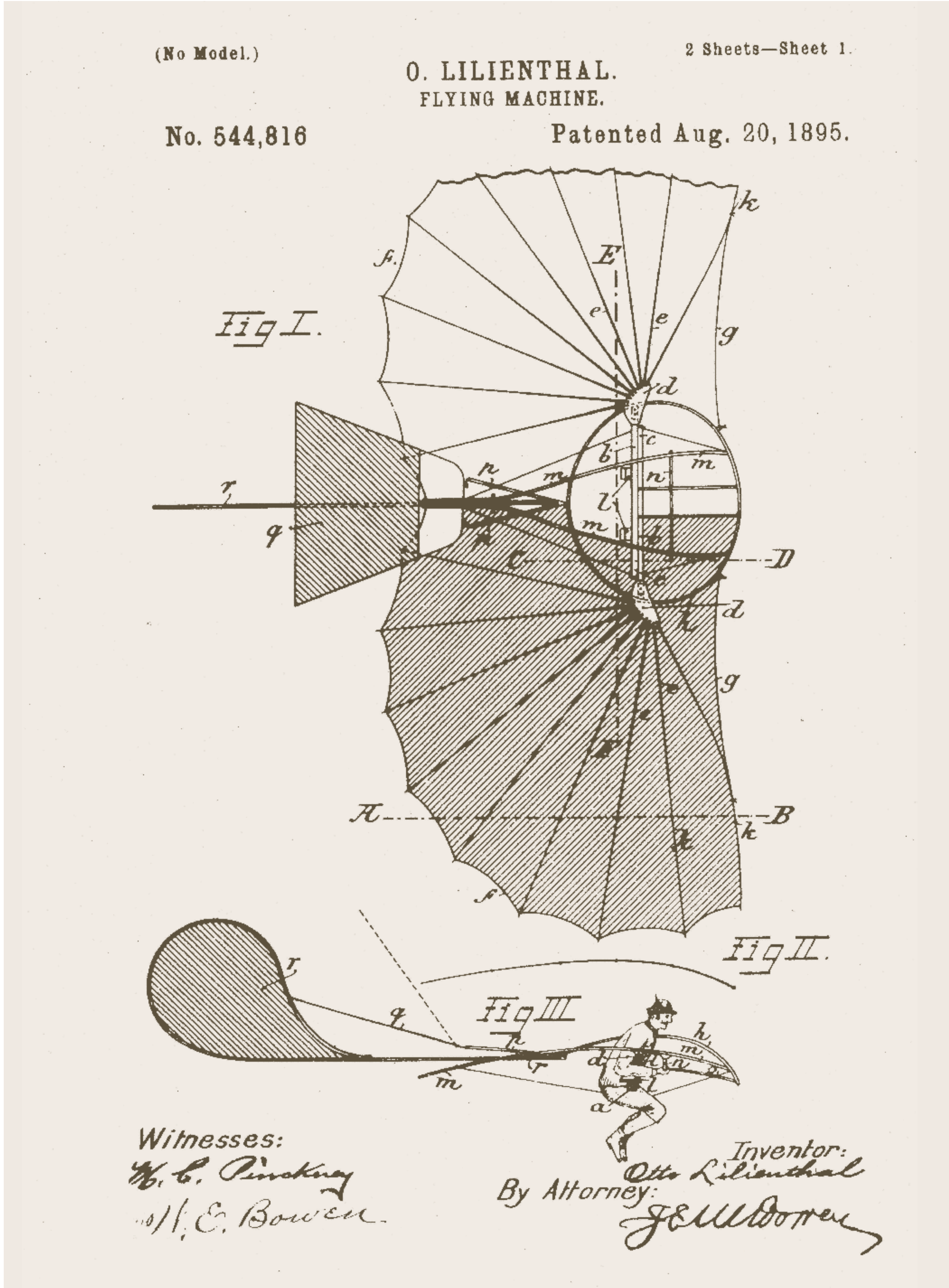


Illustration of the patent of Otto Lilienthal for an early flying machine, from 20 August 1895.

UNIQUE, VERSATILE AND GRAND

In the last 100 years, wind tunnels have become an indispensable part of aerodynamics research, but their importance extends far beyond the intention of the original builders. These large research facilities have been adapted to new challenges time and again. And in so doing, a whole new type of modern architecture emerged. The sixth and last part of the series 'The Wind Machines' takes a look at wind tunnels now, and in the past.

Part six of the series 'The Wind Machines'

By Jens Wucherpfennig

When the first wind tunnels were built in the 19th and early 20th century, the builders – whether it was the Frenchman Gustave Eiffel or Ludwig Prandtl working in Göttingen – were hoping for a tool to help them study the first flying machines, be they airships or airplanes. But it was not long before the unparalleled opportunities offered by the 'wind machines' were used for other purposes. Everything that moves quickly through the air, or that air flows around, could be the subject of a wind tunnel test. So it came about that the first train models were soon tested. At that time, one wanted to find out how to prevent the smoke of the locomotive from entering the driver's cabin. Studies in the wind tunnel delivered the answer – and with it the solution soon came in the form of the Betz smoke shield, which redirected the steam. Other questions that were posed included: What is the optimal body position of ski jumpers in order to achieve the greatest possible distance? Studies using a human-like dummy in the wind tunnel showed that a relaxed posture with arms held close to the body provides many advantages – the parallel style in ski jumping was born.

Unusual test objects

It was shown repeatedly that the question of what was to be studied in the wind tunnel depended as much on the eccentricities of individual researchers as on the historical and social environment. So during the First and Second World Wars, it was not only in Germany that wind tunnels were used almost exclusively to research combat aircraft or for the first rockets. In addition, studies on artillery projectiles in the 10 x 10 centimetre supersonic tunnel in Aachen proved that the ranges of the firearms not only depended on the barrel or ignition material used – it depended on the aerodynamic qualities of the projectile up to 50 percent. Times of war were also busy periods for the construction of new wind tunnels. As with the country's overall economy, research was at the service of 'war'.

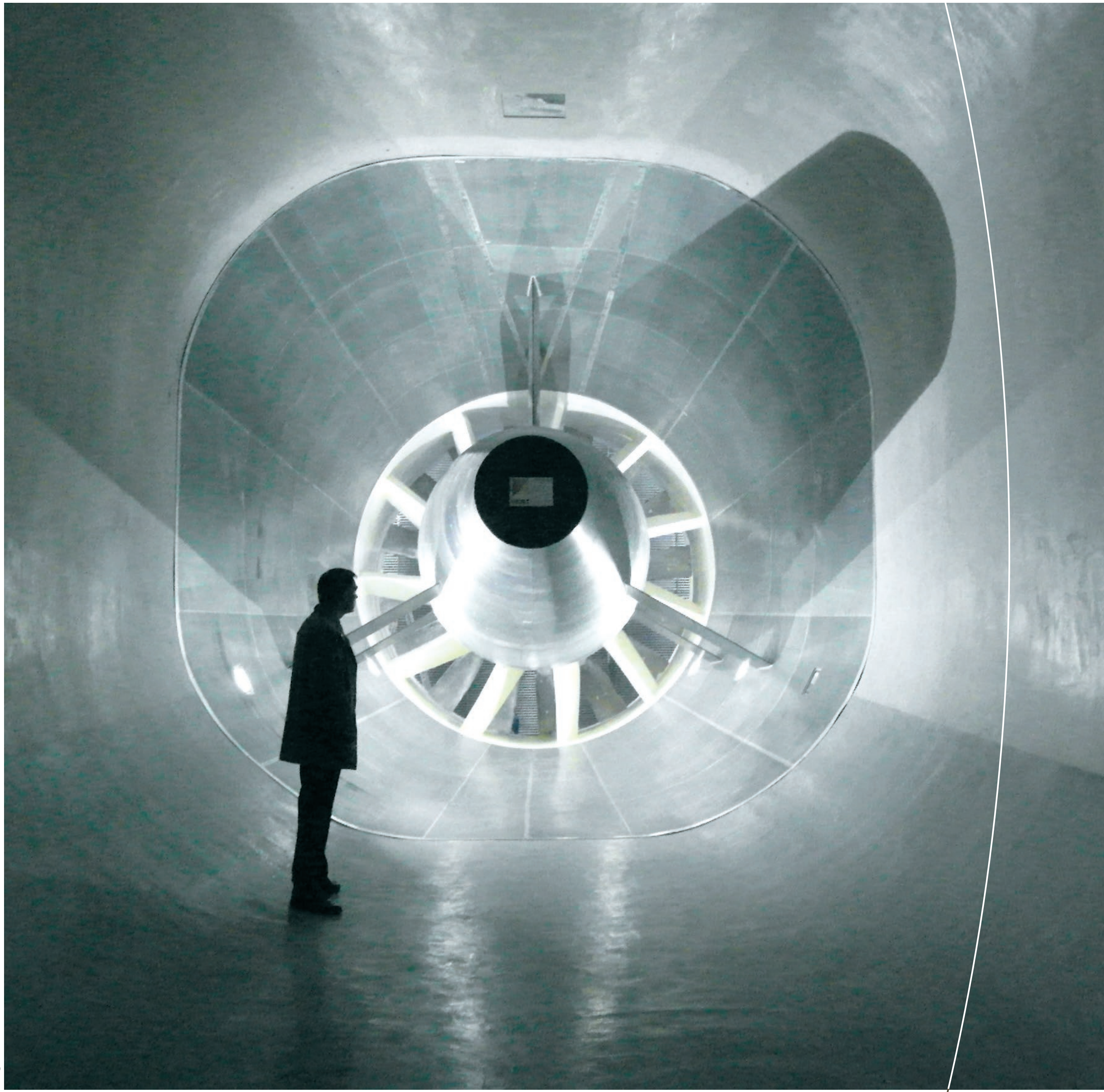


Image: DNW

Inside the low-speed wind tunnel at DLR Braunschweig

The invisible made visible – wind tunnels reveal the flow around objects placed in them. An image from the DLR_School_Lab in Göttingen illustrates this.

When, after the Versailles Treaty of 1919, Germany was banned from conducting aeronautics research, scientists had to turn to other tasks. For this reason, the knowledge gained from aeronautics found its way into automobile construction, and this led to the boom of what are known as streamlined vehicles. The aerodynamics experts helped to create a whole array of vehicles whose design was determined by aerodynamic considerations. To this very day, many people continue to be fascinated by examples such as the Göttingen Aerodynamics Research Institute's Schlörwagen – almost a 'wing on wheels' – the Rumpler Tropfenwagen or the Mercedes-Benz T 80. In another area, it was probably due only to an idea of the nautical engineer Anton Flettner that a theoretical consideration of Prandtl was turned into a rotating aircraft wing, known as the Flettner rotor. A rotating cylinder on the deck is able to drive a ship based on wind power, just as a sail does. More recently, this idea has been implemented in the 'E-Ship 1'.

Costly research instruments

The construction and maintenance of wind tunnels has been a costly affair from the very beginning. The larger the 'wind machines', and the more high-tech, the more expensive they became. It is no wonder that the largest European wind tunnels today are operated by an international association. This involves the European Transonic Wind Tunnel in Cologne, as well as the German-Dutch Wind Tunnels, with a whole series of large wind tunnels in the Netherlands and at the DLR sites in Cologne, Göttingen and Braunschweig.

Wind tunnels around the world have proven to be remarkably durable. Although they are still used in an area that is considered to be at the peak of high technology, and for which the newest supercomputers are just good enough, many wind tunnels have been used for decades. Naturally, the high costs involved in the construction of a large wind tunnel play a role in this. In addition, wind tunnels have proven to be very flexible and can be continuously modernised with the latest measurement technology. Sometimes these modernisations go well beyond this, and extensively involve the construction itself, such as at the Transonic Wind Tunnel in Göttingen, which after several such 'facelifts' bears little resemblance to the original tunnel.

What is more, users of wind tunnels value the experience and comparability of measurement results in a time-proven wind tunnel. Wind tunnel experts know their research instrument, and are able to correctly evaluate new data. However, new constructions require a certain training period, in which the operators must get to know the strengths and weaknesses. Despite these arguments, the number of new wind tunnels speaks about the research priorities of a society. While in Europe and North America no new really large wind tunnel has been built for over 25 years – although many wind tunnels were constructed for the automobile industry – in China, such installations are mushrooming, demonstrating the ambitions of an emerging aviation nation.

In the western world, starting from the United States, a new use for wind tunnels has become popular. In many places, tunnels have been built for the fashionable sport of 'skydiving'; these have nothing to do with research. In this case, it is simply about the possibility of using the principle of wind tunnels to fulfil humanity's dream of flying in the air freely.

Coveted targets

While the construction of wind tunnels is a sign of great ambition in aviation, on the other hand the loss of wind tunnels for a particular country means a blow to its ability to get involved in modern aviation. The most prominent example of this is Germany, where after its loss in the Second World War not only aviation, but also aviation research was forbidden for many years. A visible sign of this was the disassembly of practically all the wind tunnels on the territory of the former German Reich. However, not all the wind tunnels were destroyed. Many facilities were dismantled by the victorious allies in Germany, and then reassembled in their home countries. For example, one wind tunnel for high-speed research, developed by Wernher von Braun's team for the study of new rockets, wound up in the United States. A Braunschweig wind tunnel provided services to the United Kingdom after the war, and the French disassembled a whole set of still incomplete high-performance wind tunnels in the Alps in order to put them into operation in France. These French wind tunnels of German origin are incidentally still in use today. The former Braunschweig wind tunnel has been shut down, but one part, what is called the compressor screw, made its way back to Germany and is today exhibited as a monument at the DLR site in Braunschweig. The Soviet Union also put to use several seized German wind tunnels for its own purposes after the Second World War.

Wind tunnels are operated from futuristic control rooms, such as here, at the Large Low-Speed Wind Tunnel in the Netherlands.

Extravagant structures

Aside from their use for research and for commercial purposes, wind tunnels have become representatives of a very unique architectural form. Whether composed of 100-metre-long thick pipes – the so-called pipe wind tunnels – or as Göttingen wind tunnels, which are shaped like the letter O, wind tunnels have their own style. They have a special aesthetic – inside and outside. For instance, in the large examples there is a giant propeller inside a vaulted chamber. In Berlin Adlershof, the large wind tunnel and egg-shaped spinning wind tunnel are not only relics of research, but are protected as monuments to bear testimony to a special type of architecture. Anyone who has seen these unusual constructions – or even better – has ever stood in them, will never forget this quite special impression. So it is no wonder that this ensemble in Berlin Adlershof has been used repeatedly as a site for film production. Most impressively, the Hollywood blockbuster 'Aeon Flux' used the wind tunnels as a setting; this was a science fiction film for which the 1930s structures presented the perfect backdrop for a utopian, bizarre world of the future.

And this indeed appears to be a fitting description of wind tunnels: unusual, at times strange buildings, often from a bygone era, yet where highly modern research takes place – tunnels connecting the past and the future.

THE WIND TUNNEL SERIES

1. **Meaning and purpose. Overview. Importance.**
   DLR Magazine 140/141, April 2014
2. **Moths, men, machines**
   DLR Magazine 142/143, September 2014
3. **More than just air**
   DLR Magazine 144/145, April 2015
4. **Europe's flagship wind tunnel is in Cologne**
   DLR Magazine 146/147, September 2015
5. **318 metres for exclusive aerodynamic tests**
   DLR Magazine 148/149, March 2016
6. **Unique, versatile and grand**
   DLR Magazine 150, June 2016

Wind tunnels often remain in use for a surprisingly long time. They need to be repeatedly modernised, as has been the case with the Transonic Wind Tunnel in Göttingen, which has been refitted several times since its construction in 1963.

All that one needs to fly: the minimalist 'Flying Flea' (Pou-du-Ciel) based on a French design equipped with a 1300 cubic centimetre motorcycle engine – enough for a pleasant Sunday stroll.

Only flying is more beautiful, enthused our former aviation editor as he returned from vacation in Denmark, where he had visited two aviation museums whose exteriors could not have been more different: A modest hangar versus romantic castle grounds. Hans-Leo Richter visited the very special aviation exhibits at the Danish Collection of Flying Vintage Aircraft in Skjern and Egeskov Castle. Here, he tells us what awaits us inside. Take a stroll through these museums and you'll be sure to want to visit them first hand.

FACE-TO-FACE WITH THE FLYING FLEA

Aviation history in Denmark – rare vintage airplanes in Jutland and a myriad of technology in Funen

By Hans-Leo Richter

The Flying Museum in Skjern

Small-scale exhibitions can surprise visitors with their exquisite, often very delicately devised displays. These exhibitions are not always listed in travel books or easily found on the Internet. One can discover such exhibits at two historical aviation institutions of in Denmark: the 'Dansk Veteranflysamling' (Danish Collection of Flying Vintage Aircraft) at Stauning airport, north of Esbjerg on the west coast of Jutland, and an equally fascinating collection of historic aircraft and cars in Egeskov Castle, a splendid 16th-century castle surrounded by a moat in the southern part of the island of Funen.

A hidden jewel in Skjern

The Dansk Veteranflysamling in Skjern is not so easy to find. The museum, located in the midwest of Denmark, lies quite hidden at the small Stauning airport, off to the side of the Skjern-Ringkøbing main road. It was founded in 1975 by Danish aviation enthusiasts and is dedicated almost exclusively to Danish aircraft of the 'KZ' series – built by Viggo Kramme and Karl Günther Zeuthen. The complete range of products – 11 models that were created between 1937 and 1953 – is represented in the Veterans collection. All the airplanes were built by the Skandinavisk Aero Industrie (SAI).

Among those on display is the 'Flying Flea,' a curiously small, light airplane with a laden weight of just 102 kilograms. The most interesting feature of this aircraft is the tandem construction of the two wings – located behind each other and diagonally above each other – one of which also serves as a lift. It was propelled by a 1300 cubic centimetre motorcycle engine, which could 'accelerate' the device to a maximum of 100 kilometres per hour.

Egeskov Castle in Kvaerndrup

At the time, Viggo Kramme – later co-builder of these small types of airplanes – was commissioned to build a replica of a 'Flying Flea,' originally from France, by a Copenhagen daily newspaper. His colleague Zeuthen was of the opinion that he would probably be better off building a 'real' aircraft. And so the one-seater 'KZ I' airplane was born. The two builders' other models were lightweight monoplanes designed for various tasks. Somewhat exceptional in this area was the already very progressive 'KZ IV,' a twin-engine low-wing aircraft with a double rudder assembly that almost completely covered the undercarriage and was very aerodynamically effective. It was mainly used as an air ambulance, but also served as a courier plane. In addition to the crew, it could accommodate two patients and two accompanying persons.

The next hangar primarily showcases military aircraft. Various restored Sikorsky helicopters make a quite outstanding impression – as does the Hawker Hunter from the early 1960s – and are a must in these collections. Also worth seeing here are the twin-engine United States Consolidated Catalina flying boats – the giants of this hall. Likewise impressive are the twin engine Douglas C 47 'Skytrain' aircraft, the military variant of the legendary DC 3. In addition to these airplanes, information about anti-aircraft protection, radar devices, and ambulance planes and their special tasks is provided. The de Havilland Dove is an especially exotic item. A small twin engine short-haul airliner for a maximum of nine passengers, the model on display was still used in the 1970s by the small Danish airline Cimber Air on domestic Danish routes.

A look into the Stauning hangar: behind the different engines, an Enstrom F 28a light-utility helicopter and a modern Aerospatiale SN 601 Corvette business jet can be seen.

Showpiece of the excellent collection of replicas in the Flying Museum: reconstruction of a Danish Ellehammer from 1906.

A look into historic kitchen utensils at Egeskov castle: the splash of colour brightens the day.

In the third hangar, visitors are treated to numerous other classic planes, including various Piper models and a beautiful Tiger Moth biplane. Gliders are also represented in a dignified manner. Anything with a rank and name in the 'plywood era' is showcased here. The 'Doppelraab' and the 'Grunau Baby' are hardly lacking, as are different 'Scheibe' types. All in all, excellent gliding machines from the time when nobody dared to think about composite material flyers with gliding numbers of 40 and more.

Unfortunately, there is no open-air exhibition area. All the displays are set up in the three hangars, which is probably a wise decision, giving the often harsh Scandinavian winters. A certain number of historic airplanes can actually fly, and once a year fans of these oldies can admire these marvellous exhibit pieces during a live air show.

Technology at the Egeskov moat castle

The second collection of vintage aircraft, in the south of Funen island, located about 30 kilometres south of Odense, has two peculiarities. First of all, the airplanes on display, at least by their numbers, are not the central attraction. Secondly, this collection is not located in a modest hangar or exhibition hall, but in a stunning castle surrounded by a moat. The magnificent landscape alone is worth a day trip to the Egeskov Castle. From the shore of the moat, wonderful views are available of this wonderful Baroque building with gables, towers and battlements. The entire set of walls continues to rest on stable wooden pillars, which at one time undoubtedly constituted an entire oak forest ('Egeskov').

In the front of the museum wing – possibly the castle's earlier coach house – is the old-timer collection, which has been here since 1967 and features the Saab Draken, a Swedish fighter aircraft that still seems quite modern with its characteristic delta wings. Inside, visitors can enjoy a very beautiful collection of old airplanes and great cars from past decades. The airplanes hang one by one from the hall ceiling over the automobiles. These include the 'Flying Flea,' already known from the Stauning collection, the German minimal helicopter Focke Achgelis 330 from the 1940s, and the General Aircraft ST 25 monospan, a magnificent oldie from the United Kingdom. An absolute must-see are the still admirable de Havilland Tiger Moth biplane and the Alouette helicopter. Equally impressive is the Lockheed F 104 Starfighter – in its time, as famous as it was infamous.

A few noble automobiles on display include the former Danish king's Cadillac and the wonderfully beautiful blue Bentley of the one-time Prince of Siam, now Thailand. There are also many 'bread-and-butter' automobiles from earlier decades for the delight of visitors, including Volvo and Saab models – even a NSU-Ro 80. It is very stimulating to see the collection of small and very small cars from the 1950s, such as the BMW Isetta, Zündapp Janus, Lloyd and several Goggo models.

Even more exhibition areas are found on the upper floor of the gallery. Old Bicycles and mopeds ('Knallert') are carefully presented, as are an old kitchen, set-up items and a workshop. The variety of topics covered in this part of the collection is surprising. The castle offers other exhibits on agriculture, horse-drawn carriages, puppets, emergency service, a merchant museum, a working smithy and many more.

This unique castle with its diverse collections is a place for the entire family, especially for the young and the elderly to gain an insight into Danish technical and cultural history. Persons less interested in technology will find an attractive alternative – instead of the Flying Flea and the Tiger Moth, one can admire the splendid rose garden or take a walk through the marvellous hedge labyrinth …

Lovely classics in the old coach house – a de Havilland Chipmunk trainer above a Volvo 244 from the late seventies and an Opel Record Caravan P1 from the early sixties.

DENMARK'S FLYING MUSEUM

Lufthavnsvej 1 | DK-6900 Skjern
www.flymuseum.dk

Opening times: 15.03 – 30.04 daily 10 – 15 hrs, 05.01 – 31.05 daily 10 – 16 hrs, 06.01 – 31.08 daily 10 – 17 hrs, 01.09 – 31.10 daily 10 – 16 hrs

Entrance fee: Adults 70 DKK, Children (7 – 14) 30 DKK, Children (0 – 6) free entry, Group discounts from 15 persons

EGESKOV

Egeskov Gade 18 | DK-5772 Kvaerndrup
www.egeskov.dk

Opening times: 22.04 – 19.06 daily 10 – 17 hrs, 20.06 – 14.08 daily 10 – 19 hrs

Entrance fee: Day pass (22.04 – 19.06) Adults 180 DKK, Children (4 – 12) 95 DKK

AVIATION MUSEUMS IN DLR MAGAZINE

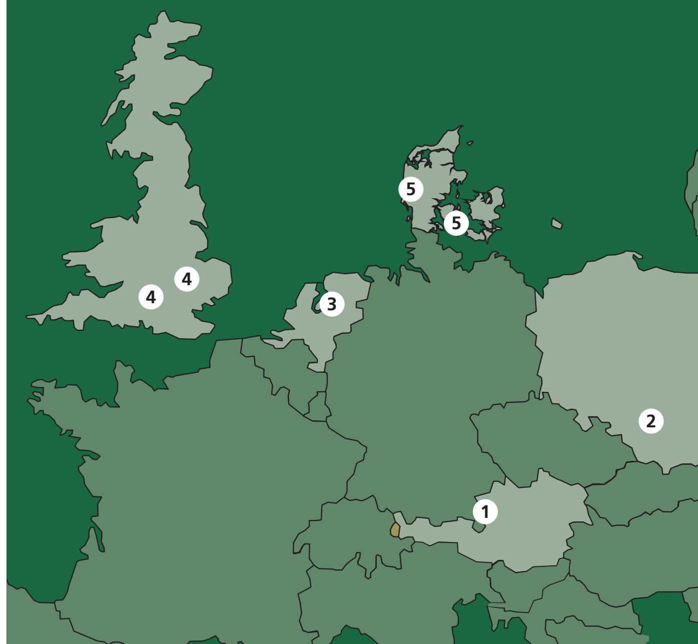
1. **Historic aircraft and more at Salzburg Airport**
   Sparkling cocktail in Hangar-7
   DLR Magazine 133, April 2012

2. **Lotnictwa Polskiego Museum near Kraków**
   Final destination
   DLR Magazine 134/135, September 2012

3. **Aviodrome in Lelystad**
   Among seagulls and windmills
   DLR Magazine 138/139, September 2013

4. **Brooklands Museum and Duxford Aviation Museum**
   The power and glory – the legend lives on
   DLR Magazine 142/143, September 2014

5. **Denmark's Flying Museum and Egeskov Castle**
   Face-to-face with the Flying Flea
   DLR Magazine 150, June 2016



TRUE TALES OF ELEMENTS AND MADNESS

In **The Disappearing Spoon**, Sam Kean reads the periodic table, one of the great scientific accomplishments of humankind, as a storybook about the many characters who shaped it. There is a funny, odd or sometimes even chilling tale attached to every element in the periodic table and Kean presents them in quick succession to his readers.

For instance, we find out that Dmitiri Mendeleev, the man generally credited with the creation of the first periodic table, was in fact one of six scientists who attempted to organise the known elements into a workable system. Mendeleev threw together his first draft of the table under pressure from a deadline from his publisher. He was intrigued by his own creation, however, and rejected a job as consultant for local cheese factories to work on it. He even predicted that new elements would be discovered – including their density and atomic weight. His personal life was also colourful; after divorcing his first wife he did not want to wait the mandatory seven years before remarrying and bribed a priest to perform his second nuptials, thereby effectively making himself a bigamist.

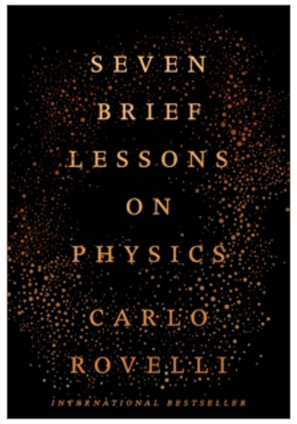
Another interesting story details that chemical warfare dates back to ancient Greece. The Spartans were besieging the city of Athens in the fourth century BC when they came up with the ingenious idea of smoking out their enemies. The bundles of wood, pitch and sulphur that they lit on fire around the city did not achieve the desired result, however; the Athenians suffered the stink bomb but did not flee their city and ultimately won the war. It was not until the late nineteenth century that the deployment of gases as weapons was again pursued. Further research led to the invention of industrial fertiliser, which enabled much higher agricultural yields and probably saved millions of people from starvation.

A favourite story is that of Stan Jones, who (unsuccessfully) ran for the U.S. senate twice (in 2002 and 2006). Afraid that in the chaos of the new millennium antibiotics would become unavailable, he decided to boost his immune system with a heavy dose of silver. For four and a half years, he drank a heavy-metal moonshine that he distilled in his own backyard, thereby overdosing his system and contracting agyria. This condition, while it does not cause internal damage, does leave its sufferers tinged what Kean describes as a "ghastly grey zombie-Smurf blue." Jones, however, does not regret the copious ingestion of his home remedy, noting that "being alive is more important than turning purple."

Other subjects Kean touches on range from the history of the Solar System and what killed the dinosaurs, to the Cold war of chemistry, bubbles, alchemy, counterfeit money, DNA structure, vitamins, poison, Parker pens, mad artists, mad scientists, prosthetics, atomic clocks and the reason why Gandhi loathed iodised salt. Even, or perhaps especially, readers who do not have a background in chemistry will be readily entertained by the interesting and amusing anecdotes with which Kean brings the periodic table to life.

Merel Groentjes

SEVEN BRIEF LESSONS ON PHYSICS



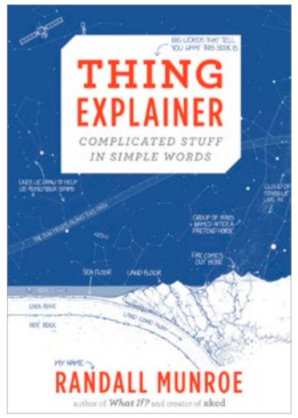
At 79 pages, **Seven Brief Lessons on Physics** is a very short overview of the major questions, groundbreaking discoveries and unsolved mysteries of modern physics. Written with a non-scientific audience in mind, these brief lessons are an expansion of a series of articles written by Carlo Rovelli for an Italian newspaper that, nevertheless, would appeal most to those for whom physics is a curious hobby rather than a professional pursuit.

The lessons build upon each other, starting with Einstein's theory of relativity and covering quantum mechanics, cosmology, particle physics, quantum gravity, thermodynamics and probability, ending with a reflection on humanity's existence in this beautifully complex world. But the list of topics need not be intimidating. Rovelli succeeds in breaking down very nuanced and complex problems and theories in language that is still smart and accessible – at times even poetic. Some lessons are intense for their proposal of a theory of reality that goes against what we have come to observe as 'natural', such as the concept of flowing time and objective space. But this is expected, given the ultimate goal of modern physics to come up with a theory that accounts for everything.

The biggest lesson learned from this small book is a refined definition of and appreciation for physics on the most basic of levels: when scientific jargon and mind-numbing complexity are boiled down, physics – like philosophy, literature, and history – is just another way of learning about ourselves.

Laylan Sadaaldin

INCREDIBLE THINGS



How many times have we been curious about something, and when seeking to find out more, been set back by complex and technical jargon? For those that have experienced this first hand, this is the book. In **Thing Explainer – Complicated stuff in simple words**, Randall Munroe provides simple explanations to interesting everyday occurrences and things using line drawings and only the thousand most common words.

He explains 45 'things' and gives them simple names – helicopters are sky boats with turning wings and microwaves are food-heating radio boxes. Often, one wonders what was so difficult to understand about a certain thing. He covers topics ranging from the International Space Station and the lift to the human body or the laptop.

This is no conventional book, no list of mere facts. Always understandable, funny and intriguing, it will leave you wanting more. So if you are inquisitive by nature and are constantly asking yourself what and why, this is a must-read. Whether you are ten or 90, your curiosity is likely to be sparked!

Karin Ranero Celius

RECOMMENDED LINKS

IN SPACE WE TRUST
inspacewetrust.org
Labeled as an 'art project', this interactive site takes users on a chronological walk through major events in space exploration history. With stunning visuals, clips and links to further reading, this site is truly an art project celebrating the greatest step in human evolution.

SOLAR WALK 3D SOLAR SYSTEM APP
apple.co/1T7M545
This free interactive app takes you on a journey of discovery through the Solar System. Study cosmic objects through stunning photographs with zoom-in features and detailed information on their compositions, trajectories and history of exploration.

WORLD GEOGRAPHY GAMES
world-geography-games.com
Interested in geography? Test your skills with one of many quizzes sure to delight eager, young students and seasoned enthusiasts alike. Quizzes cover everything under the Sun – from flags and countries to mountain ranges and rivers to Earth's composition and the atmosphere.

INTERNET ARCHIVE BOOK IMAGES
bit.ly/1sQZYaj
US research fellow Kalev Leetaru has made more than 14 million high resolution images covering diverse topics spanning five centuries from the Internet Archive public domain eBooks available for free on Flickr. Images include detailed descriptions and citation information as well as subject tags and links to the actual page within the eBook.

OTTO LILIENTHAL'S FIRST FILM
http://bit.ly/1SUdyoJ
Only photography technology was available to document the historic flights of Otto Lilienthal. Animator Johannes Hogebrink has pieced together all the original photographs of Otto Lilienthal's historic flights (between 1893 and 1896) to create Lilienthal's first 'film'.

DLR IN VIDEOS
youtube.com/DLRde
Get a glimpse of the research conducted at DLR – comet landers, aircraft research, astronauts in space, robots, cars, satellites and more. In our YouTube page you will learn about our work and meet our scientists.

About DLR

DLR, the German Aerospace Center, is Germany's national research centre for aeronautics and space. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

DLR has approximately 8000 employees at 16 locations in Germany: Cologne (Headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Göttingen, Hamburg, Jülich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stade, Stuttgart, Trauen and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington DC.

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Cover image

The 30-metre antenna at DLR Weilheim. Researchers at the DLR Institute of Communications and Navigation have received and analysed navigation signals using the antenna.

DLR Deutsches Zentrum für Luft- und Raumfahrt
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