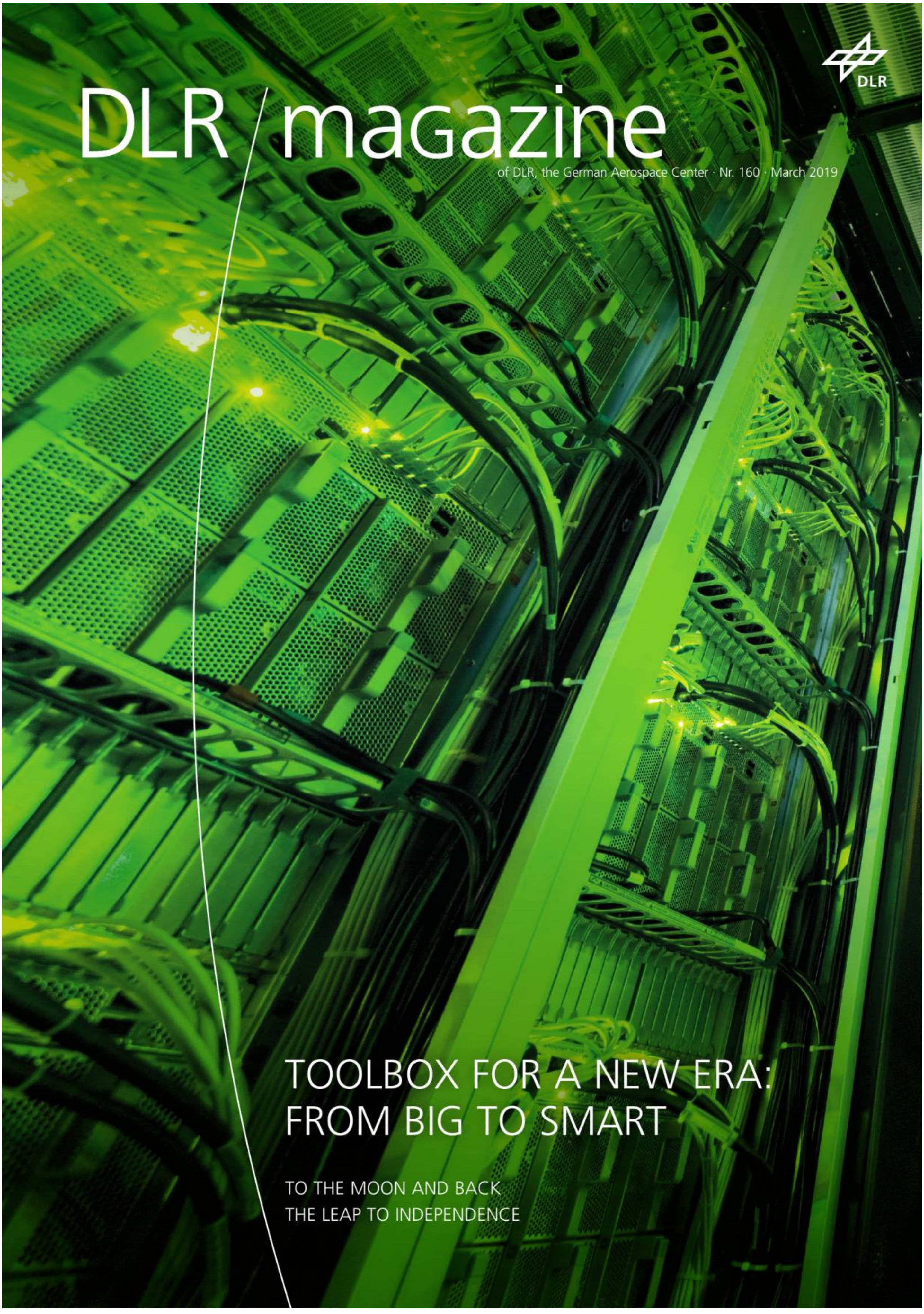

# DLR magazine

of DLR, the German Aerospace Center · Nr. 160 · March 2019

## TOOLBOX FOR A NEW ERA: FROM BIG TO SMART

TO THE MOON AND BACK
THE LEAP TO INDEPENDENCE

**Dear reader,**

Small words can often be highly significant: Stop, go, space, Earth, the Moon, heart, dance and time. And courage, too. You'll come across all of these in this issue of the DLRmagazine – some figuratively, but most in a very literal sense. Take courage, for instance. Two researchers at the DLR site in Stuttgart had the determination to take a concept and carry it forward. Their area of expertise is repairing high-performance plastics, such as those used in aircraft or wind turbines. They had a brainwave about the possibility of repairing damage to such components without having to replace them altogether. To pursue their idea, the two moved into a bunker in Empfingen, in the Black Forest, where they tested the process on large-scale original components. They are now independent, thanks to support from DLR Technology Marketing. In this edition we meet these two intrepid entrepreneurs.

There's not much left to be said about the Moon almost 50 years since the first landing, right? Wrong. Find out what Apollo means for science today in a piece by two DLR planetary researchers. The journalist and author Stefan Aust also provides a view from outside the research community.

Time to turn our gaze to the future. What will happen when we encounter self-driving cars in years to come? How will we communicate with them? DLR scientists are using virtual reality glasses as they work towards achieving unambiguous human-machine dialogue. This plunges us into the realms of simulations and computer models, the tools of this new age and the focus of our cover story. We take a close look at data quality, consistent access to scientific information from a range of sources, and the question of how this can benefit human beings. It's all fairly abstract stuff, but highly relevant to tomorrow's technology and an area that our researchers have poured their hearts and souls into.

In the DLRmagazine, we always meet people who search meticulously and enthusiastically for answers to a wide variety of scientific questions. In some cases, they have travelled great distances to do so. The rocket engine researcher Justin Hardi is one example, having come to DLR all the way from Australia. We are grateful to Justin for sharing his story, as we are to all of our contributors. Which brings us neatly to another small word: goal. Because if, among the people and projects of these articles, you find something to inspire and interest you, then we have indeed achieved our goal for this edition of the DLRmagazine. Enjoy!

Your DLRmagazine editorial team




# DLRmagazine 160

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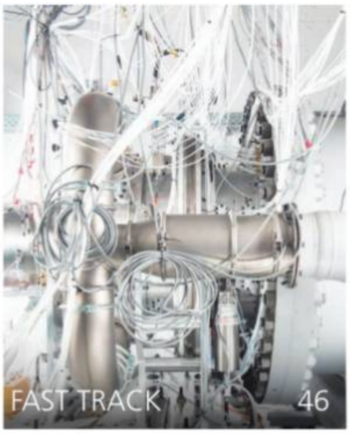

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# PARTNERSHIPS AS OPPORTUNITIES FOR INNOVATION

Rolf-Dieter Fischer is Director of DLR Technology Marketing

A commentary by Rolf-Dieter Fischer

It may come as something of a surprise – Germany is more innovative than any other country in the world. The World Economic Forum (WEF) concluded as much in 2018, in its annual competitiveness report. Based on 10 criteria, Germany offers the best conditions for handling innovative processes – from the initial idea through to marketing. Among other things, the WEF praises the strong research institutions that work with businesses as part of dedicated networks. In cooperation with both national and European industry partners DLR makes a significant contribution to this in the fields of aeronautics, space, energy, transport, as well as the cross-sectoral areas of security and digitalisation.

In line with its 2030 Strategy, DLR will draw upon its strengths to expand technology transfer to the wider economy, where it will act as a driver of innovation not only in its core research areas, but across all economic sectors. In the future, five percent of the institutional funding received from the German Federal Ministry for Economic Affairs and Energy and the financial support from the respective federal states will be invested in innovation projects. These projects will be carried out in cooperation with industry, particularly small and medium-sized companies, as well as with other research institutions. DLR will also increase its support to spin-off companies and expand opportunities for entrepreneurial investment in its spin-offs. In addition, DLR is extending its cooperation with industry in the context of new and existing strategic innovation-based partnerships. As part of this, DLR will work with companies to prepare and implement future applications and technologies.

New digital methods will be increasingly applied in the idea development process. The new DLR.IDEASPACE platform – a system for exchanging and developing innovative ideas – is already available to all DLR employees. Under the slogan #inspire, #ideate, #innovate, experts exchange ideas on innovation topics, generate ideas together and initiate promising new projects. Innovation drives focus on future topics at DLR and pave the way for disruptive ideas and new ways of thinking.

The partnership-based DLR.InnovationHub, which is currently being planned, is another important contribution towards strengthening Germany as a business location. It will make a new kind of brainstorming in an innovation laboratory possible, together with strategic industry partners, associations, users and business developers. By opening up what was previously an internal innovation process within DLR to external partners, the platform represents an opportunity to enable, set up and implement breakthrough innovations.

The opportunities to open up even more new applications for the economy are thus plentiful. It is all about identifying them, getting partners on board, and implementing them together. DLR is ready for this.

# NEW DE-ICING METHOD SAVES FUEL

Even a slight build-up of ice on an aircraft can adversely affect the aerodynamics and increase fuel consumption. The DLR Institute of Composite Structures and Adaptive Systems in Braunschweig is developing a new electrical de-icing technology. Ice on wings can be melted or prevented altogether using carbon fibres. The electrical resistance heating system works in a similar way to a window heater in a car, where delicate conductive wires in the glass provide heat. What makes this different to existing de-icing systems for aircraft is that the heating structure is also made of carbon fibres and is manufactured along with the leading edge of the wing in a single step, so that the loads borne by the leading edge are also carried by the heating system. The heating structure is divided into individual heating zones, which can be controlled separately, making the de-icing system more flexible.

The electrical heating system causes the ice on the leading edge of the wing model to melt

This innovative heating system was tested at the Technical University of Braunschweig. Various strategies were used to test it. The impacting water, which immediately freezes to form ice, can either be melted or evaporated by using more energy (anti-icing). Alternatively, de-icing allows a limited amount of ice to accumulate on the wing leading edge, before it is melted at intervals. The tests demonstrated the functionality of both heating strategies and showed that energy efficiency can be improved.

**t1p.de/7bct**

# SOLAR ENERGY FOR CEMENT PRODUCTION

Cement is one of the most used goods in the world. Producing it requires high temperatures, which are predominantly generated using fossil fuels. Researchers at the DLR Institute of Solar Research are investigating how solar energy could be used for this purpose. The raw materials for cement production – usually limestone, clay, sand and iron ore – are mined in quarries, broken up in crushers, and then pulverised and dried in the cement plant. The DLR researchers are investigating the first stage of production – the calcination of raw cement powder – in a rotary furnace at the solar simulator in Cologne. The raw material is heated up to a temperature of 1000 degrees Celsius in order to remove any water. The scientists have succeeded in producing raw cement powder of the same product quality as that achieved by conventional reactors.

Handling the material presented the biggest challenge. The flowability of the very fine powder is very limited, and processing it at 1000 degrees Celsius while keeping dust to a minimum is difficult. Previously, initial tests had shown that the rotary furnace is a highly robust reactor, with which it is possible for particles of different sizes to be heated reliably to any temperature up to 1100 degrees Celsius. Using a solar-powered reactor would be useful not only in southern Europe, but also in developing countries in sun-rich regions, where it would allow the need for cement to be met locally, thus eliminating the need for transport.

Pouring the raw cement powder into a the bin of a helical conveyor, which uses a screw to move the bulk material without producing dust.

**t1p.de/2o7r**

# TOOLBOX FOR A NEW ERA

**Since 2018, a total of 21 DLR institutes and facilities have been working together to collect tools for handling large quantities of data and to develop new tools in a more efficient way. More than 50 projects will address four key issues in the age of Big Data, namely methods of analysis, data quality, standardised access and the potential benefits for society.**

## The DLR cross-sectoral project 'Big Data Platform'

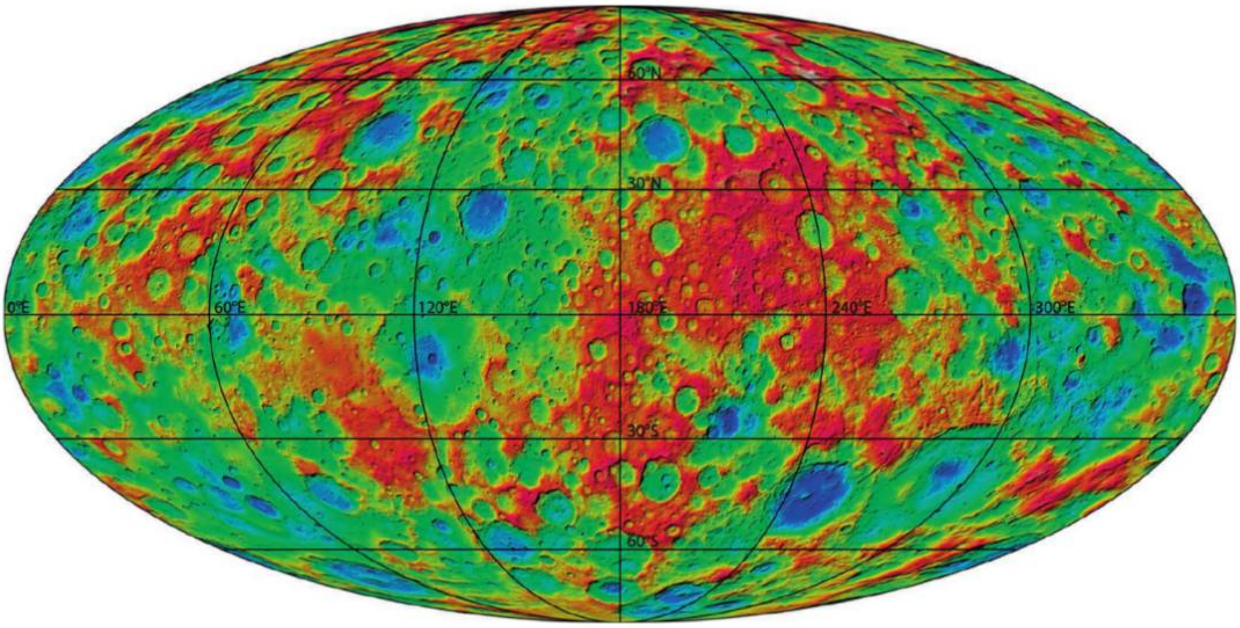
By Florian Kammermeier

Good craftspeople know how to use their tools – they know how to swing a hammer correctly, how to slide a carpenter's plane over wood, and which screwdriver works for which screw. After years of practice, such tasks come as naturally to them as tying their shoelaces. However, it is not only their many years of experience but also their orderliness that makes it possible for craftspeople to work quickly and efficiently with their tools: A large and well-stocked toolbox makes sure that the appropriate tool for the right task is always at hand.

The situation for 21st-century scientists is very similar. They work with ever-growing data sets. They can no longer focus on a single research subject, and must master statistical and empirical methods. And most importantly, they have to be experts in data processing and stay ahead in this ever-expanding field of data science methods: How are data sets stored whose size is measured in petabytes? How can they be sorted and accessed efficiently? How can their quality be maintained when they include 'noisy' values? How can adaptive algorithms recognise patterns? Data science methods must answer these questions and more. For this reason, the scientists of the 21st-century, need their own well-stocked toolbox – one in which the right data science tool for the right situation is always at hand.

Such a toolbox has been assembled at 21 of DLR's institutes and facilities since 2018. They are carrying out more than 50 projects with an overall budget of over 21 million euro. Within each project, mathematicians, software developers, engineers and other researchers are combining their ideas and tools to create the Big Data Platform. Its aim is to answer four key questions over the next four years: How are platform techniques created that enable standardised data access? How can data management techniques ensure high data quality? How can knowledge from these data be generated by using intelligent analysis methods? And finally, how can the pilot-scale demonstrators benefit society? Each project in the Big Data Platform addresses at least one of these four questions. The platform thus becomes a place of knowledge exchange for scientists from all of DLR's major research areas, namely space, aeronautics, transport, energy, security and digitalisation.


DLR's German Remote Sensing Data Center (DFD) operates the German Satellite Data Archive (DSDA) in Oberpfaffenhofen. DFD is setting up a processing and archiving centre on behalf of the European Space Agency (ESA): The robot-based DSDA stores, among other things, the image data acquired by the Copernicus satellites Sentinel-1 and Sentinel-3.




The more researchers know about celestial bodies, the deeper they can look into the evolution of the Solar System. This image shows a global surface model of the dwarf planet Ceres, which was computed from approximately 3000 individual images acquired by the Dawn mission using approximately four billion image points.

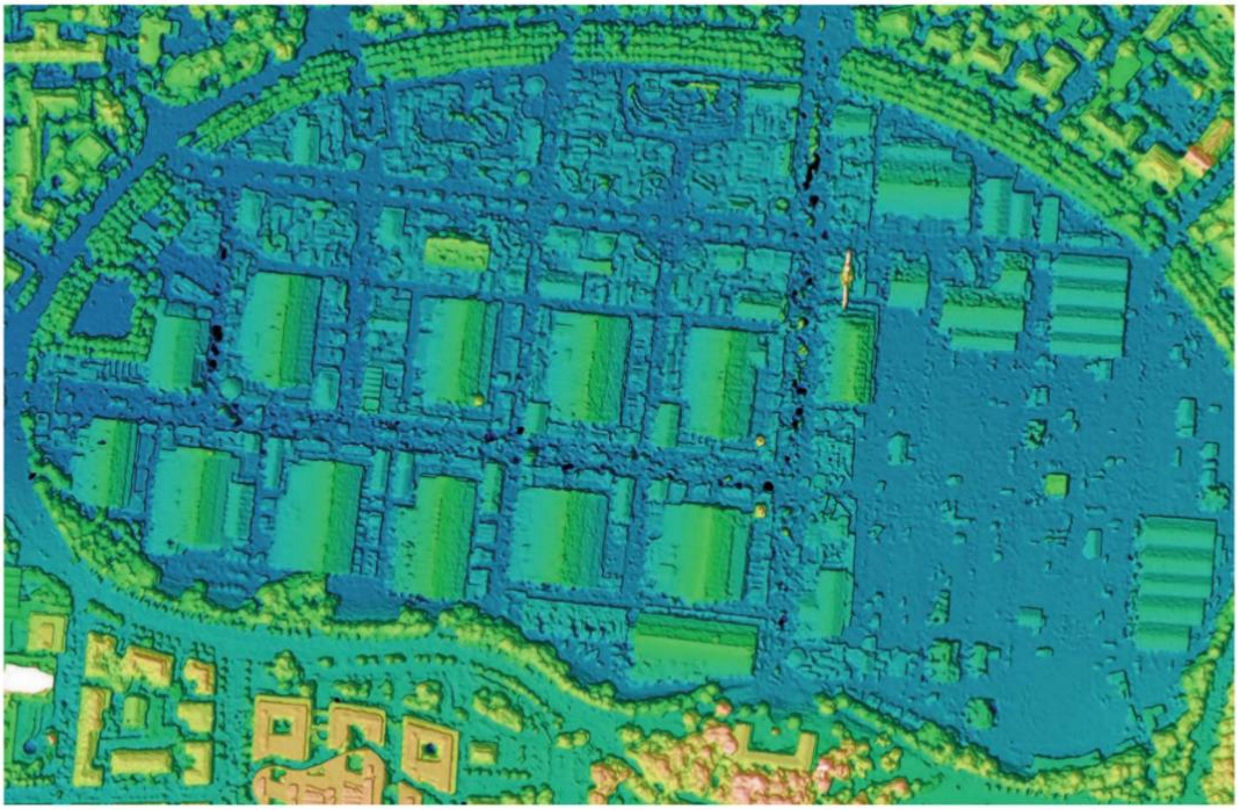
**Scientists from 21 institutes are exchanging knowledge to become more efficient**

"Many institutes have been engaged in Data Science for decades and have acquired a wealth of experience. Often, researchers in different institutes have developed similar data science methods that exist side by side," says Rolf Hempel, Project Coordinator and Head of DLR's Simulation and Software Technology Lab. Currently, about a quarter of the personnel costs at DLR go towards software development.To avoid the risk of two institutes developing similar methods, we have to establish common standards in data science. A further positive effect of these platforms is that they lead to an exchange of knowledge. "The institutes' experience with data science varies considerably," Hempel says. In fluid mechanics and satellite-based Earth observation, for example, huge amounts of data have been stored and evaluated for decades. On the other hand, some institutes have only been recently established or have only started to focus on data science in the last few years. If all of these researchers develop software together, the knowledge about data science methods will be disseminated very efficiently.

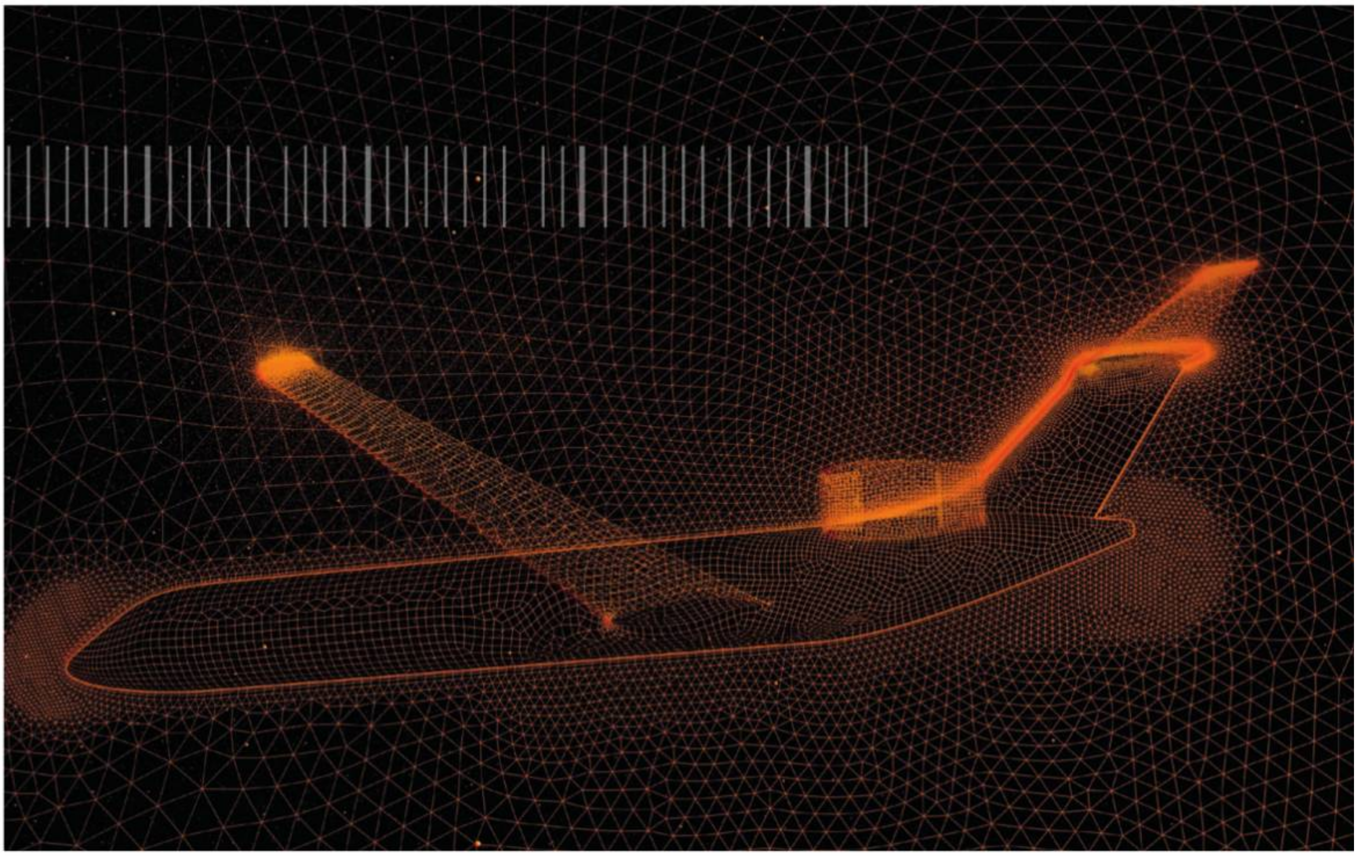
**Decades of research as 'food' for Artificial Intelligence**

The fact that DLR has been collecting large data sets for decades has another advantage – this information is like food for Artificial Intelligence. Such algorithms can only detect patterns in the movement of clouds or in the gas of a combustion chamber if there is a lot of data to train them. DLR's satellites and test facilities provide vast quantities of such data – for example, the German Satellite Data Archive stores over 15,000 terabytes. We estimate that this database will grow by 12,000 terabytes every year from 2020 onwards.

Achim Basermann and Alexander Rüttgers from DLR's Simulation and Software Technology Lab lead the Big Data Platform. They are responsible for coordinating the various individual projects. Alongside the Big Data Platform, there are seven other cross-sectoral projects that focus on topics like cybersecurity and smart robotics in digitalised production environments and bring more of DLR's major research areas together.



Algorithms are also used in traffic analysis, for example in large cities. They determine the types of vehicles, the route they travel and can help to understand movement patterns and traffic jams. These images of the Oktoberfest in Munich were acquired on 30 September 2016 using a 3K-camera system on board a Dornier Do 228. Researchers at the DLR Remote Sensing Technology Institute subsequently computed the 3D model on the basis of the aerial images. This provides authorities and traffic planners with additional situation information. In the VABENE++ project, DLR is researching methods and technologies for, among other things, airborne position detection and data transfer to the ground.



# FOUR QUESTIONS – FOUR PROJECTS

### HOW CAN STANDARDISED ACCESS TO DATA BE ENABLED?

Some projects focus on standardised tools and interfaces for software development. Thereby, we avoid the double development of software both in the Big Data Platform and in the Helmholtz Association of German Research Centres. In this process, we also discuss fundamental design decisions, for example, whether it is sufficient to collect numerous data science methods, instead of developing an all-new, powerful method. An example of the latter is the HeAT software.

**HeAT – algorithm testing in a combustion chamber**

Everything happens very quickly during engine combustion tests at the DLR site in Lampoldshausen. The fuel is injected and burned. The whole experiment lasts no longer than it will take you to read this sentence out loud – three seconds. Yet in that time, the cameras acquire 30,000 images of the engine's interior. In view of the relatively short period of time, this is an enormous amount of data – up to eight gigabytes (GB) in three seconds. It is also a very large amount compared with what a human would be able to analyse. Nobody would be able to click their way through 30,000 images and examine the colour and spread of the flame in order to optimise the combustion process. However, adaptive algorithms, in the form of Artificial Intelligence, manage to recognise and analyse patterns within the images, and then compare them with hundreds of other test runs.

Researchers in many disciplines are facing similar challenges, whether they relate to combustion, neurobiology or particle research. This is why the DLR researchers involved in the Big Data Platform are also working on the Helmholtz Analytics Toolkit (HeAT), a project that involves several Helmholtz institutions. Its goal is to develop a collection of algorithms that combine Artificial Intelligence and high-performance computing. HeAT is intended to learn from data and split this process between several computers or processors in order to speed it up. The project is part of the Helmholtz Analytics Framework initiative. The immediate beneficiaries of this are the DLR researchers in Lampoldshausen. Their engine combustion project is the first DLR data set to which HeAT is being applied. Over the next few years, the collection of algorithms will be further developed and made available to all of the Helmholtz centres.

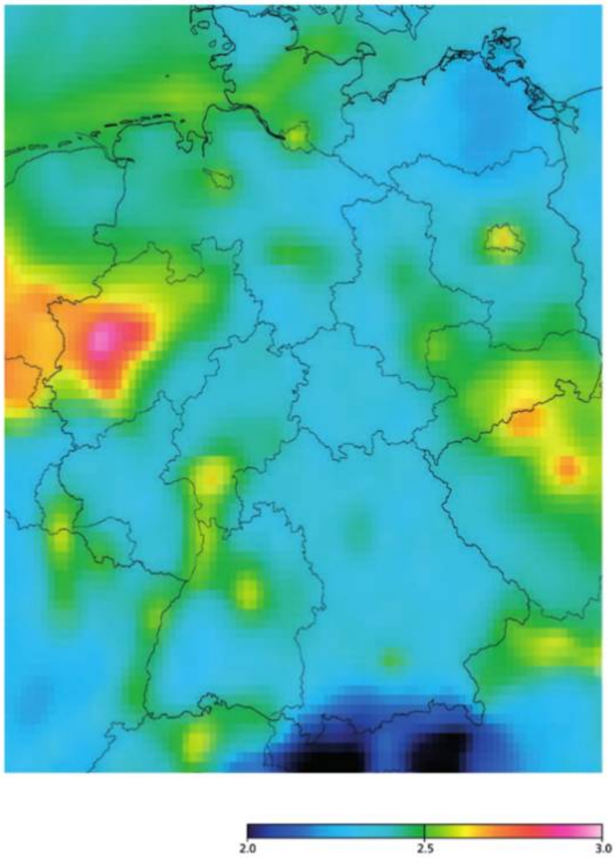
### HOW CAN HIGH DATA QUALITY BE ENSURED?

Even the best analysis techniques will fail if the provided information is insufficient or heterogeneous. Data sources in the Big Data Platform come from many different resources, such as planetary research, air traffic management and citizen science. For this reason, we may find measurement errors or data gaps.

**Data collection by laymen**

People who have first-hand experience of some research objects on a day-to-day basis have the closest proximity to them. Such individuals can open up new perspectives for researchers and contribute specialised or local expertise. With this in mind, laymen and scientists are increasingly working together on what are referred to as citizen science projects.

Millions and millions of equations have to be solved before a picture of the behaviour of an aircraft in the air can be formed. To get as close as possible to reality in numerical simulations, researchers divide the space around the aircraft into cells of different sizes. For each of these cells, the velocity, density and pressure of the air are calculated. If normal personal computers were used for the calculations, several thousand devices would need to be employed. Instead, mainframe computers such as $C^2A^2S^2E$ at DLR in Braunschweig are used. Its base measures three by four metres and it can perform 262,000,000,000,000 compute operations per second. In the end, the consequences of structural changes to the aircraft become visible in the computer long before a component is created.




Fine dust and trace gases pollute the air that humans breathe – and increase the risk of illness. If the 'cumulative health risk' reaches a value of three, this means that air pollution has increased the risk to health by around 12 percent. The values are averaged over the years 2010 to 2016.

"Citizen science initiatives have huge potential for the scientific community and also help to raise the visibility of scientific activities," says Friederike Klan, who manages a citizen science project in DLR's Big Data Platform. Together with her team, she is seeking to address a central problem affecting citizen science – data quality. A range of issues arises when hundreds or thousands of people around the world conduct measurements and provide researchers with their data. Researchers receive some data in the form of spreadsheets or text documents, some as a database, sometimes with the rows and columns swapped; often, units are given with different notation or abbreviated; the language may be different; and sometimes certain data are missing altogether. For those who have to process the data, integrating everything is a major task, and it is nearly impossible for a computer. "Without additional information, the computer cannot understand or convert things like measurements and units," Klan says. Her team is therefore working towards equipping the software with this knowledge. Eventually, the data will automatically be made available to researchers around world in various formats.

## HOW CAN ACTUAL KNOWLEDGE BE DERIVED FROM THE DATA?

Intelligent methods of data analysis, such as machine learning, should help us to derive reliable knowledge from data. Now, this process is addressed by more than two-dozen Big Data Platform subprojects. For example, Earth observation data allow roads and road markings to be pinpointed with a high level of accuracy, so that free parking spaces can be found within a city using real-time analysis.

### Millions of observations provide insights into the evolution of ´celestial bodies

The more researchers know about planets, planetary moons and asteroids, the deeper they can look into the evolution of the Solar System. Space missions are supplying data in an ever-greater quantity and quality. This requires more powerful methods and computers, but it is also opening new doors for scientists. The planetary researcher Hauke Hußmann is one such scientist. His Planetary Geodetic Models project is aimed at analysing the surface, rotation, gravitational field and more complex processes of celestial bodies, such as tides, in a new way. Three kinds of data are combined for this purpose: images of the surface; time-of-flight measurements using a laser, which measures the distance to the surface with high precision; and radio Doppler data that determine the position of the spacecraft.

"Until now, researchers wanting to identify the rotational state of an object, for example, have used deterministic approaches. For this, they design a model based on many simplified assumptions, in order to cope with the vast quantities of data," Hußmann says. "We take a stochastic approach. This allows us to set relevant parameters for complex models using a large amount of observational data." The results obtained without any simplifying assumptions are more precise, according to the planetary researcher.

However, stochastic approaches are complex. Large-scale, computationally-intensive calculations have to be performed and compared with the actual measurements. Thousands of images have to be reconciled using distinctive reference points to create 3D surface models. The datasets are completed by around 100 million transit-time measurements derived from laser altimetry and the corresponding positions and orientations of the spacecraft. Two methods are set to reduce the extensive computing time – many computers will perform calculations in parallel, while high-performance graphics cards will be used in addition to conventional microprocessors. Software that can process data from the MESSENGER, Rosetta and Dawn missions should be ready by 2022, thus enabling improvements to the previous models. However, the researchers have 2025 as their long-term goal. This is when the European Space Agency's BepiColombo mission will reach Mercury, and its data will be processed by software developed at the DLR Institute of Planetary Research.

### WHAT ARE THE POTENTIAL BENEFITS FOR SOCIETY?

The pilot-scale demonstrations should make the Big Data Platform projects fit for society and the economy in the coming years. Due to automatically evaluated Earth observation data, rescue workers will be provided with support in crisis situations, while lightweight production processes will be improved by extensive data evaluation.

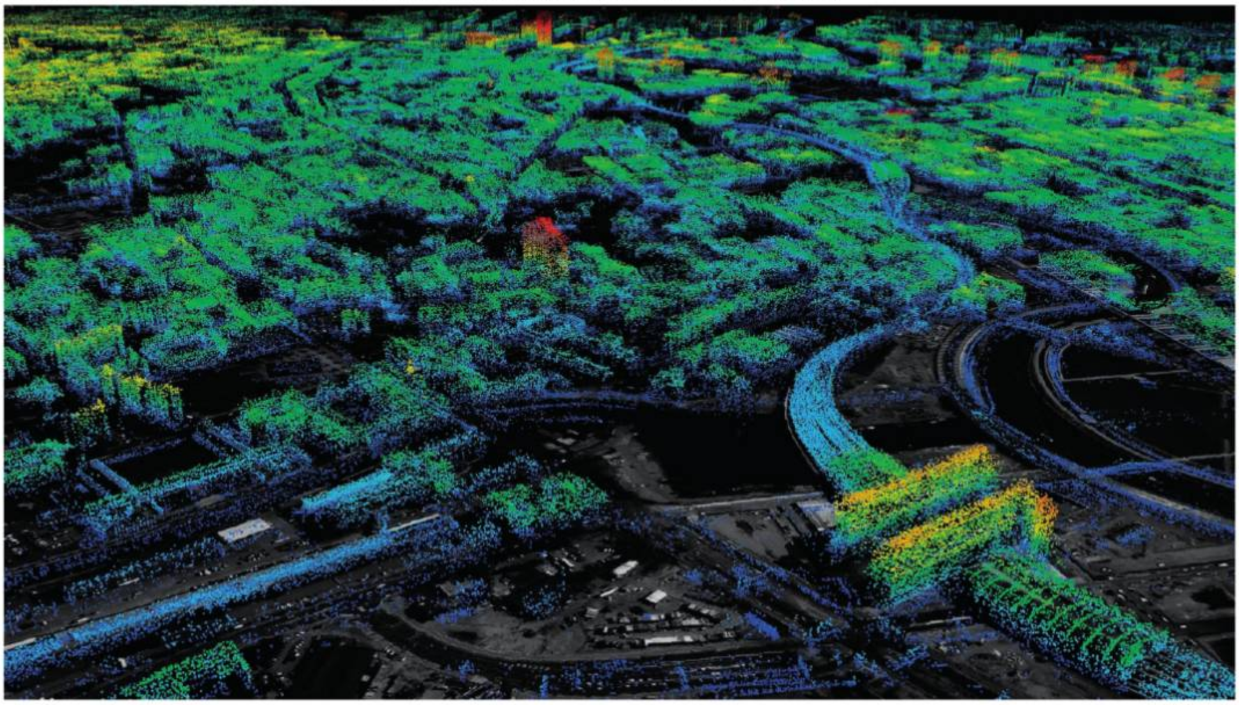
**Calculating environment-induced health risks for humans**

Environmental factors such as air temperature, radiation, humidity, wind and the chemical composition of the air can affect human health in a number of ways. Pollutants in the air are partially responsible for asthma and allergies, while heatwaves put a strain on the cardiovascular system. "Climate change also has an impact on these factors," says Michael Bittner, Head of the Atmosphere Department at DLR's German Remote Sensing Data Center in Oberpfaffenhofen. "Our analyses clearly show that we are already seeing an increase in extreme weather conditions. This presents new challenges for the human body." Bittner's team is working on a project that seeks to assess the impact of atmospheric climate and environmental parameters on human health on the most individual scale.

Using data from ground-based instruments and from satellites, algorithms are being designed to model the health risks to groups of people, such as the elderly and the young, as well as people with specific health problems. These models will provide a daily – and later hourly – level of temporal resolution. "Ultimately, we are aiming at town- or even street-level precision," Bittner says. Working with medical experts from DLR, the aim is to develop a program – perhaps in the form of an app – over the next few years, according to Bittner. This will allow people to enter details such as their age and previous illnesses, turn on their GPS and give feedback on their perceived state of health. Artificial Intelligence, coupled with numeric modelling, will then be able to draw conclusions on the basis of the app user's pattern of movement, modelled health risk, personal characteristics and feedback. It will also provide the user with warnings or advice. Such an app could answer questions such as – which cycle route to work is least polluted? How much water should people of a certain age drink on a particularly hot day? And lots more.

This is the ambitious target. There is a long way to go – at present, many causal relationships in medicine are still unclear, admits Bittner. And the Big Data techniques must be refined in such a way that they can evaluate and interpret all this data in real time. But once the app is ready for use, it will be a powerful tool.

As part of the TanDEM-X mission, two almost identical radar satellites orbit the Earth only a few hundred metres apart. For nine years, the twins have been 'scanning' Earth's surface with radar systems. The close flight formation allows images to be taken from different angles – simultaneously and as the satellites are using radar, both at night and through clouds. The image shows the Mitte district of Berlin with the main railway station. The 'skeletons' of buildings can be seen like an X-ray – the corners and edges at which the radar signals are reflected particularly strongly. In addition to 3D city models, time series of such images are also used to produce maps showing elevations and subsidence in the millimetre range caused by construction work or groundwater extraction.



**Rolf Hempel** – Project Coordinator for the Big Data Platform at DLR.

# THE MAN BEHIND THE SCENES

**Rolf Hempel heads DLR's Simulation and Software Technology Lab. He says software developers have long been somewhat on the periphery of space research. Nonetheless, he made it into space himself, in a manner of speaking.**

Creating networks and communication pathways that allow thousands of entities to work together was the focus of Rolf Hempel's work even before he joined DLR in 2001. He and his team are now bringing together more than 50 individual projects and even more scientists in the Big Data Platform. However, he used to form his networks in a slightly different way. Around the turn of the millennium, he was working on the Japanese Earth Simulator – the most powerful supercomputer of its time. Hempel's team was responsible for developing the communications software that linked the supercomputer's processors. Together with three colleagues, he is also one of the founding fathers of the global Message Passing Interface (MPI) standard, which has harmonised communication in supercomputers.

Today, the 62-year-old no longer works on networking thousands of processors. As Head of the Simulation and Software Technology Lab, Hempel instead creates networks for people and coordinates projects. "These days, I work behind the scenes," he says. Clad in a white shirt and jacket, Hempel sits in his office at DLR in Cologne. His blue-grey eyes are attentive and friendly behind his rimless glasses. "As Head of Lab, I don't really do any of the programming myself any more. That's why I sometimes envy my employees," he adds.

Programming was one of his hobbies while studying mathematics at university. He wrote a software package for the Astronomical Calculation Institute (Astronomisches Rechen-Institut; ARI) in Heidelberg, which computes an optimal orbit of a minor planet from hundreds of observations. Software later became his profession. His work as Head of Lab, however, has meant that writing software has been eclipsed by his management tasks. At the same time, software has become a key element in many areas of DLR's work, including space research, Hempel recalls.

Yet those outside the field of software did not always perceive its importance. Back in 2010, Hempel said in an interview: "Although much complex software is being developed at DLR, it often does not receive its deserved recognition." Back then, proper space research was seen as something practical – people testing and working on prototypes in large experiment halls, not sitting in front of a screen and writing software, the mathematician says.

Hempel's office certainly does not look like an experiment hall. There is no engine prototype on his tidy desk, but there is a monitor. Nevertheless, he has achieved something that remains a dream for many space researchers – he has made it into space. The proof hangs on the wall of his office. Hempel's son has immortalised this feat in a drawing of the Solar System, showing 9820 Hempel – with a diameter of about 2.3 kilometres – on its orbit between Mars and Jupiter. The International Astronomical Union named this minor planet after the mathematician.

During his time at school and university, Hempel was one of Germany's most active minor-planet hunters. He also created the software for the ARI during this period. Twenty-five years later, Hempel again met the professional astronomer Lutz Schmadel of the ARI. What Schmadel told him still makes Hempel chuckle to this day – without him being aware of it, Hempel had been part of the ARI ever since their last meeting a quarter of a century earlier, albeit in the background. Schmadel explained that he was still using the software that Hempel had written as a student to calculate the orbits of minor planets.

**Professor Xiaoxiang Zhu**

conducts research at the DLR Remote Sensing Technology Institute, where she heads the Earth Observation Data Science department. She also teaches at the Technical University of Munich, where in 2015 she became one of the youngest professors in Germany, at age 30. Her research work has already won several awards, including the Early Career Award from the Leopoldina – Germany's National Academy of Sciences – for her outstanding achievements in satellite-based Earth observation, monitoring global urbanisation and natural hazards.

# DERIVING KNOWLEDGE FROM MOUNTAINS OF DATA

**Professor Xiaoxiang Zhu sees herself as a bridge builder. She unlocks the information that satellites send to Earth for scientists, commercial users and decision-makers who are looking to obtain concrete information from this colossal mountain of data. The 34-year-old scientist who works at the DLR Remote Sensing Technology Institute must combine various disciplines to do so: Earth observation, the processing of data from very different sources, and computer science. She uses Artificial Intelligence (AI) to understand the changing world and gather geospatial information. In this interview, she explains how this opens up an array of possibilities.**

## Interview on DLR research into Artificial Intelligence

**How does machine learning fit into your research? What can AI do that a large team of scientists cannot?**

**:** You mean things like manually evaluating satellite data? [laughs] That is just not feasible...

**Is that because the quantity of data is too large, or because merging the data in a meaningful way is too difficult?**

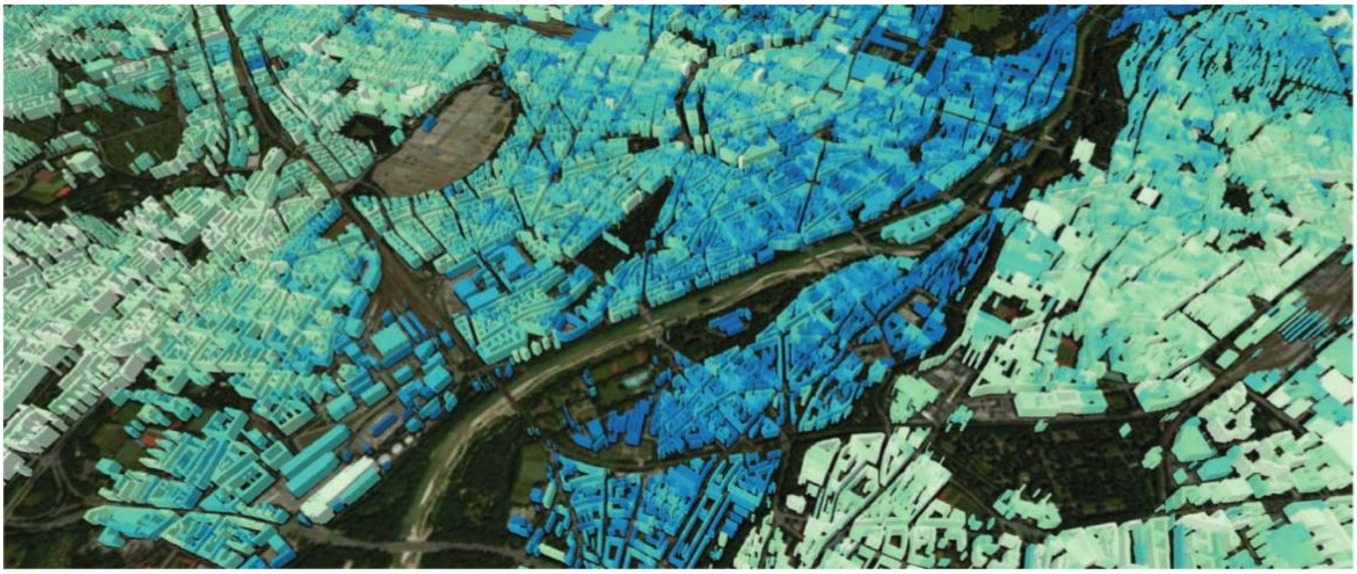
**:** Both. New developments such as the Copernicus satellite programme have provided so much freely accessible data from Earth observation satellites that the conventional techniques are no longer sufficient to derive information from them in an efficient way. Today, we are already looking at 20 petabytes, and in three years it will be 60 petabytes. This requires data-driven analysis, which is where Artificial Intelligence comes in.

**What data from Earth observation can you obtain using Artificial Intelligence?**

**:** My team and I are currently working with colleagues at DLR's Earth Observation Center on the global mapping of cities, among other things. At present, the number of people living in cities is greater than that of those living in rural areas. At a global level, however, our information base is still very meagre – often we can only tell where there are buildings and where there are not. Many of the rural-to-urban migration flows end up in slums or informal settlements, and if one is looking to make real improvements in such areas, having better information from the start is vital. For example, we are merging optical data from the Copernicus programme with data provided by the German TerraSAR-X and TanDEM-X radar satellites to generate 3D models of all buildings. With this, we are able to infer the function of the buildings and, for example, deduce the population density.

**You mentioned that different kinds of data are being generated. But you also use data from social media platforms. How do you combine all of this?**

**:** Optical data gives us the outlines of buildings, while radar data helps us to deduce their height. The combination of these two pieces of information results in a useful 3D model. Of course, our methodology here involves deep learning and other machine learning processes. Once we get into the details, for instance if we want to distinguish between residential and commercial buildings, it gets even more complicated. This is the point at which we may turn to images from social media platforms: These are taken from the ground, so you are not just seeing the roof, but also the façade. We can also look at messages posted on social media channels. We know, for example, that numerous tweets are sent from residential buildings in the mornings and evenings, while in an office building this mostly happens during the day. We can also analyse the content of the tweets, as the topics discussed in the office and residential buildings differ.




This digital elevation model of Munich was created using five images acquired by TanDEM-X. The surface area of the buildings was reconstructed from optical data and height (colours) from the point cloud of TomoSAR (Tomographic synthetic aperture radar). For example, solving global problems of urban settlements requires precise information about the buildings. Scientists obtain this information by intelligently combining different data sources.

**You are working with very personal data. How do you ensure data privacy? Do the scientists also know how to deal with this?**

**:** Of course! The data we receive does not include user information or usernames; it only does so in the case of those users that have consented to the scientific use of their published data. It is also worth noting that our aim is to derive globally consistent information, so we do not work at a high resolution.

**How do you filter out the tweets that contain useful information?**

**:** That is done with data mining. We are developing tools that allow us to randomly select one percent of tweets in a given area. We then have to devise algorithms to give these unstructured tweets a structure. This is followed by information mining: which information is relevant, and what statements can I make about the content? Finally, I have to combine this social media data with my satellite data.

**Let's go back to the advantages: Who actually needs to know how tall buildings are, or what they are used for?**

**:** Let's take one example: there have been 50,000 fires over the last few decades in the Indian city of Mumbai. Approximately two thirds of these were caused by illicit and incorrectly installed undersized power cables. If I want to eliminate this risk, I need information: How many buildings are there? How many people are living in them? Basic information like this enables a more effective organisation of water distribution, education and even health services. What we are doing with Artificial Intelligence and Big Data helps people in developing regions.

**Do you think that AI will change your work or that of your colleagues? Will there be less need for scientists in future?**

**:** If an algorithm has only learned what a cat and dog are, it will not know what a car or aircraft are. In other words, humans are very important in the development and training of algorithms. There is a huge need for computer and data scientists, and recruiting such specialists is incredibly difficult. Internet companies and the car industry represent strong competition. And then you have to get these experts interested in Earth observation, completely from scratch. That is why we are also investing in education. Earth observation is providing incredible amounts of valuable data, but we are only beginning to exploit its potential. And there are plenty of innovative applications, which we will bring to the attention of data and computer scientists. This will trigger greater recognition of the market value of Earth observation, and therefore increased interest.

**How far along are you with applying Artificial Intelligence to the observation of global change?**

**:** We have been working with machine learning in Earth observation for decades, while data-driven analysis of satellite data has been a core area of study at DLR's Earth Observation Center for 30 years. Now it is a hot topic, primarily due to the vast quantity of satellite data that exist today, but also because computing power is now so immense that we can train large models, and finally as a result of breakthroughs in machine learning thanks to deep learning. But we have only been conducting research into the use of social media data for two or three years.

**Imagine looking back on the development of Artificial Intelligence 30 or 40 years from now. What do you hope will have happened?**

**:** I would be particularly pleased to see that we were able to utilise this hype surrounding AI towards the significance of AI in Earth observation. I also hope that the processes that we have developed will have created added value, and that thanks to our geospatial data, a solution for societal problems that previously had no solution has been found.

The interview was conducted by **Manuela Braun** from DLR's Strategic Communications for Space and **Peter Poete** from Think Tank.


DNW
German-Dutch Wind Tunnels

# A WIND TUNNEL 'EUREKA' MOMENT

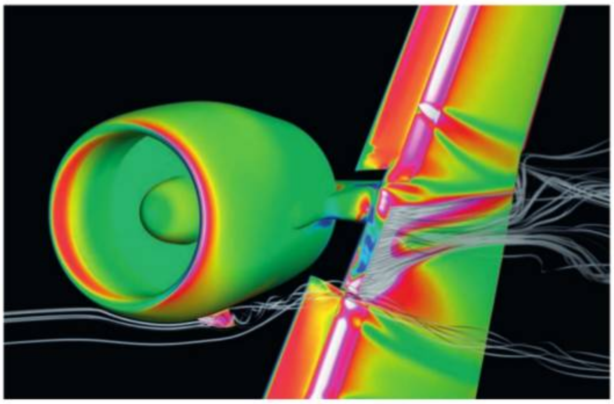
**Fine jets of air provide better lift – it might sound simple, yet the technology behind it is highly complex. In order to blow air over an aircraft wing, the wing must feature small slots through which air can be expelled. It streams out of chambers within the wing and flows out over its outer surface, 'pulsed' periodically. This creates small vortices, which mix the air on the wing's surface with the surrounding airflow and thus transfer the energy of the flow into low-energy areas. Flow separation is suppressed as a result. Lift increases, while drag decreases. The fuel burn decreases and the aircraft is also able to fly more slowly, so runways do not need to be extended for larger aircraft. This technology can contribute significantly towards efficient, low-emission flight, and has now been tested for the first time on a complete wing model in the Cryogenic Wind Tunnel in Cologne.**

Researchers use the world's coldest wind tunnel to demonstrate how expelling compressed air over a wing can control airflow

By Yvonne Buchwald

A murmur echoes through the wind tunnel's control room in Cologne. Then an excited exclamation. Silence. All of a sudden, laughter and exclamations of delight. This goes on for a while. Vlad Ciobaca and his colleagues are standing in front of the control room monitors. They are all gazing intently at what is happening in the wind tunnel. In the measurement section, small tufts stuck to the wing surface of their wind tunnel model flutter wildly in the wind. The scientists then switch on their new system, which begins to blow out air intermittently through the six thin double slots on the leading edge of the wing. The tufts immediately attach to the wing's surface. Relieved, the scientists point out the obvious effect of the air blowing through the slots – the flow is on and the system is working. In order to check the repeatability of the measurements, they turn it off before pressing the button again, waiting, watching, and confirming that yes, it does work – the tufts are attached again. Fluttering, attached, fluttering ...

Vlad Ciobaca is elated. "It is a great feeling to see so directly how our active flow-control system works in practice." It is an ingenious system that the researchers have been working on for some time. "What makes this test stand out is where and how we are conducting the measurements," explains the aerospace engineer from the DLR Institute of Aerodynamics and Flow Technology. For the first time, a complete 3D wing is being tested in the wind tunnel, with actuator's chambers embedded in its leading edge to provide the compressed air. In addition, different engine nacelles can be attached to the model and measured. This is vital: "Our aim is to alter the airflow at the transition between the engine and the upper surface of the wing, especially if there are particularly large engines attached to the wing." The researchers have attached this kind of Ultra-High Bypass Ratio (UHBR) engine to the model. To do so, they had to shorten the leading-edge slats between the engine nacelle and the fuselage. Ciobaca explains: "The ever-bigger engines of modern passenger aircraft are providing more and more power, but the very large diameter of their fan casings means that they affect the airflow on the wing surface." In future, these engines will be approximately 30 percent larger than those found on today's standard short-haul aircraft, such as the A320neo, according to Ciobaca. In addition, the



The visualisation of the small tufts on the model wing (left) allows the researchers to see the effect of the compressed air jets. When the air is flowing in the measurement section of the tunnel, they flutter around wildly. As soon as the flow control system is turned on and jets of air are expelled through the slots on the wing's leading edge, the airflow – and with it the tufts – follows the contour of the wing surface. The computer simulation (right) shows the airflow at the junction between a large UHBR engine and the wing surface. The small double slots in the leading edge of the wing, through which the air is expelled, are clearly visible. In the airflow behind the slots, the streamlines follow the surface contour of the wing, and the flow separation is suppressed at this point.

slat has less space and must be shortened; this is realistically reproduced on the wind-tunnel model. All of this means that aircraft have to fly ever faster, particularly during take-off and landing, in order to obtain the necessary lift. This would also mean that runways would have to be made longer and longer.

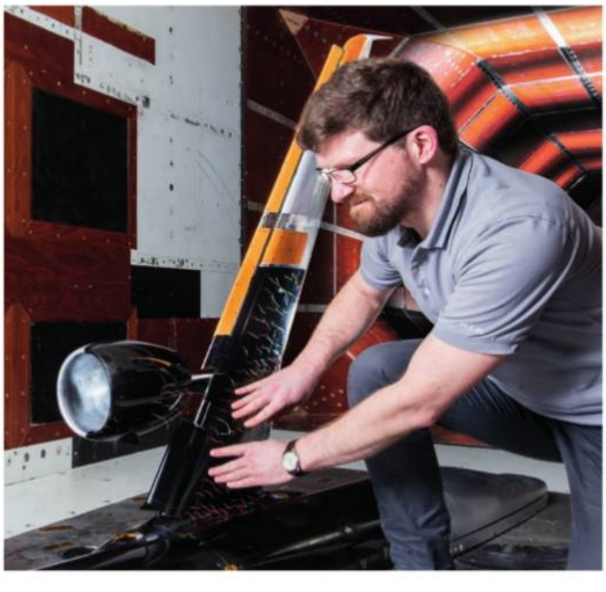
The concept of hydraulic actuators, which allow the intermittent blowing of air, dates back to the 1970s. It continued to be developed, but has so far only been implemented on research aircraft. "We are the first to test it out on the complex engine-wing junction, and in almost real-life conditions," the aerodynamics expert says. The cryogenic wind tunnel offers the unique opportunity of controlling the Reynolds number, which is crucial for flight conditions. To this end, several tonnes of nitrogen are pumped into the measurement section. This makes the air colder and less viscous, so that despite being scaled down, the model is subject to almost exactly the same physical forces as those exerted on the aircraft during a real take-off and landing. As Ciobaca speaks, the temperature within the tunnel drops to an icy minus 170 degrees Celsius, and the air rushes through the tunnel at a speed of up to 360 kilometres per hour.

"We have found that the effectiveness of the system is dependent on the Reynolds number," Ciobaca and his colleagues report, based on their first observations and results. Then, the researchers need to be a little patient, as the model is lowered through the tunnel airlock and the measurement section is closed. The researchers can only make changes to the model once sufficient heat and oxygen have been reintroduced into the model lock. Then it is time to make changes and cool things down, as the 1.3-metre-long wing model goes back up into the measurement section. More tests take place and for about a week the researchers work on the tunnel in multiple shifts, making adjustments and checking the data.

**Numerical simulations and wind tunnel tests provide crucial results for industry**

The wind tunnel has become a part of life for the aerodynamicists. Although in recent years they have mainly carried out computer simulations and developed their system for active airflow control using simulation data, they were able to test their system in a wind tunnel a year earlier. "It was a remarkable experiment," Ciobaca says of the preliminary work that led up to their current research. "We tested a very big 1:2-scale model in the large TsAGI wind tunnel in Moscow." The experiment at the Central Aero-Hydrodynamic Institute ran for almost three weeks. Designing that large model and then seeing it in the colossal measurement section was an extraordinary experience for everyone involved. "Our colleagues at TsAGI built the model, a section of a wing with an UHBR engine nacelle in front of it, and we designed the aerodynamics and put it into the wind tunnel," Ciobaca says. The experiments in Moscow tested whether the system would work on a large scale, at the very outset. "The technology worked very well, with no problems or malfunctions occurring under realistic loads, and the air jets created the expected flow conditions," the DLR researcher recalls with satisfaction.

During the tests in Cologne, the focus was not on the system capability itself, but rather on the overall aerodynamic effect. Flow measurements were therefore conducted not just on a section, but



The effect of 'pulsed discharge' for active flow control was measured on a model of a complete wing in the Cryogenic Wind Tunnel Cologne, which is operated by the German-Dutch Wind Tunnels foundation. For this purpose, small actuator chambers were installed in the leading edge of the model, from which compressed air can be blown through six small double slots onto the wing surface connected through a small tube to the external energy source. Vlad Ciobaca from the DLR Institute of Aerodynamics and Flow Technology is in charge of the measurements and checks the installation of the model.

rather on a complete wing model. One thing is clear: "We have demonstrated here that localised flow separation at the junction between the engine and wing can be suppressed under real flight conditions by the periodic discharge of jets of compressed air. Unlike conventional airflow control systems, pulsed jets consume less air and energy, and the system is almost maintenance free. This technology is therefore of great interest to industry," Ciobaca says.

What began with past numerical studies was technically refined as part of the European Union project AFLoNext, tested during large-scale trials in the T-101 wind tunnel at TsAGI, and is now being continued as part of the EU project Clean Sky 2. This means that the DLR researchers have many partners working alongside them. "The technology was developed at TU Berlin, after which it was refined and tested in several different projects," says Ciobaca, summing up the many years of research into active airflow control. "For the current Clean Sky 2 project, we are working closely with the aircraft manufacturer Airbus, the start-up company NAVASTO GmbH, the Netherlands Aerospace Centre (NLR) and the Cryogenic Wind Tunnel Cologne." The primary goal of Ciobaca and his colleagues: "…after the measurements in the Cryogenic Wind Tunnel Cologne, at some point, to trial the system during a flight test. And put it into service, of course …"

**Yvonne Buchwald** is responsible for internal and external communications at the DLR Institute of Aerodynamics and Flow Technology.

Images: TsAGi

In autumn 2017, the first wind tunnel test was carried out as part of the EU AFLoNext project to test the flow control system. This was a remarkable large-scale test; DLR researchers travelled to Moscow to study the functioning of this technology in Europe's largest wind tunnel – the T-101 tunnel at the Central Aero-Hydrodynamic Institute (TsAGI) – using a large high-lift model measuring three by five metres.

## GLOSSARY

**Reynolds number**
In the 19th century, the physicist Osborne Reynolds discovered an essential property of fluid flows – the point at which a laminar (uniform or ordered) flow changes into a turbulent (chaotic or, disordered) flow depends on three things: the velocity, friction and viscosity of the flow. Put simply, the faster a gas or liquid flows and the lower the friction – for example from adjoining surfaces – the easier it is for vortices to form. Meanwhile, the more viscous a gas or liquid, the more difficult it is for the flow to become turbulent. Reynolds summed up the three crucial factors as a single, dimensionless number. In general, gases and liquids with the same Reynolds number behave in the same way. This hydrodynamic similarity allows scientists to perform wind tunnel measurements on scaled-down models and to transfer the observed aerodynamic properties to their original scale. In doing so, they simply have to take care to configure the airflow conditions in the measurement section in such a way that the Reynolds number is the same as that of the full-size aircraft in flight.

**Flow separation**
The airflow around a body always involves a frictional interaction between the surface of the body and the passing air. This interaction results in the airflow being slowed down close to the surface. The kinetic energy is thus converted into thermal energy. In addition, the airflow must have enough energy to overcome rising pressures on the surface of the body. If the flow no longer has sufficient energy for this purpose, flow separation occurs and the air no longer follows the contours of the body. Flow separation is always associated with a significant increase in drag.

**TsAGi**
Russian abbreviation for Central Aero-Hydrodynamic Institute

**NLR**
Netherlands Aerospace Laboratory (formerly Nationaal Lucht- en Ruimtevaartlaboratorium)

**AFloNext**
Active Flow, Loads & Noise control on next generation wing

**Andreas Klöckner** coordinates research into electric flight at DLR

# CHANGE IS IN THE AIR

**The vision of the quiet and climate-friendly aviation of the future is at the heart of DLR's aeronautics research. Andreas Klöckner sees electric propulsion as a vital part of this change – hardly surprising, given that the aeronautical engineer coordinates research on electric flight at DLR. Hybrid-electric commercial aircraft have the potential to bring about a mobility revolution that is now within reach. In this interview, Klöckner explains the research challenges still to be addressed by DLR scientists, and the innovations needed before e-mobility can really take off.**

An interview with Andreas Klöckner on electric flight

**Electric cars are now part of the cityscape in many places. When will electric mobility manage a similar feat in the air?**

**:** Efforts towards developing increasingly electrified aircraft are a step in the right direction and they are important, because today's aviation is facing huge challenges. Electric propulsion can provide part of the solution. Air traffic is already responsible for around five percent of the global climate impact, yet the demand for mobility in the air continues to rise steadily. The International Air Transport Association estimates that air traffic will double every 20 years. If we want to achieve the targets set by the European Commission to reduce carbon dioxide emissions by 75 percent by 2050, we have to start thinking about making radical changes to our air transport system now.

**Is aviation on the threshold of sweeping change?**

**:** Yes. Electric propulsion marks a radical shift. Imagine using an electric motor to drive the propeller or fan, instead of using a conventional gas turbine. This change, while ostensibly simple, entails numerous changes. For one thing, we have to provide the electrical energy somehow. Ideally, we would do that with batteries or fuel cells, or use an electric generator on a power turbine. In all likelihood, however, we will need a hybrid solution with several energy sources that can, for example, be used for different flight phases. We have to make similar decisions about the distribution of power within the aircraft. The focus here is on the technical constraints dictated by the voltage level and current, so we also have to think about superconductive solutions. Last but not least, power needs to be converted into motion. Alongside the usual aircraft configurations, electric propulsion also opens up the possibility of distributed propulsion, boundary layer ingestion or air taxis with vertical take-off.

**Is electric flight no longer just a pipe dream?**

**:** Over the last few years, there has been a growing interest in this area, which has been reflected in increasing investment in research. To give some examples, Airbus and Siemens have taken on 200 employees at their new site in Ottobrunn, near Munich, for this very purpose. One of the six programme lines within the German Federal government's aviation research programme is explicitly dedicated to electric flight, and the European Union is also providing funding for electric aviation projects to the tune of several million euro. That kind of investment is vital because if electric aviation succeeds, it will have a huge impact on the supplier pyramid in the aviation industry. The two principal components of the aircraft – namely the airframe and the engine – will no longer be considered separately, as they are today. As a result, engine manufacturers will increasingly be on an equal footing with aircraft manufacturers. Some people are already predicting that the airframe will be built around the propulsion system.

**What is driving the increase in research relating to electric flight, and large-scale investment by aircraft manufacturers?**

**:** Essentially, there are three advantages to electric flight. Firstly, flying powered by electricity alone is locally emission-free. This means that the aircraft itself does not emit any pollutants. Noise pollution – whether at the airport or inside the cabin – could also be significantly reduced. Secondly, electrical systems are expected to incur fewer production and maintenance costs due to the lower number of moving parts. That said, we still face major challenges in terms of the mass production, ageing and maintenance of key components, such as the batteries. The third benefit is that electric engines enable completely new aircraft configurations, which should further reduce fuel consumption, and thus emissions. All in all, electric flight brings completely new transport services into the realm of the possible. A quiet, clean and cost-effective mode of transport – perhaps with vertical take-off – could mean, for instance, that flying shuttle services from the city centre to the nearest big airport are quite conceivable. It is a scenario to which a whole series of start-ups have already committed themselves ...

**Successful interaction between all these components would therefore pave the way for completely new mobility concepts. How will electric aircraft change the face of aviation?**

**:** Plenty of small electric aircraft are already being flown by amateur enthusiasts. Gliders with electric auxiliary engines have also been around for years. Electric aircraft will start to conquer new niches, starting with the general aviation sector. In a few years, we might indeed see the first electric air taxis carrying well-off customers across megacities like São Paulo or Mexico City. Over time, electric engines will reach a larger customer base and also find their way into larger commercial aircraft. Initially, we are likely to see the greatest changes at the regional and national levels: I am thinking of shuttle services that might be set up at small airports, or a further expanding air transport network. This would be particularly useful for businesspeople who do a lot of travelling. However, we are still very far from being able to fly with electric power across the ocean – and when it happens it will be with hybrid propulsion systems.

**Norway aims for all short-haul flights to be on electric aircraft by 2040. How feasible do you think this is?**

**:** It is ambitious, but completely achievable. We are already managing to transport two to four people several hundred kilometres using e-power. Our fuel cell research is looking at ranges of up to 1500 kilometres. That would make it possible to fly almost the entire length of Norway, but most routes are much shorter than that – usually around 500 kilometres. The challenge is to scale the systems up to passenger numbers of 50 to 80, as is normal for aircraft flying regional routes. We will probably not be able to do this on battery power alone in the near future, due to the weight. With the same energy content, batteries are around 60 times heavier than kerosene. However, hybrid transitional solutions could allow us to

View of a national electric flight test facility planned by DLR.
It will be used for test flights with an electrically powered commercial passenger aircraft.

combine the energy density of kerosene or hydrogen with the emission-free properties of batteries. Of course, this still leaves a lot of questions up in the air – from optimal configuration to infrastructure such as charging facilities, not to mention the renewable generation of the electrical energy required, or even just the hydrogen. At DLR, we are addressing all of these issues.

**The need for individual mobility is a driving factor in road transport. Does this also apply to aviation?**

**:** A large number of start-ups and research groups are dedicated to pursuing the dream of individual aviation. These days, it is possible to rent your own helicopter in the world's biggest cities, but that is still unaffordable for most people, and it is likely to remain this way for the time being. The sheer effort of coordinating thousands of individual air taxis in urban areas using the procedures required today effectively prohibits any widespread rollout of such solutions. Nonetheless, extensive research is being carried out into automated, unmanned aircraft. For example, we are working on a comprehensive, automatic and, most importantly, scalable solution for air traffic management. These solutions could certainly be applied to individual air transport, including automated aircraft, in the future.

**What do you consider to be the biggest obstacles to electric aviation?**

**:** For one thing, there is the propulsion system. At DLR we are investigating different propulsion technologies – from concepts, simulations and laboratory set-ups through to integration into new aircraft configurations. The impact on the overall aviation sector is another concern. In this area, we are looking at the consequences for travellers, airlines, regulatory authorities, other airspace users, airports and even local residents. In doing so, we have to consider the scaling aspects: bigger aircraft, more travellers, more frequent flight movements, and so on.

In everything that we do, it is important to understand and develop the basic technology, but also to think ahead and keep looking at the big picture. We have already achieved huge success with technology demonstrators such as the HY4, which is being used to test pioneering fuel cell technologies in flight. The next step is to think about aircraft in the next size class – and we are not the only ones who will be doing so.

**How is Germany, and Europe as a whole, positioned for the market launch of electric aircraft?**

**:** In Europe, and Germany in particular, we are in an excellent position. DLR is the only large-scale research institution in Europe with the capability to study all aspects of electric flight at the required level of detail, and to follow it through in actual demonstrations. There are only a handful of comparable research institutions around the world. We collaborate with universities that are outstanding in this field, as well as with innovative industrial companies. Clearly, the boundaries between traditional aviation and other sectors of industry are becoming increasingly blurred. When it comes to electric flight, it is important not only to have the big names of the industry on board, but also electrical engineering companies, which have not traditionally been closely associated with aviation. In addition, an ever-growing number of small businesses and start-ups are injecting the necessary agility into the system. What we really need next is a research aircraft that allows us to test all of the technology required for electric flight, and which is accessible to all of the parties involved. DLR should play an integrative role here, and we are ready to do that.

**What about the certification procedures? There are bound to be a lot of issues to address there ...**

**:** Yes, indeed. Some are obvious. For instance, how do we deal with large, flammable batteries? Others are more entrenched in the system: the current approval requirements simply do not cater for any type of drive systems other than piston engines and turbines. Nevertheless, we are working under the assumption that electric engines will be used in aircraft sooner or later. The regulatory authorities are also starting to cooperate with research, industry and standardisation bodies. We are benefiting from the fact that aviation certification is also having to address other challenges at the moment. Unmanned systems may be far more difficult to certify than electric engines. The European Aviation Safety Agency (EASA) has already developed much more flexible regulations in conjunction with its sister organisations around the world. Previously, these bodies prescribed specific tests, but now they only stipulate the overarching criteria. Aviation authorities are working closely with standardisation bodies to devise specific and appropriate inspection methods. These are mostly based in the United States, though, so we could do more work on this in Europe. In any case, DLR will continue to bring its expertise to bear on all these issues, as stated in a recently signed framework agreement with EASA.

**Mr Klöckner, could you sum up the current state of electric flight in one sentence?**

**:** Electromobility is already in the air, and research is still required before it can enter the commercial market, but as far as DLR is concerned, the aviation Energy Transition is already under way.

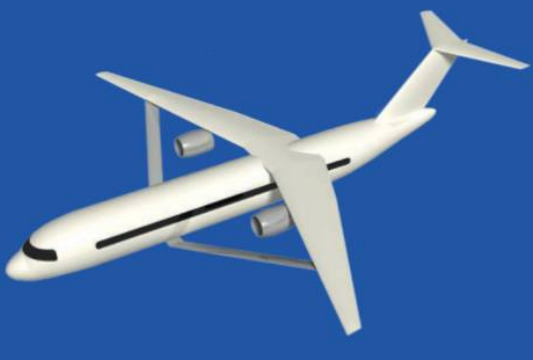
The interview was conducted by **Annabel Brückmann** of the Aeronautics Programme Strategy Department at DLR.

**Regional Hybrid Demonstrator-MH**

Concept for a regional airliner with distributed engines. By arranging many power units along the wing, the lift can be increased and the propulsion efficiency improved. The increased lift can be used to reduce the required wing area and thus to reduce weight and drag. In addition, control of the aircraft can be performed in part by individual control of the propulsion motors. This means that the tailplane and horizontal stabiliser can be of a smaller design and thus also lighter and offering lower drag. This concept was considered in the context of the Clean Sky 2 project ADEC.

**ADEC BLI Canard 01**

Concept for a short- and medium-range aircraft with a hybrid electric propulsion system. An electrically driven fan at the rear draws in the fuselage boundary layer and thus improves the propulsion efficiency. This research is being carried out as part of the ADEC W.P.-1.6.1.4 project (Advanced Engine and Aircraft Configurations), which, in turn, is part of the European Clean Sky 2 programme. In addition to DLR, research facilities from France (ONERA) and the Netherlands (TU Delft, NLR), and the industrial partners Airbus and Rolls-Royce are involved.



**NACOR SBFSW-WE**

Concept for a short- and medium-range aircraft with a forward-swept, strut-supported wing. The braced wing has a lower mass than a self-supporting design. The negative sweep enables natural laminar flow in some areas, which significantly reduces drag. The research work is ongoing in the NACOR TS A-1.3 project (Novel High-Efficiency Configurations) as part of the European Clean Sky 2 programme. In addition to DLR, research institutions from France (ONERA) and the industrial partners Dassault Aviation and Airbus are involved.

The InSight robotic arm deployed DLR's Mars 'Mole' on 25 February 2018

# 'MOLE' ON MARS TO DISCOVER THERMAL FLOW FROM THE PLANET'S INTERIOR

The DLR Heat Flow and Physical Properties Package ($HP^3$) got underway on Mars on 28 February 2019. Deployed next to the NASA InSight lander, the geothermal probe struck the first of some 4000 hammering strokes on the planet's surface. Millimetre by millimetre, the hammer first penetrated the soil, before proceeding to burrow down to a depth of between 20 and 50 centimetres. At this point $HP^3$, also dubbed the 'Mole', came upon an obstruction in the form of rock or a layer of gravel. It was able to push the obstacle to one side and slide past it at an angle of 15 degrees, but then the inclinometer indicated that something else was blocking the probe's path.

DLR scientists are controlling $HP^3$ and analysing all of its information from the control centre at the Jet Propulsion Laboratory in Pasadena. The team had hoped that there would be relatively few rocks beneath the Martian surface, as images of the landing site show hardly any boulders on the surface near the landing module. In principle, the Mars 'Mole' has been designed to push smaller stones aside, and proved capable of doing so in tests conducted before it set off for Mars. The researchers are therefore hoping that the 'Mole' will succeed in creating a narrow shaft, pulling down with it a tether studded with 14 temperature sensors. The tether will allow the accurate measurement of both temperature increases and temperature cycles on a daily and yearly basis. The aim is to gauge the heat flow from the planet's interior, in order to determine how Mars evolved and whether it still has a hot, molten core.

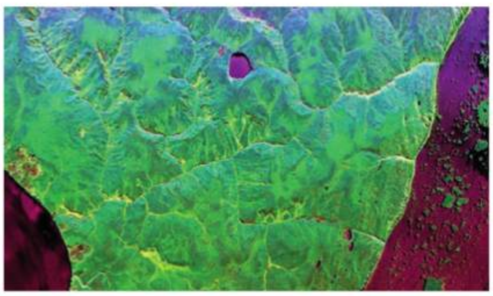
**DLR.de/HP3**

# FOLLOWING IN THE FOOTSTEPS OF THE 'ANTARCTIC GARDENER'

The moment of truth will come at the end of April 2019, when the young winners of the EDEN ISS drawing competition plant their lettuce seeds. This horticultural prize will be a just reward for their imaginative efforts in designing their own greenhouses. The children, aged from six to 12, are likely to be just as excited as their idol Paul Zabel was when he headed to Antarctica in 2018. They will also be hoping for a harvest as bountiful as Zabel's, after he sowed the same seeds in the EDEN ISS greenhouse near Antarctica's Neumayer Station III of the Alfred Wegener Institute. Known as the Antarctic Gardener, Zabel successfully cultivated various kinds of vegetables throughout his year amid the frozen continent, and made sure that the crew at the station had their fill of fresh produce. By carrying out this project, the DLR scientist wanted to come as close as possible to the conditions of a long-term space mission, and test out vegetable growing for future manned missions to the Moon and Mars. The project is also aimed at researching food production on Earth, specifically in climatically adverse areas such as deserts and polar regions. DLR will continue to carry out research at the EDEN ISS greenhouse in conjunction with the AWI and other partners until 2020.


Paul Zabel says goodbye to his Antarctic greenhouse, EDEN ISS.

**t1p.de/xhjc**



Herschel Island is located on the northwestern tip of Canada and is characterised by continuous permafrost. The PermASAR radar image reveals vegetation in the L-band frequency range (dark green colour) in the otherwise treeless tundra.

# THAWING PERMAFROST VISIBLE USING RADAR

As Earth's climate continues to heat up, ground that has been frozen for millennia is starting to thaw. This accelerates the rate of climate change. The DLR Microwaves and Radar Institute is conducting the Permafrost Airborne SAR Experiment (PermASAR) with a view to achieving high-precision observations of permafrost.

Ground that is permanently frozen, whether a few metres from the surface or over a kilometre deep, holds dead plants within its mass. While these plants remain at sub-zero temperatures, there is no effect on the environment, but permafrost regions have been experiencing thawing for several decades. The defrosting plants are decomposing and releasing greenhouse gases into the atmosphere.

In order to provide accurate predictions of the resulting impact on climate change, DLR has conducted numerous measurement flights over the permafrost region of Canada, using the Dornier Do 228-212 research aircraft together with the Canada Centre for Mapping and Earth Observation. It is now embarking on ongoing observation using radar satellites in space, provided by the German TerraSAR-X and TanDEM-X missions and the RADARSAT Constellation Mission of the Canadian Space Agency (CSA).

**t1p.de/k674**

# SMARTBLADES2: TESTS IN COLORADO

Three 20-metre-long rotor blades are being tested in Boulder, Colorado, as part of the SmartBlades2 project. The rotor blades, designed by the Fraunhofer Institute for Wind Energy Systems (IWES) and built by DLR, need to demonstrate that they can adapt to peak loads in strongly fluctuating wind conditions. They feature bend-twist coupling for this very purpose, meaning that at higher wind speeds the rotor blade twists, thereby presenting a smaller surface area to the wind forces. This reduces the loads on the system and increases the blades' lifespan. The project partners integrated specially developed measuring technology into the rotor blades during production at the DLR Center for Lightweight-Production-Technology (ZLP) in Stade. This instrumentation will give the development engineers a thorough understanding of the aeroelastic behaviour of the newly designed blades during testing.

The project will run until autumn 2019. It will help to support industry in the further development of rotor blades with bend-twist coupling and is set to pave the way for the wider roll-out of this technology.

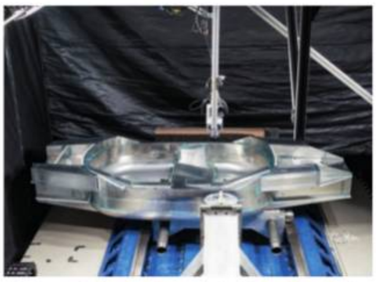
**t1p.de/2sde**

Image: Lee Jay Fingersh, NREL 54220

The rotor blades are able to adapt their geometry to the wind conditions. At higher wind speeds the rotor blade twists, thus exposing less contact surface to the wind, which enables the load on the installation to be reduced.

# SMALL, LIGHTWEIGHT, SAFE

Technology should be produced on a small scale, in a resource-efficient manner and with safety as a key consideration. DLR researchers at the Institute of Vehicle Concepts are developing the Safe Light Regional Vehicle (SLRV) for tomorrow's cars, as part of their overarching Next Generation Car (NGC) project. The small vehicle is designed primarily to serve commuters and can be used wherever local public transport is not readily available. Weighing just 80 kilograms, the electric car has space for two people and is powered by a fuel cell, offering a range of 400 kilometres. The sandwich construction of the bodywork uses materials sparingly, thereby reducing production costs. The panels consists of a metal skin with a plastic foam internal layer, while the passenger compartment is essentially a shell with a fitted ring structure. The safety of the construction has been proven in frontal and pole crash tests, with both tests yielding positive results. The next step will be to use the real crash behaviour to calibrate the results of the computer simulations. The DLR researchers will then move on to constructing a drivable demonstrator.



The body of the small car of the future in a crash test

A total of 20 DLR institutes are involved in the Next Generation Car project.

**t1p.de/p0ae**

**MEET DLR AT ...**

HANNOVER: DLR will have a stand in the Energy section of the Hannover Messe trade fair from 1 to 5 April 2019 (Hall 27). Among other things, the stand will feature networked energy systems, numerical models for battery development and micro gas turbines as combined heat and power plants. Ten leading international trade fairs from various industrial sectors will come together under one roof at the Hannover Messe. Today's hot topics across all sectors will be discussed in numerous forums and at the exhibition stands. About 6500 exhibitors from 73 countries and over 220,000 trade visitors are expected to attend the event.

BONN: The sixth national 'Satellite Communications in Germany' conference will take place on 14 and 15 May 2019 in Bonn. DLR is providing a forum for leading players in industry, along with research and public sector clients, to discuss future communication networks and satellite communications.

ESSEN: From 16 to 20 June 2019 the ESA symposium 'European Rocket and Balloon Programmes and Related Research' will see European scientists and engineers discussing current successes and future plans for research rockets and balloons. This public symposium is organised by the European Space Agency (ESA) and DLR.

PARIS: Now in its 53rd year, the Paris Air Show will present the latest developments and current projects from the aerospace sector from 17 to 23 June 2019. DLR will be in attendance at Le Bourget Airport as part of the delegation from the German Aerospace Industries Association. The first four days of the fair are reserved for aerospace professionals, followed by three days open to the general public.

MOSCOW: The International Aviation and Space Salon (MAKS) 2019 will take place from 23 to 28 July in the town of Zhukovsky near Moscow. DLR will once again be present. Held in the grounds of the Gromov Flight Research Institute, this is one of the world's leading aerospace shows. The 2017 event drew in around 450,000 visitors and almost 900 exhibitors.

WASHINGTON D.C.: The International Astronautical Congress (IAC) is considered to be the summit conference on manned spaceflight. This year's event, running from 21 to 25 October, will mark the 50-year anniversary of the Apollo 11 Moon landing.

**EVENT.DLR.DE: YOUR GATEWAY TO DLR EVENTS**

Here you will find information on events organised by DLR or in which DLR participates, including trade fairs, exhibitions, workshops and congresses, in Germany and worldwide.

event.DLR.de/en

# ONE GIANT LEAP FOR GREATER KNOWLEDGE

**Houston: Tranquility Base here. The Eagle has landed! – Almost 50 years ago, on 20 July 1969 at 20:17 UTC, Neil Armstrong and Edwin 'Buzz' Aldrin landed on the Moon, achieving a goal that had become so important to the United States of America that for a decade they had prioritised it above almost everything else. Towards the end, the landing became quite difficult because there was only enough fuel for a few more seconds of flight and the landing approach almost had to be aborted. However, the two new national heroes – and not forgetting Michael Collins, the pilot of the Command and Service Module that remained in lunar orbit – mastered this situation with ice-cool professionalism. They ignored – after an "OK" from ground control – yet another (false) radar alarm. Admittedly, the first crewed Moon landing was largely a political demonstration. But regardless of how today's historians judge the outcome of the 'race to the Moon' that culminated in Armstrong's "That's one small step for [a] man, one giant leap for mankind", the Apollo project was much more than just 12 astronauts walking on the Moon. For technology, but even more so for scientific research, this was a giant step forward: the Apollo programme was the birth of planetary research.**

## The Apollo programme paved the way for insights into the Solar System

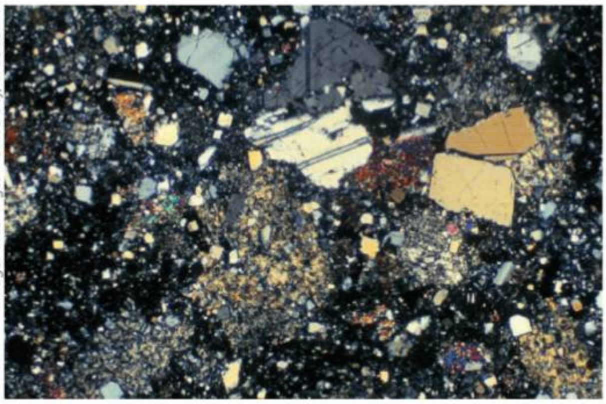
By Ralf Jaumann und Ulrich Köhler

There it stood, the US flag, planted on the Moon, just metres from the Eagle Lunar Module. In fact, this was not the first flag to be placed in lunar soil. At the beginning of their two-and-a-half hours of extra-vehicular activities, Armstrong and Aldrin installed a 'measuring device': a piece of aluminium foil measuring 130 by 30 centimetres, suspended from a kind of flagpole. It was intended to catch solar wind particles, which do not reach Earth due to its magnetic field and could therefore be collected for the first time on the Moon. The experiment was devised by scientists at the University of Bern. But two other scientifically relevant events took place before that: Neil Armstrong secured a sample of lunar dust in a fire-retardant sample return bag shortly after taking his first steps on the surface of the Moon and stowed it away in his space suit, so that he would have 'a piece of Moon' with him if they needed to make a speedy escape from the surface. And as Buzz Aldrin looked closely at the first footprints made by his 'Moon boots', he thought "That's interesting" – when realising that the edges of the impression did not slip away. "The lunar dust behaved like cement powder!" He then took a photograph of his footprint in the fine Moon dust, the regolith, never suspecting that it would become an iconic image of humankind's history of discovery – and probably the most printed photograph of the Apollo era.

These events, which took place during the first half-hour of humans landing on another celestial body for the very first time, show how adventurous the Moon missions were and give some idea of the pressure those involved must have been under. The Apollo era began dramatically on 27 January 1967, with the posthumously named Apollo 1 mission, which claimed the lives of Gus Grissom, Roger Chaffee and Edward White while still on the ground – they burnt alive locked inside the command capsule, which was pressurised with pure oxygen. The Apollo 4, 5 and 6 missions follow – all without a crew. With Apollo 7, humans orbited Earth for the first time with the Command and Service Module, launched previously with a Saturn-1B; with Apollo 8 they circled

Image: NASA

The first 'flag' on the Moon was not the US flag, but a sail made of aluminum foil, with captured solar wind particles.
The experiment was contributed by Switzerland.




A 25 micrometre thin slice of a rock shattered by asteroid impacts in polarised light under a microscope. Studies of the 382 kilograms of rock collected on the six lunar landings reveal how the Moon and Earth evolved in their early days.

the Moon at Christmas 1968 – the first time the fabolous Saturn-V rocket was used. During Apollo 9 and 10 – dress rehearsals for landing – the lunar module came to within 14 kilometres of the lunar surface. Then finally, the first Moon landing took place during Apollo 11. This was followed by another five successful lunar landings up until December 1972, including the dramatic rescue of the crew of Apollo 13, who were forced to loop round behind the Moon and continue back to Earth. These technical masterstrokes, the planning, construction, control and completion of which involved up to 400,000 people over time, have gone down in history.

Fifty years ago, the focus was not on lunar research, but it was precisely this that made the success of the Apollo missions possible and undoubtedly led to the lasting triumphs of this project – the exploration of the Moon.

**A new science**

Ensuring a successful first Moon landing – comprising the approach to the Moon, a safe landing and exit from the landing probe and, above all, the return of the astronauts to Earth alive and well – required knowledge of the characteristics of this somewhat unfamiliar celestial body. It was important to know more about its surface and conditions, such as its load capacity, topography, radiation environment, temperatures and much more. Despite high-precision observations with terrestrial telescopes, much remained unclear. The Earth's atmosphere set unassailable physical limits on Moon observations: even the most powerful telescopes only enabled the identification of features one kilometre across on the Moon – about 380,000 kilometres away. That was not precise enough for landing.

Only space travel made close-up observations possible. In 1959 – two years after Sputnik 1 –the Soviet Union photographed the far side of the Moon for the first time with the Lunik 3 probe. From the mid-1960s onwards, the US began researching the Moon intensively using probes and robotic tools in the run-up to the Apollo missions. The kamikaze Ranger series of probes delivered the first high-resolution images of the lunar surface during their deadly nosedive flight. Five probes of the Lunar Orbiter series mapped the entire surface of the Moon from their orbit, making it possible to carry out large-scale geological and geodetic studies and determine landing sites. Finally, the slender yet robust Surveyor lander probes demonstrated that the Moon had a firm surface and that a lunar module would not sink into the lunar dust. However, as large footpads had already been constructed and attached to the spider-shaped landing struts of the Lunar Module, they were not removed due to safety reasons and time constraints.

The scientists who studied the Moon, selected the landing sites and made the preparations for the activities on the lunar surface were geologists, geodesists, geographers, geophysicists, geochemists and mineralogists. In addition to the physicists and astronomers, there were mainly geoscientists. Of course, 'geo' refers to Gaia, or Earth, but when it comes to the Moon we are talking about something definitely extraterrestrial. So how should these researchers be referred to? At NASA and the United States Geological Survey (USGS), they were categorised as astrogeologists – geologists of the stars. But this was far from accurate for the pioneers of this collection of disciplines – the Don Davises, the Ron Greeleys and the James Heads, not to mention the tireless Eugene Shoemaker (who would have loved to become an astronaut and, as a geologist, wanted to carry out research on the Moon). They made a huge contribution towards the Apollo moon landings. They described the Moon and the landing sites, devised an all-encompassing concept for the accompanying scientific programme and prepared the astronauts, who were – with the exception of geologist Harrison 'Jack' Schmidt on Apollo 17 – US Air Force and Marines fighter pilots, training them to achieve the objectives of their missions through field exercises and seminars. As 'Gene' Shoemaker said, "It only takes a couple of minutes to plant a flag, so what do you do for the rest of your time on the Moon?" NASA saw the wisdom of this and made the comprehensive study of the Moon an integral part of all its Apollo missions. This was especially true of the three last missions – Apollo 15, 16 and 17 – which benefited from electromobility – how progressive at that time… – in the form of a rustic mobile device called the Lunar Roving Vehicle.

Astrogeologists soon became lunar geologists, as the methods and tools used were the same as those used on Earth. After Apollo, the profession of planetary researcher continued to develop, not least because together with the long sought-after landing of humans on the Moon, Venus and Mars also began to attract the attention of the two space nations, the US and the USSR. Earth's two neighbouring planets began to be explored up close by numerous robotic probes at the same time as the Apollo project. Of course, the Moon is not a planet, but – and this was one of the first great discoveries made by Apollo – its development and many of its characteristics make the Moon a planetary body. This is due to its solid surface and mineral composition, with a high proportion of silicon and aluminium, and deeper inside, in its mantle, a high quantity of heavy minerals, rich in iron and magnesium, and even a small iron core, like Mercury, Venus, Earth and Mars. Above all, the crust of the Moon is far older than Earth's dynamic crust, which is constantly changing because of plate tectonics. As such, the Moon offers scientists a window into the past of planetary evolution.

The astronauts used their Hasselblad cameras to capture dozens of frames using Zeiss lenses.
The Panorama Mosaic shows the experiments carried out during Apollo 17 along a route that is more than 100 metres long.

### 382 kilograms of Moon – the 'Holy Grail'

On 14 December 1972 Eugene Cernan, Commander of Apollo 17, was the last visitor from Earth to lift off from the Taurus Littrow valley, returning to Earth in the Challenger Lunar Module. No one has set foot on the Moon since then, and there has been a hiatus of almost three decades during which no robotic probes have visited the Moon on scientific missions. There are good reasons for this. In political terms, the Moon had served its purpose, following six triumphant, accident-free landings – in other words, mission accomplished. In addition, scientists then had enormous quantities of data, measurements, images, and above all, Moon samples to analyse. In total, the 12 moonwalkers brought 382 kilograms of lunar samples back to Earth – the Holy Grail of planetary research! Previously, there were no samples of precisely known extraterrestrial origin on Earth. Examining them under a microscope and using geochemical analysis methods opened up a wide portal to fundamental findings for planetary research.

### What the samples have taught us

How did the Moon form? Almost all of the knowledge we have acquired up until now from the lunar samples indicates that a Mars-sized body grazed Earth 4.52 billion years ago, when Earth was just 20 to 30 million years old and in bulk still molten-hot. The impact affected parts of Earth's first crust, the early mantle and core, which then mixed. So much material was thrown off and evaporated from Earth's mantle that a satellite – the Moon – emerged as the ejected materials cooled and condensed. How did this planetary duo develop? Under heat, not cold! There was a great deal of controversy over whether the Earth had assembled as a cold mass after being formed out of small bodies – planetesimals – or whether it had undergone an extremely hot stage of development due to the heat released in the collisions and the high temperatures generated by the decay of radioactive elements.

Today we know that the latter is the case: in the beginning, the young Earth and the Moon were both covered in a glowing ocean of magma hundreds – and in the case of Earth, thousands – of kilometres deep, with lighter minerals rising up and cooling on the surface, while heavier minerals sank into the depths, forming a thick mantle and an iron and nickel core. This process was typical of all planets in the inner Solar System (and the Moon). It also occurred on some larger bodies at a greater distance from the Sun and is referred to as differentiation by geologists. The scientists learned all this and more from the lunar samples. Even so, the matter of the Moon's formation has yet to be completely determined. The answers could lie in samples from a huge impact crater on the far side of the Moon, where material from great depths can be found.

Six Moon landings with Apollo landing capsules have impressively demonstrated that humans – namely astronauts – play an invaluable role in exploring our immediate cosmic neighbourhood. This was even truer decades ago, when automation and robotics were not as advanced as they are today. The immense yield of data and research findings provided by remote-controlled lander probes and rovers on Mars is utterly awe-inspiring. Yet the achievements of the astronauts on the Moon remain unsurpassed: people can apply their intuition to solving tasks to a degree that is thus far unmatched by any robot, and humans can also make decisions without the need for ground control and information. A Mars rover requires many days or indeed weeks of pre-programmed steps, steered from Earth, to complete a task that could be accomplished by an astronaut in a matter of seconds, minutes or hours.

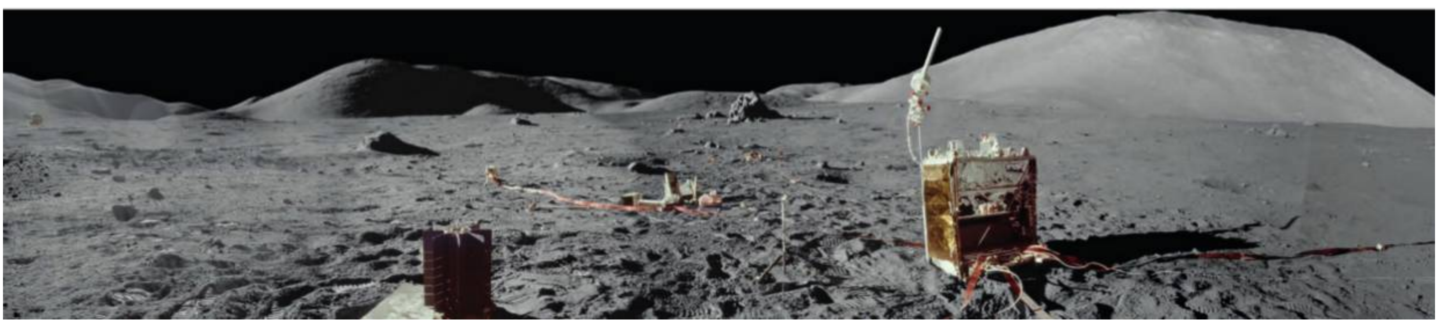
### Back to the Moon? Yes, back to the Moon!

What does this snapshot mean for the future of lunar research? Many questions relating to the origin of the Moon and the early history of the Earth-Moon system remain unanswered. Finding solutions is hugely important, not least to resolve the mystery of when and how life developed on our planet. Earth's development over its first 4.5 billion years is not yet fully understood, and the Moon, and indeed Mars, can provide answers. At the top of the lunar research wish list is the (preferred robotic) extraction of more samples, especially from the depressions in the South Pole-Aitken impact basin at the far side of the Moon, which could reveal rocks from the Moon's mantle. These could show us what happened during the early days of the inner Solar System. The far side of the Moon, which is never visible from Earth due to the fact that it rotates once around its own axis every 28 days, and once around the Earth in that same amount of time, would also provide a remarkable observation platform for radio astronomy. Here, radio signals from Earth would not interfere with the search for the echo of the Big Bang – and the perfect vacuum on the Moon would provide materials scientists with an ideal laboratory.

Humans – whether astronauts, cosmonauts, taikonauts or 'euronauts' – are also set to return to the Moon in the medium term, whether in pursuit of a temporary or even permanent settlement on another celestial body, or to use the Moon, where the gravitational pull is six times lower, as a springboard for missions to Mars. The Moon's poles are pockmarked with craters that inside never see the Sun and, due to the lack of atmosphere, never warm up. There is ice in these permanently dark places, observed by spacecraft, and it could be used for hydrogen and oxygen rocket fuel. The steep crater rims are always lit by the Sun and are in constant direct visual and radio contact with Earth.

It is precisely at one of these shaded craters that the research community has paid tribute to the man who, at the beginning of the Apollo missions, insisted that landing on Earth's satellite also be put at the service of science. On 31 July 1997, the Lunar Prospector space probe was deliberately crashed into the floor of a crater that would be named after him. At the end of its two-year mission, it brought part of the ashes of lunar geologist Eugene Shoemaker, who died in 1997, to the site of his longing.

**Ralf Jaumann** and **Ulrich Köhler** are planetary geologists at the DLR Institute of Planetary Research in Berlin-Adlershof. Both studied Geology at the Ludwig-Maximilian University in Munich and have been looking at the geology of the Moon ever since they started working at DLR in the mid-1980s, or early 1990s, respectively. They co-wrote the book Der Mond in 2009.



# TO THE MOON AND BACK

By Stefan Aust


Since the dawn of humanity, people have gazed up at the Moon. Even today, many do not believe that it is possible to send people there and bring them back to Earth. To them, the words 'One small step for man, one giant leap for mankind,' originated in a science fiction film studio in Hollywood.

One Christmas, when I was a fourth- or fifth-grade student, I received the youth encyclopaedia 'The World from A to Z'. The cover could be folded out into a big map showing a precise diagram of a planned journey to the Moon, explained by one Wernher von Braun. I contemplated it for hours, wondering if I would ever witness it for myself.

It happened sooner than I expected – first came Sputnik and Gagarin. Ten months later, Americans dared to orbit the Earth. United States President John F. Kennedy boldly declared: '…We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard …'

This photograph does not show the first footprint on the Moon, nor is it the pattern of Neil Armstrong's sole: Edwin 'Buzz' Aldrin was rather stunned at how sharp the tread patterns in the lunar dust are and thought the photograph of his footprint would also interest the scientists. The result was one of the most famous pictures of all time.

Images: NASA/KSC

These were exciting times, with the Vietnam War, student unrest and, above all, the Cold War between East and West. Of course, we all knew that the tremendous efforts being made towards developing rocket technology did not solely serve the purpose of reaching the Moon. And Wernher von Braun - hadn't he already constructed Adolf Hitler's V2? For all that, the fascination with space travel was part of the whole Zeitgeist of the 60s. Stanley Kubrick's space epic '2001 – A Space Odyssey' was released in cinemas in April 1968, anticipating the Moon landings and introducing an element of philosophy to the human history in the making. Might the Soviets be the first to land on the Moon? And would that indicate the superiority of Communism? Americans were still conducting rehearsals with repurposed intercontinental missiles. Luckily, these were unmanned, as one in every three launches abruptly ended in a fireball. Not even fearless test pilots wanted to buckle in at the tip of such an infernal device. The failed launches were almost always recorded by film and TV crews, instead of being conducted in secret, as in Russia. And so, although the United States made themselves the laughing stock of the world, they did not let up. Controversial German engineers led by Wernher von Braun worked for NASA – others worked for the Soviets. Half a century later, the US astronaut Bill Anders, who orbited the Moon for the first time on the Apollo 8 Mission, told me, with a touch of irony, that: "Our Nazis were better than their Nazis".

It was Christmas 1968, and William 'Bill' Anders, Jim Lovell and Frank Borman were to be the first to leave Earth's gravitational field and enter the Moon's orbit. After two Earth orbits, they ignited the final stage of their Saturn V rocket, giving them enough speed to set course for the Moon. From the narrow windows of their spaceship they looked back at their home planet as it receded into the distance. "We were probably the very first to see in one glance that the Earth is a sphere," recalls Anders. "It was not flat like some people claim."

After orbiting the Moon, Anders took the most famous photograph in history with his Hasselblad camera – the Blue Planet rising above the Moon's horizon – 'Earthrise'. During Christmas 1968, I watched the TV broadcast of the Apollo 8 mission and listened to Bill Anders and his colleagues read the Book of Genesis from the Bible – literally from the heavens.

At the beginning of 1969, I travelled to the United States. The first stop on my trip was Cape Kennedy, although I was not lucky enough to watch a rocket launch. Later, I read Norman Mailer's 'Moonfire' and Tom Wolfe's 'The Right Stuff' – both brilliant books about the race to the Moon. I never imagined that I would one day meet both of those authors and many of the protagonists from their books.

I interviewed the writers – Tom Wolfe for TV and Normal Mailer for the news magazine Der Spiegel – and I met the astronauts at Barron Hilton's Flying M-ranch in Nevada. The hotel magnate was a passionate aviator and regularly held gliding competitions across the globe. The winners were then invited to his ranch, where gliders were used to explore the unparalleled thermals over the ranch, which covered an area almost the size of Luxembourg. A glider pilot can stay in the air over the Sierra Nevada for as long as the Sun continues to shine. I was invited there regularly. Among the astronauts staying at the Hilton ranch were both the first human to set foot on the Moon as well as – for now – the last: Neil Armstrong and Gene Cernan. I asked Neil Armstrong a question suggested by my youngest daughter: "You planted the United States flag in the lunar dust. Is it still there? After all, the Moon has no atmosphere." "No," replied Armstrong. "The flag is no longer there. It blew over due to the exhaust from our lunar module when we took off." So that was settled.

Those weekends at the Flying M-ranch were hot, with plenty of discussions about space travel, science and politics. It transpired that the astronauts were more than just pilots. A brief departure from Earth – even if back then it lasted only a few hour or days – makes people

Image: NASA/

The Apollo 11 astronauts affixed a stainless steel plaque to the ladder of the lunar lander: "HERE MEN FROM THE PLANET EARTH FIRST SET FOOT UPON THE MOON, JULY 1969 A.D. WE CAME IN PEACE FOR ALL MANKIND."

change their way of thinking. Bill Anders, whom I interviewed on the 50th anniversary of the first orbit of the Moon at his Heritage Flight Museum in Burlington for the documentary 'The Discovery of the Blue Planet', said: "Seen from lunar orbit, the Earth is about the size of your fist at arm's length. It didn't take much of an engineer like me to imagine that if we were at 10 lunar distances, then the Earth would go from a fist to maybe a marble. And at 100 lunar distances, it would be a grain of sand. We are stuck together and ought to learn how to get along on this tiny little planet." It is no wonder that Bill Anders' 'Earthrise' photograph went on to become an iconic image for the environmental movement.

Last year, Bill Anders visited Germany with his wife Valerie. Together, we took a trip to Peenemünde, where Wernher von Braun developed his 'vengeance weapons' – the V-rockets – during World War II. Bill Anders wanted to see for himself where his journey to the Moon had begun, leading to his 'discovery' of the Blue Planet and changing his entire mindset: "If we realise that we are an accidental species on an accidental planet, fitting into a huge universe, then maybe we will think we are not quite as important as we think we are."

This line of thinking on the ranch led to the creation of an aid organisation called 'Wings of Help'. This organisation, led by the German Frank Franke, has been providing relief supplies to disaster-struck regions around the world for years, and was honoured at the annual Living Legends of Aviation Awards in Los Angeles. Buzz Aldrin, the second human to set foot on the Moon and the last surviving astronaut from the Apollo 11 mission, was also present at this year's ceremony. His Moon landing took place on 21 July 1969 – now 50 years ago. I remember that evening well, watching the live broadcast on our black-and-white TV. It was one small step for astronaut Neil Armstrong; whether it really was one giant leap for mankind remains uncertain. The first Moon landing symbolised what humankind and technology can achieve when they really commit to it – nothing more, nothing less.

**Stefan Aust** (72) is a journalist and author. He was Editor-in-chief of the news magazine 'Der Spiegel' from 1994 to 2008 and has been publisher of the German newspaper and broadcast company WELT since 2014. He has been fascinated by the Moon and the Apollo project his whole life. His profession and passion have provided him with opportunities to meet the people who, half a century ago, as pioneers, dared to travel to the unknown – a journey that shaped them and their time.

The two founders, Markus Kaden (right) and Marvin Schneider (left), in front of their experimental bunker on the innovation campus in Empfingen.


Image: DLR/Frank Eppler

# SQUARE AND PRACTICAL – MSQUARE

**Empfingen is a municipality in the northern Black Forest region in Germany. Since the mid-1960s, the Federal Armed Forces have stored munitions on a roughly 10-hectare site nearby, in case the Cold War should ever heat up. The bunkers and buildings, situated in an idyllic forest setting, remained empty for some 20 years after the site was cleared in the 1990s. Now it is used for something quite different – since 2014, the Empfingen Innovation Campus has provided a home for young companies and start-ups dedicated to sustainability, allowing them to work on their ideas and test products and facilities.**

## Two young DLR researchers are taking the leap into running their own business with new technology for repairing high-performance composites

By Denise Nüssle

Markus Kaden and Marvin Schneider from the DLR Institute of Structures and Design have established their company in one of the Empfingen bunkers. The two researchers are working on the technology that lies at the heart of their 'msquare' venture – a new and efficient repair process for high-performance composites. They are currently performing tests on a now-redundant rotor blade from a wind turbine – it was roughly 60 metres long and weighed 12 tonnes, and has now been divided into five pieces for ease of handling.

### Fibre-reinforced composites are light and strong …

Whether it be for aircraft, wind turbines, vehicles or ships, high-tech composites are increasingly being used whenever light – yet strong – materials are required. These account for more than 50 percent of the fuselage and wings of the latest addition to the Airbus family, the long-haul A350 aircraft, while the BMW i3 electric car has now brought high-performance composites to mass-market car manufacturing. Their advantageous properties are based on the combination of a polymer matrix and reinforcing fibres, which is why they are also known as fibre-reinforced polymers (FRPs). Depending on the way in which the fibres and the matrix are combined, it is possible to achieve special mechanical and thermal properties, which explains the attractiveness of such materials.

### … but, until now, not very easy to repair

However, they do not come without their disadvantages – repairing FRP components is a relatively complicated matter. "The fibres are load-bearing, so they ensure the integrity and load-bearing capacity of the structure, but this also means that we cannot simply drill or add rivets to them, as we can do with metal components – this might further damage the fibres," explains DLR researcher and company founder Markus Kaden. Large structures, such as those found in an aircraft fuselage, are designed for a service life of up to 30 years. The previous repair procedures are very time-consuming, not very flexible and correspondingly cost-intensive. Kaden and Schneider are seeking to change that. With the process that they have developed, they aim to significantly extend the useful life of high-performance composite components, and thus make these special materials more competitive and economically attractive.

The technologies developed at DLR can be tested directly for their operational capability using a rotor blade segment

Image: DLR/Frank Eppler

Repair test on the outer skin of a rotor blade with the vacuum heating mat developed at DLR

**Fast and even warming – success with special heating technology**

The technological focus of the repair process offered by 'msquare' is the innovative FlexIn Heat® concept. This consists of a special heating mat comprising an induction coil sewn onto a plastic fabric, together with a silicone vacuum pad. The mat heats up a metal sheet that corresponds to the size of the area to be repaired. Beneath the metal sheet lies a patch, which is similar to the sticking plasters used to treat wounds in humans. This patch consists of the same material and has the same fibre orientation as the damaged component. Under heat and pressure, the patch attaches itself to the surrounding structure, thus repairing the damage. The process is easy to control and document using a mobile repair case.

The DLR duo's method offers far more flexibility compared with the best technology previously available – the size of the heating mat can be varied depending on the client's requirements and the extent of the damage to be repaired. As it is highly flexible, it can also be adapted optimally to edges and curved surfaces. Similar to induction cooking in a kitchen, only the area to be repaired – not the whole structure – is quickly and evenly heated to a temperature of up to 400 degrees Celsius. "We provide customers with a solution that consists of just a few components, yet offers around 30 percent faster, more accurate and higher quality repairs," says Marvin Schneider, summing up the advantages. These are all unique selling points that make the process attractive to the market.

**From research to business start-up**

The two engineers first came up with the idea for a start-up in the course of their work at the DLR Institute of Structures and Design in Stuttgart. There, more than 100 researchers are investigating structures and components that must deliver excellent performance and have applications in the fields of aerospace, vehicle construction and energy technology. Their research primarily involves fibre-reinforced polymers and ceramics.

"At first, it was mostly about repairing FRP materials and addressing some fundamental questions – can this work, and which approaches are best?" Kaden recalls. He has been working in this field since 2011, initially on his own and later with support – Schneider joined DLR as an intern and research assistant, before being promoted to the position of research associate in 2015, when he completed his studies. Together, they developed the FlexIn Heat® technology step by step, considering how it might be used by industry and analysing the industry requirements. As part of a project funded by DLR Technology Marketing, they applied for patents, presented their work at relevant trade fairs and events, and sought potential clients and licensees.

**Passion and motivation: seeing their company grow**

The idea of starting their own company began to take hold. "We kept getting enthusiastic feedback on our visits to potential clients. So then we thought, we already have lots of contacts and we understand the technology, so why don't we try selling it ourselves?"

FlexIn Heat® combines an induction coil and a silicone vacuum mat

Image: DLR/msquare

Kaden and Schneider recall. They had the incentive of creating something themselves, seeing their own idea grow, putting it on the market and experiencing it in action. They quickly came up with a name for 'their baby'. "As our first names both begin with 'M' and our core product is a flat, rectangular heating system, we soon coined 'msquare' as our company name," Schneider explains.

The two young minds received support for their undertaking from the Institute itself, from of their colleagues, their head of department and the Institute's director. DLR Technology Marketing also guided them over the entire period and provided assistance with legal matters, such as patents and property rights. It also arranged workshops for the preparation of business plans, helped with development of the business model and offered advice on funding programmes.
One or two surprises were nevertheless inevitable: "We soon discovered that we, too, only have 24 hours in a day. Particularly, if you are doing everything yourself in the initial stages, you have to keep an eye on a lot of different things," says Schneider, casting his mind back over recent months. "Some things do not work quite as expected, but they open new doors that we did not foresee," Kaden adds. In May 2018, the pair of DLR researchers officially founded their company and msquare GmbH was born. They took on some extra assistance for their business development, finances, sales and administration in summer 2018, when experienced company founder Max Eberl joined the team.

**First focus – the wind power and aviation sectors**

A handful of repair kits have already been sold, licensing and cooperation agreements have been negotiated with DLR, and the future is looking promising. Kaden and Schneider believe that there is a great market potential, particularly in the wind energy and aviation sectors – Germany alone has almost 30,000 wind turbines, which regularly suffer damage, for instance due to lightning strikes, while aircraft with fibre-composite components have to be repaired seven times a year on average. However, 'msquare' also has the manufacturing industry, the vehicle construction sector, shipbuilding and motorsports on the radar, and are looking to win over customers in these areas, thus gradually opening up other markets.

**Meeting your growth goal 'in the bunker'**

Despite several exhausting months behind them, the DLR duo is still driven by an entrepreneurial spirit: "In the long term, we want to build a stable and innovative medium-sized company," Kaden and Schneider say in agreement. "We are looking for investors, and we want to continue to grow and employ three or four more people," they say, setting out their goals for the year ahead. Together with their commitment and passion, the small team is clearly brought together by a sense of enjoyment in their work – if the next customer is urgently waiting for delivery of their order, the pair sometimes find themselves doing one final test run on the kitchen table at home or in a hotel bedroom. In the evening or on the weekend, Kaden and Schneider are often to be found in their little workshop in east Stuttgart, or indeed in the bunker. There, they conduct experiments, develop their product and put their heads together to come up with new ideas.

## THE FOUNDERS OF MSQUARE

Image: DLR/Frank Eppler

**Markus Kaden**
Age: 34
Hometown: Mulda, Saxony
Studied: Aerospace Engineering in Stuttgart
At DLR: From 2007 as a student trainee; from 2009 as a research associate
Hobbies: Playing football, travelling
What he has to say about Marvin Schneider: All-rounder, cool guy

**Marvin Schneider**
Age: 30
Hometown: Herrenberg
Studied: Aerospace Engineering in Stuttgart
At DLR: From 2010 as an intern, then as a student assistant, and since 2015 as a research associate
Hobbies: Playing squash, restaurant dining
What he has to say about Markus Kaden: Creative and good fashion sense (laughs)

# GIVE ME A SIGN!

**It is a familiar scene: a pedestrian is waiting to traverse the road at a zebra crossing. A vehicle approaches. The pedestrian tries to make eye contact with the driver. Will the driver see him and slow down? Within the space of a few seconds, the pedestrian must decide whether it is safe to walk across the zebra crossing. But what happens if the person encounters an automated vehicle on the road? How can the pedestrian know if the car has noticed him? And how can the machine indicate to the person that its technology can be trusted? Researchers at the DLR Institute of Transportation Systems are grappling with these complex questions as part of the interACT project, which is funded by the European Commission.**

DLR is investigating the interaction between automated vehicles and road users as part of the EU project interACT

By Vera Koopmann

Road users communicate with one other in all sorts of ways, including flashing lights, hand gestures, sound signals and head movements. Particularly in urban environments and car parks, road users communicate with one another to resolve unclear situations through cooperation. "For communication between humans and machines to work properly, people must build up trust in automated vehicles over a long period of time, and also know what they are capable of," explains DLR's Anna Schieben, project coordinator for interACT. Eight industry and research partners from four European countries are working with the team of DLR researchers to improve the safety and acceptance of automated vehicles. As part of interACT, the DLR researchers are developing a human-machine design that serves both the on-board and the surrounding road users. They are also developing a central software module that enables the automated vehicle to react in real time and to move without any time lag. In doing so, the scientists are focusing on what are known as shared traffic environments, in which both automated and non-automated vehicles, pedestrians and cyclists cooperate with one another.

Zebra crossings, right-of-way intersections and car parks are environments of particular interest. The project developments are based upon observing how humans interact in Athens, Munich and Leeds. The findings will be used to put together a catalogue of human communication requirements and models that automated vehicles will need to meet. In addition, the project partners are developing algorithms and sensor capabilities to predict the behaviour of road users and recognise their intentions in traffic. "The combined work of the various interACT partners will serve as the basis for the development of future-oriented technological solutions that will one day enable reliable and understandable interactions between automated vehicles and road users," Schieben explains.

A participant in the interACT project moves through the virtual city and describes her impressions of the different communication designs on the automated driving cars

However, as autonomous vehicles cannot nod their heads or make hand gestures, the researchers are developing special universally comprehensible human-machine designs. To do this, they lead the participants through a simulated city using virtual reality glasses. There, they encounter automated vehicles and have to cross the road. A driverless car approaches from the left. A single light strip on the windscreen provides the pedestrian with additional information about the car's behaviour. "In our study, we want to find out how pedestrians respond to specific information displayed on the vehicle's exterior," says Schieben.

The vehicles used in the simulation are equipped with colourful LED strips; sometimes they pulsate, light up at defined points or change their flashing frequency. "What is important to us now is determining how the test subjects interpret the different light signals," she adds. "Do they perceive a pulsating light as a signal to stay where they are, or do they interpret it as a sign that the vehicle is waiting for them to cross?" The results will provide the researchers with information about which design concepts should not be used in the development of communication signals for automated vehicles in the future.

As yet, there are no concrete solutions for how autonomous vehicles can communicate with other road users optimally and, most importantly, in the safest way. All of the project partners involved will conduct experiments using test participants to devise suggestions for enabling reliable communication between the human and the vehicle. The communication solutions, developed using virtual reality technology, will then be integrated into research vehicles before being tested and analysed using pedestrian simulators, driving simulators and test vehicles. In addition to safety, the criteria include acceptance and practicality for all road users. "Automated vehicles will eventually become an everyday sight on our roads," Schieben says. "We are working to make sure that all road users feel safe and that they do not become uneasy if a self-driving car approaches."

**Vera Koopmann** is responsible for public relations at the DLR Institute of Transportation Systems.

INFORMATION

www.interact-roadautomation.eu/
www.interact-roadautomation.eu/interacts-1st-video/

**Justin Hardi**

The aerospace engineer investigates thermoacoustic instabilities in rocket engines. "As soon as the flames couple with acoustic oscillations, they dance back and forth in the combustion chamber. This in turn affects the acoustics, and closes a feedback loop. If we are able to observe the flame with cameras fast enough, we can characterise the flame's behaviour. We can then see, so to speak, the 'dance step' of the flame to the acoustics and draw conclusions about the energy transfer."

# DANCES WITH FLAMES

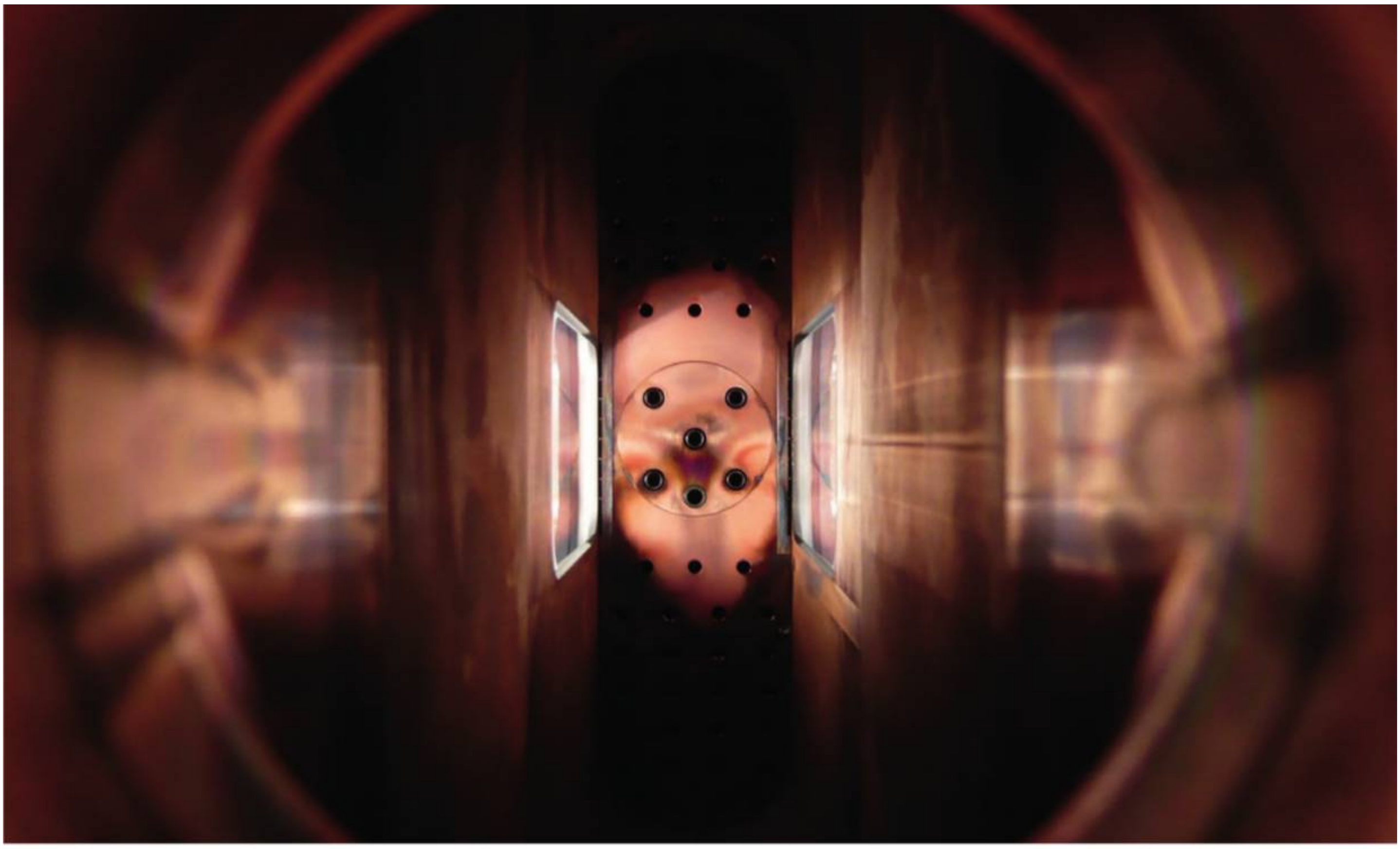
**My favourite space – that is how Justin Hardi describes the object of his research. The 36-year-old Australian researcher is investigating the processes that take place inside rocket combustion chambers. When observing a flame in the combustion chamber, he proceeds with the utmost precision, uncovering details of the lightning-quick combustion process as he does so. The operation of the engine – and thus the success of the space mission – depends on stable combustion chamber processes. Justin Hardi travelled all the way from Australia to Lampoldshausen in the Harthausen Forest to bring these flame dynamics under control.**

## Justin Hardi tames the 'untamed' in his work on rocket engines

By Anja Kaboth

Everything that can be visualised will be visualised. Justin Hardi, a man with a penchant for flames, is quite sure of that. As far as this engineer at the DLR Institute of Space Propulsion is concerned, it is clear: we need to understand the processes at play inside flames. A rocket engine's combustion chamber is about as extreme as places get, but for Hardi it has its own special charm. Engines are one of the safety-critical systems of a launcher. If they are faulty, the entire system fails. Instabilities during combustion are much feared, so the combustion process is an important topic of research in the development and operation of rocket engines.

Hot run of the experimental combustion chamber model 'H' (BKH). Justin Hardi wants to contribute his knowledge of the processes in rocket combustion chambers to the development of new space propulsion technologies.



View through the nozzle to the injection elements of the experimental combustion chamber model 'H' (BKH); optical access windows are on the left and right walls.

Combustion processes obey their own laws. Understanding exactly what happens when the fuel and oxidiser are injected into the combustion chamber of a rocket engine with great force is necessary. Hardi has set himself this task. He wants to find out how thermoacoustic oscillations occur, and how they depend on operating parameters, such as combustion chamber pressure and the propellant mixture ratio. He is getting to the bottom of these questions using equipment such as high-speed cameras. This remarkable task requires 60,000 pictures to be taken per second with the highest possible resolution and a recording time of more than 10 seconds. The images are taken in sync by multiple cameras, each capturing a different wavelength in order to dissect the anatomy of the flame.

"What I am doing is applied research – we want to know which chemical and physical combustion phenomena interact with acoustic oscillations in rocket engines," he says. "Understanding these relationships will give us better insight into the causes of anomalies in engines and help us to develop countermeasures." The special draw for Hardi is that his team is able to carry out experimental studies on a rocket engine test stand that is unique in Europe. "That fascinated me during my PhD," he recalls.

The Australian spent five years studying at the University of Adelaide before joining the DLR Institute of Space Propulsion in Lampoldshausen as a doctoral student in 2007. During his doctoral studies at DLR, he was able to familiarise himself with complex research topics in the field of chemical space propulsion, as well as the cultural quirks of southern Germany. "Over the years, I have not only built up a research network; I have also made many friends here, which have made it easier for me to feel quite at home," Hardi says. Today, 12 years later, despite being far from his native continent, Hardi is firmly rooted in his new homeland as a group leader in the research field of combustion dynamics and as father of two children.

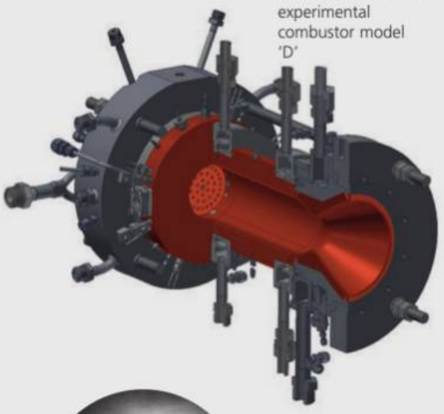
**The rocket engine as an entire system**

The aerospace engineer's job means that he is just as often at the test bench as he is at his computer. For him, it is important to carry out tests on research combustion chambers himself. Although it might sound simple, it is highly complex in practice: a precise understanding of how individual propellants behave within the combustion chamber of a rocket engine is necessary to be able to control the ongoing combustion. However, such studies look far beyond the combustion chamber itself: "We look at combustion processes in terms of the entire system," says Hardi, describing the challenges posed by combustion dynamics. As such, the entire supply system to the rocket combustion chamber is also among the research topics being investigated by Hardi and his colleagues.

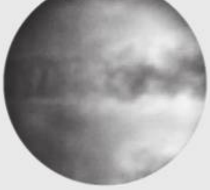
They are focusing on what are known as transient flow phenomena – what happens in the supply line from the tank to the injection element, and then up to the time of ignition. Their research also covers the ignition itself and new methods of ignition, such as laser ignition. "When dealing with a topic as complex as combustion dynamics, you need an array of different skills," he says. "No one can do everything, so it is important to work in a team in which the expertise of all members on the various aspects of engine development is brought together."

**International exchange between scientists and engine designers**

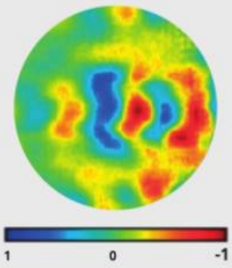
Understanding the interplay between combustion processes and the relevant operating parameters – such as combustion chamber pressure and ratio of fuel to oxidiser – "makes research into rocket engines difficult but also very exciting," according to Hardi. Anyone wanting to make a change to the propellant properties or combustion chamber design needs to take a long, deep breath and will certainly require input from good cooperation partners across national borders. Hardi and his research team collaborate with an international network of experts from industry and other research institutions. "Application-oriented, industry-related research benefits both sides of the equation – industry and science." Hardi believes this to be the essence of modern, innovative research work. For around 20 years, the Lampoldshausen-based research team has been working on the international cooperation project REST (Rocket Engine Stability iniTiative), a Franco-German collaboration on combustion instabilities in rocket combustion chambers. "Together, we are looking to find out how combustion instabilities occur, how they can be predicted in advance, and which measures we might recommend to operate rocket combustion chambers reliably and safely, yet also with a high level of performance," he says. Close cooperation with the space industry allows this expertise to feed directly into industrial applications in short development cycles. "We need this kind of interaction in order to assert our technological know-how on the world stage," Hardi adds. He also believes that it is important to contribute crucial information to the rocket designer's manual, to be used for future design decisions. This is what spurs the Australian on and continues to bring him satisfaction in his work, despite being 15,000 kilometres from his homeland.



Cross-section of the experimental combustor model 'D'



Raw shot of the dynamic behaviour of the flame




Evaluation of the raw data: the result shows oscillatory combustion incited by an acoustic field.

### Detecting anomalies before they occur

The scientists use test combustion chambers with optical access and special diagnostic instruments in order to gain insights into the processes inside a combustion chamber, where temperatures surpass 3200 degrees Celsius and the pressure can be more than 100 atmospheres. Clever use of the best cameras and sensors available on the market allows Hardi and his team to look deep into the combustion processes in rocket combustion chambers – in real time and under realistic conditions. They are able to see how and where propellants react with one another, detect extreme temperature gradients and hear the 'voice' of the flame in the combustion chamber. "This enables us to study combustion chamber processes in a completely new way," Hardi says. "We are not inventing any new measurement techniques, but we are optimising and getting as much as we can out of the extreme conditions to reveal some extraordinary insights into combustion chamber processes."

The use of innovative sensor systems in technology programmes, such as research into the liquid oxygen and liquid methane propellant combination, has shown how quickly processes can be optimised. In the space sector, too, development times for launcher systems are becoming ever shorter. The digital development of engine components and the use of the very latest sensor technology are giving engineers new impetus and helping to make development processes more efficient. "The information that we can glean from the huge quantity of data acquired using increasingly complex measuring methods will continue to enhance our understanding of the combustion processes at play in rocket combustion chambers," says Hardi, looking to the future.

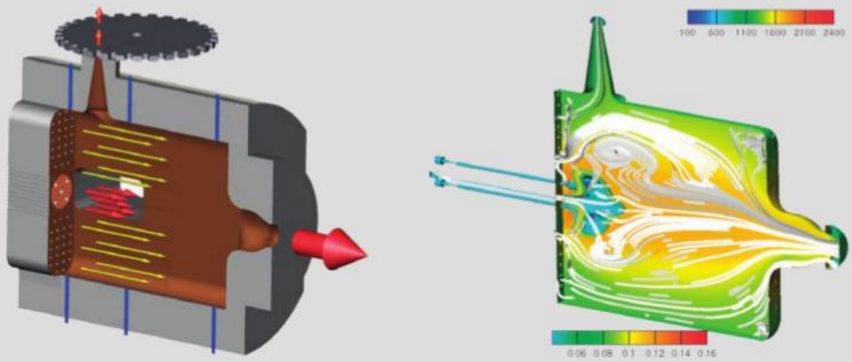
### Experimental investigation and numerical simulation in the mix

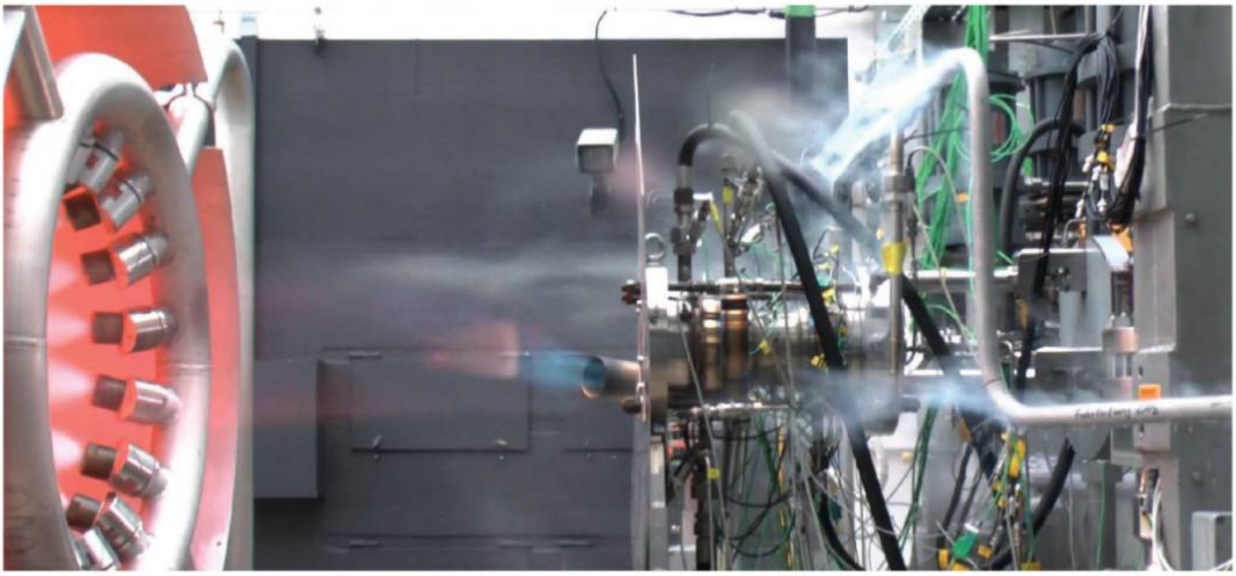
Experimental investigations at test stands continue to be necessary for the development of engines. But thanks to increasing computer power and understanding of the physical conditions, engineers involved in space research have another tool at their disposal: numerical simulation. This allows the real engine conditions to be reproduced on the computer with a high degree of precision. As far as Hardi's field of work is concerned, these numerical tools are not yet sufficiently developed to make valid predictions. Hardi is endeavouring to ensure that the experimental tests on combustion chambers provide the kind of information that, in the future, will allow the processes taking place in rocket combustion chambers to be predicted as accurately as possible.

The efficient processing of the data obtained in the experiments is extremely important. This is where DLR's TAUROS project comes in: "Together with our colleagues from DLR in Göttingen and Stuttgart, we are working on a meaningful combination of experiment and simulation." The aim is to make the modelling tool – in this case the TAU code – fit for liquid propellant rocket engines, so that it can replicate the processes within a rocket combustion chamber as closely as possible. "The interface between the measured data and our simulation programs is therefore paramount," Hardi explains. The data measured during the hot run makes it possible for the researchers to validate their TAU code, and subsequently – supplemented by values from the real test – create further predictions that are much more reliable. The scientists involved in the TAUROS project are therefore laying the foundations for the development of predictive tools that can be used to reduce the number of expensive experiments on test stands for future rocket engines.

However, there will not be any breakthroughs overnight. Developing advanced and reliable engines is more of a marathon than a sprint, and mostly requires perseverance and the ability to overcome hurdles as they arise, one after the other. Meet this Australian aerospace engineer and you will soon realise that, despite how serious the work is and how long it takes to get results, he is highly enthusiastic about his research field. As he says: "In our work on combustion dynamics, it sometimes takes ages to make a substantial contribution towards rocket propulsion as a whole. But that in no way diminishes how fun the work is. Rocket combustion chambers really are my favourite space.

A conceptual illustration of the inside of the BKH experimental combustor, which has a rectangular cross-section, a siren in the upper wall for acoustic forcing, and optical access windows. On the right is a numerical simulation of the cryogenic flames and flow field inside BKH. This kind of result is compared to experimental data from BKH to validate the simulation method.



Combustion chamber 'D' during a hot run on the test stand P8. Using fibre-optical probes and additional optical access windows, the DLR team of scientists 'looks' into the combustion chamber to measure the self-excited flame dynamics.

Follow-up of a test on the P8 test stand: aerospace engineer Justin Hardi and colleagues Federica Tonti and Wolfgang Armbruster analyse the data obtained in the experiment. From them, they draw conclusions about the course of the combustion process in the rocket combustion chamber.


Hannah Böhrk and Master's candidate Jonas Peichl in the laboratory: the X-ray furnace developed by the Young Investigator Group allows research into the thermal behaviour of materials and the generation of 3D images of the material samples heated inside it.

# SEARCHING FOR THE PERFECT COOLING SYSTEM

**Upon re-entering Earth's atmosphere, spacecraft must be able to withstand temperatures of several thousand degrees. Hannah Böhrk and her team from the Institute of Structures and Design in Stuttgart want to better understand how heat loads on structures made of fibre-reinforced ceramics can be reduced. For the past five years, the scientist has been leading a Helmholtz Young Investigator's Group examining technology for modern heat shields through simulations and experiments. The project is now nearing its conclusion.**

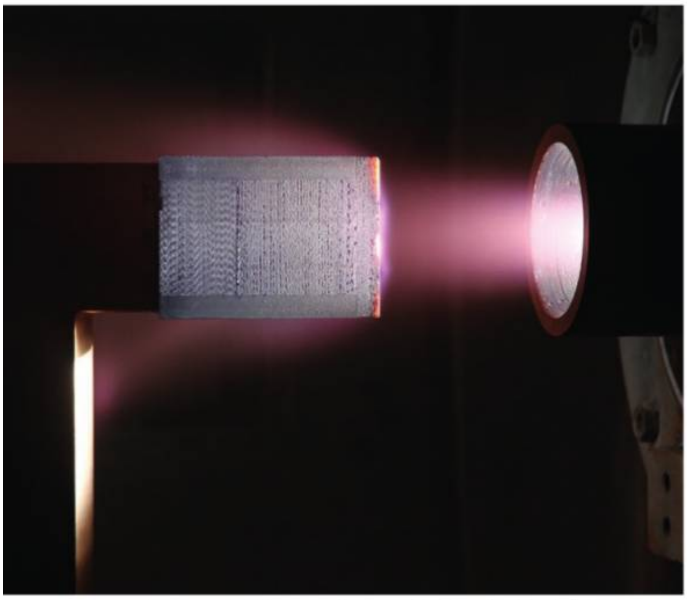
## Young Investigator Group 'High Temperature Management for Hypersonic Flight' – an enthusiastic small team ready for a challenge

By Nicole Waibel

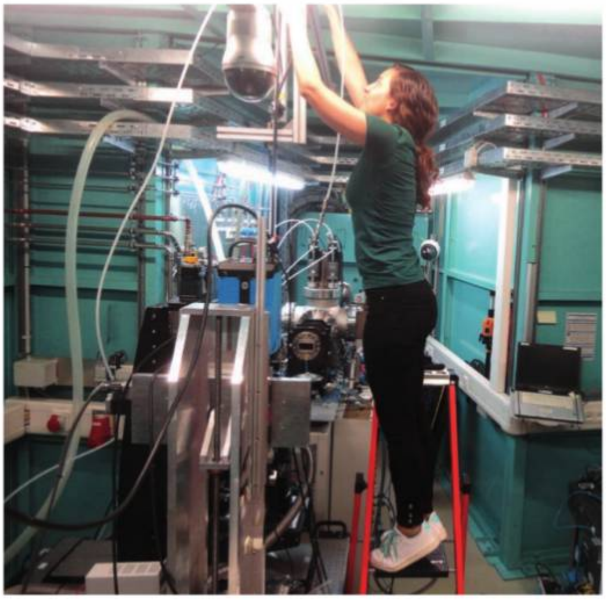
In order to protect space vehicles in the hot phase of flight, researchers at DLR in Stuttgart are focusing on transpiration cooling. Here, a cooling gas such as nitrogen flows out through porous fibre-ceramic tiles, forming a cooling protective layer on the surface. The world's first flight-test of this kind of cooling system was made as part of the SHEFEX II (Sharp Edge Flight Experiment) project at DLR. "SHEFEX II was a great success, as we were able to show that the transpiration cooling system developed by DLR really works," recalls Hannah Böhrk. The young scientists hope to be able to use this approach to cool critical areas of complex structures, such as the sharp front edge of spacecraft or combustion chamber structures.

**Gaining a better understanding of complex thermal behaviour**

How does a cooling gas flow inside a complex structure at different temperatures and pressure? How can we make it flow to the hottest point? "There were so many exciting questions that I wanted to pursue," says Böhrk, "but, particularly in the areas of design and instrumentation, there was a lack of tools to answer them satisfactorily." This gave the scientist the idea of applying to set up a Helmholtz Young Investigator Group. The Helmholtz Association programme promotes internationally outstanding post-doctoral students and enables them to set up and lead their own research groups. Böhrk still remembers the selection process: "There was a multi-stage process involving expert assessments and presentations in front of examiners from different disciplines." Böhrk won the jury over. She received a grant that would allow her and her assembled team to focus intensively on 'High-temperature management for hypersonic flight'.



A transpiration-cooled, fibre-ceramic sharp edge from the Helmholtz Young Investigator Group in the air plasma flow of the plasma wind tunnel PWK4 of the Institute of Space Systems at the University of Stuttgart.



Postdoc Işıl Şakraker Özmen installing the X-ray furnace at the particle accelerator of the Karlsruhe Institute of Technology (KIT)

### A small team with big goals

Böhrk has been leading the Young Investigator Group for the last five years, consisting of two doctoral students at DLR, a doctoral student at the University of Stuttgart, and numerous other students with their final theses. Her focus is on the sharp leading edge. The researchers developed theoretical and experimental tools to investigate the limits and possibilities of cooling. This included analysis of the aero- and thermodynamics, as well as characterising materials and developing sensors. One of the doctoral students dealt with health monitoring and developed a structural monitoring system for fibre-ceramic heat shields. "The great thing about having a small team is that you are constantly interacting with one another. You can work together intensively on an overarching issue," says Böhrk of the benefits of the Young Investigator Group. In order to put her idea of a new translucent furnace into practice, Böhrk recruited another post-doctoral student for the team in 2016.

### Uncovering what lies beneath

"What I really appreciated about the grant was that it gave me the opportunity to think and work freely. One outcome of this freedom in research was a portable furnace that enables us to observe the processes at play inside a material sample during an experiment." The design of the furnace allows the transmission of X-rays to study the 3D sample volume. For this purpose, the scientists installed the furnace on a special particle accelerator at the Karlsruhe Institute of Technology (KIT). "Internal processes such as the burning of a material can be recorded in split seconds and at high resolution," says Böhrk, explaining what makes the test facility special. The DLR researchers were able to capture 3D images of the heated samples, which revealed how material changes in the interior and on the surface interacted with one another. "The images and tests help us describe the behaviour of the material. They form the basis for simulating heat transfer within the material," summarises Böhrk.

In future, Hannah Böhrk's team intends to develop the furnace further, with a view to investigating the reactions that occur in the outer flow upon entering the Earth's atmosphere or that of other planets. One example is Mars, where the atmosphere consists almost exclusively of carbon dioxide. For this, the plasma generator on the furnace must be further improved.

### Unique experience of leading a group

Böhrk would like to encourage young post-doctoral students to apply to form a Young Investigator Group to study interesting topics: "Making contact with the Helmholtz Association was rewarding, as it opened up new sources of knowledge. Simply bringing the individual questions and answers together to form a whole study was a massive help." And the funding also brings with it other benefits: "It raises the profile of a research topic. It becomes more visible – both externally and internally."

Böhrk notes rather wistfully that that after five years, the group of researchers has now reached the project's natural end point: "Leading a research group was a unique experience, and I also gained teaching experience at the University of Stuttgart." Böhrk also lectures at the Hochschule Furtwangen and the University of Augsburg. She hopes to become a professor one day, noting that "leading the Helmholtz group has brought me closer to that goal."

**Nicole Waibel** is responsible for public relations at the DLR Institute of Structures and Design.

**Hannah Böhrk**

is a research associate and Deputy Head of the Space System Integration department at the DLR Institute of Structures and Design in Stuttgart. She spent five years (2013 - 2018) leading the Helmholtz Young Investigator Group studying 'High-temperature management for hypersonic flight', which she initiated.

Before joining DLR in 2007, Böhrk received a doctorate from the Institute of Space Systems at the University of Stuttgart, where she investigated increasing the performance of electric space propulsion with hybrid plasma generators. Böhrk has received several scholarships and awards and has conducted experiments on five space flights.

She gives lectures on porous media in aerospace at the University of Stuttgart, and on hypersonic flight at the Hochschule Furtwangen and the University of Augsburg.

Hannah Böhrk is mother of two children.

## THE HELMHOLTZ YOUNG INVESTIGATOR GROUP PROGRAMME

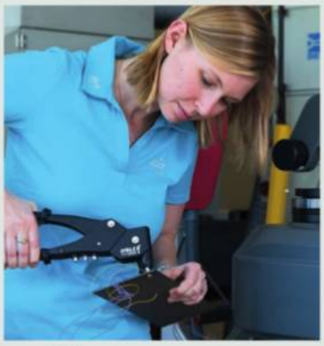
The Helmholtz Association offers post-doctoral researchers the opportunity to put together and lead their own research groups in cooperation with a university. Every January, up to 20 Young Investigator Groups are provided with a maximum grant of 150,000 euro per year in the form of co-financing.

Scientists who obtained their doctorate two to six years ago can apply. The prerequisite besides the young investigator's excellence is a promising research plan in one of the Helmholtz research areas: energy; earth and environment; health; aeronautics, space and transport; matter; and key technologies

**More information:** helmholtz.de/en

## THE THREE PHD STUDENTS IN THE HELMHOLTZ YOUNG INVESTIGATOR GROUP

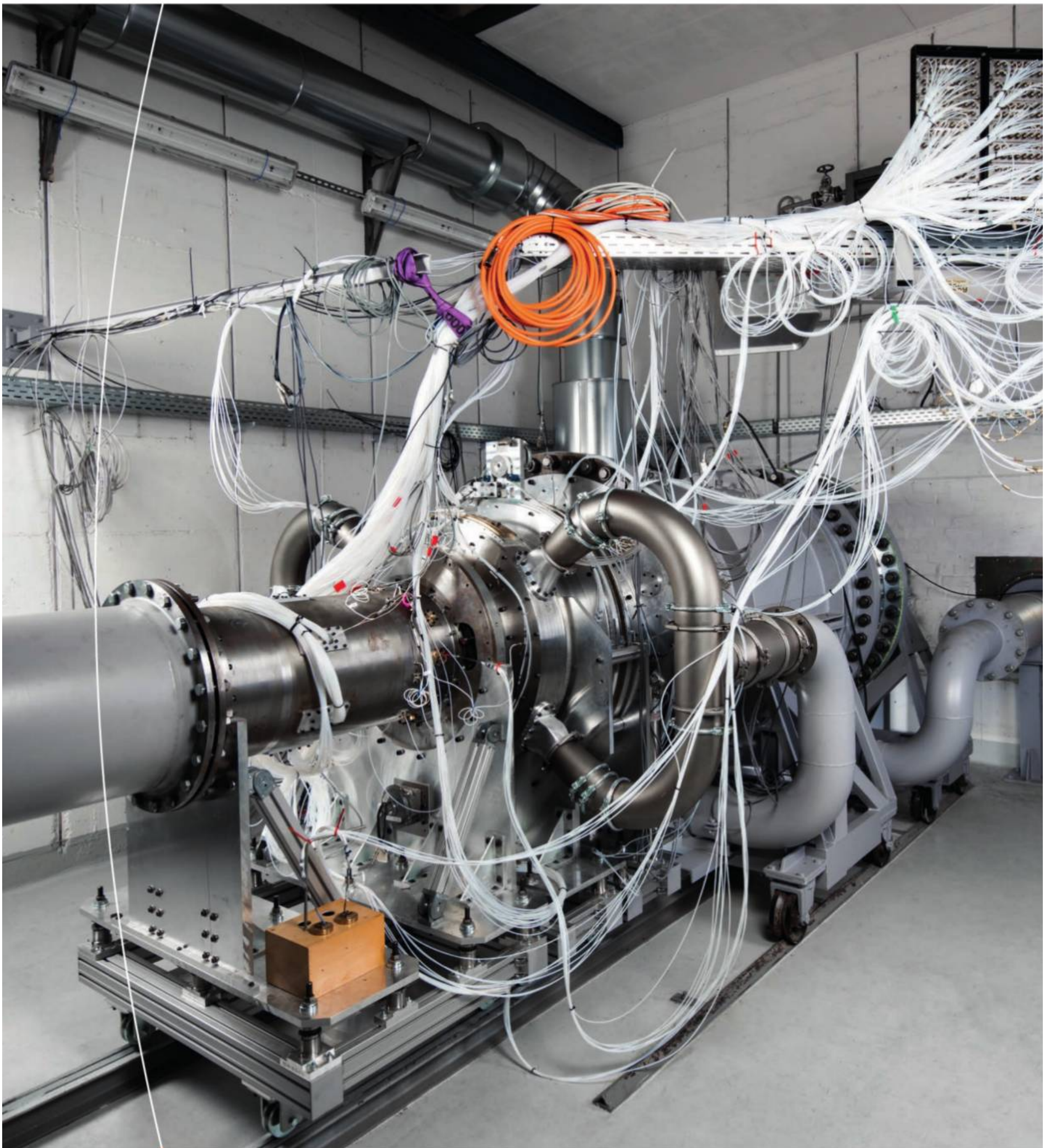
**Christian Dittert**
specialises in the design and calculation of transpiration-cooled sharp leading edges of hypersonic vehicles



**Tina Stäbler**
submitted her dissertation on the topic of 'Electrical process for monitoring the condition of thermal protection systems in space' in November 2018.

Image: ITLR, Universität Stuttgart

**Daniel Prokein**
while setting up an experiment at the supersonic test facility at the Institute of Aerospace Thermodynamics of the University of Stuttgart.



The Inter-Compressor Duct wind tunnel with its complex instrumentation

# FAST TRACK TO HIGHER THRUST

## Research into next-generation engines at DLR's compressor test facility in Cologne

By Doris Pfaff

The noise is as deafening as if one were standing on a runway. Powerful engines and gearboxes are roaring and the ground is vibrating in the compressor test facility at the DLR Institute of Propulsion Technology in Cologne. The test object, which looks almost like a passenger car engine, is integrated into an impressive test system and connected to approximately 1000 sensors. The various measurement devices and dedicated probes are determining the pressure, temperature and flow conditions. In this unique test facility the compressor runs just as it would in an operational aircraft engine. The collected data are transmitted to the control room. The complex design of the research compressor known as RIG 250, which is just one of several engine components, gives an insight into the amount of work required to make next-generation aircraft engines significantly quieter and more fuel efficient.

A number of aerodynamic forces are involved when an aircraft takes off. First of all, the thrust is generated by engines mounted under the wings. An aircraft engine works in a similar way to a four-stroke petrol engine. First, air is drawn in by the fan – the large bladed structure that can be seen at the front of the engine. This is then compressed by the intermediate- and high-pressure compressors, where it reaches a high temperature. In the third part of the cycle, the fuel – kerosene, for example – is then added and a controlled combustion process is initiated by an electrical discharge. The fan-generated airflow that is not used for combustion (the bypass flow) and the exiting hot gases produce the thrust that the aircraft needs to take off and fly. The larger the fan, and hence the greater the bypass ratio, the more efficient the engine becomes. But the extra weight due to the larger fan size also leads to higher fuel consumption, and therefore a greater environmental impact.

This is the area where DLR's propulsion researchers are working – they are developing engines that are lighter and thus require less fuel. At the same time, they want to make them quieter, but – and this is one of the biggest challenges – keep them just as powerful. Aeronautics research is therefore making an important contribution to climate protection in a project that is part of the German federal government's research programme.

How do researchers set about optimising the fan and compressor components? "It is important to know that there are different types of compressors – such as intermediate-pressure and high-pressure compressors – depending on the pressure range. The air drawn in by the fan is compressed in the subsequent rotor/stator configurations (compressor stages) and then it enters the combustor," explains Andreas Peters, an engineer in the Fan and Compressor Department who is responsible for the test stands. The optimisation of blade geometries makes it possible to reduce the number of compressor stages, thus making the compressor design more compact. This is being made possible by new software developed at the Institute, Peters says. Modern materials are playing a key role here – together with titanium, carbon fibre composites or combinations of both materials are now being used. Both are lightweight and have high strength. The manufacturing of compressor rotors, in what is referred to as a blisk (a portmanteau of 'bladed disk') design, has also proven successful. This means that the rotor is not assembled from individually manufactured blades, but rather machined in its entirety from solid material. "Whether these new rotors and compressors will actually deliver

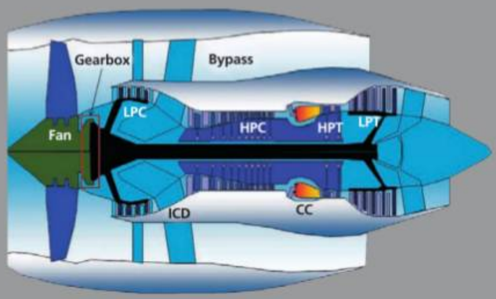
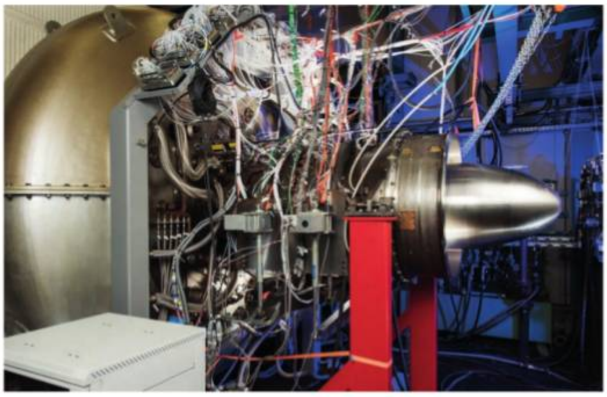


Diagram of a geared turbofan engine

## UNIQUE TEST STANDS TO CREATE THE OPTIMAL ENGINE

The Institute of Propulsion Technology is one of DLR's largest and oldest institutes, with around 200 employees spread across four sites – Cologne, Göttingen, Berlin and Trauen). With Fan and Compressor, Combustor and Turbine departments, the Institute's structure partially corresponds to that of an aircraft engine. Each of these departments is dedicated to their respective component and all have the common objective of developing optimised engines. There are also other departments with cross-sectoral responsibilities, such as assessing the engine as a whole, investigating ways to reduce engine noise, and developing special measurement and simulation techniques used to examine the test objects.

The Fan and Compressor Department in Cologne is tasked with optimising the foremost components of the engine – the fan and compressor. Thirty employees have access to three test facilities: the Multistage Two Shaft Compressor Test Facility (M2VP), the Centrifugal Compressor Test Rig (RVK) and the Transonic Cascade Wind Tunnel (TGK). The TGK is the department's oldest test facility, but it is still important for fundamental research.


RIG 250, a four-and-a-half stage research compressor, in the test facility.

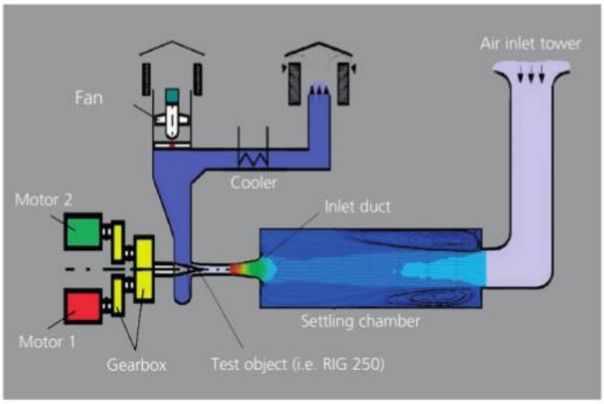


Diagram of the Multistage Two Shaft Compressor Test Facility (M2VP)

the promised increase in performance while at the same time delivering greater reliability is being determined in the measurement campaigns being conducted on the various test stands," Peters explains.

### Complex test set-up and lengthy evaluation

This is how a test works in practice – the test object, in this case the multistage high-pressure compressor RIG 250, is installed in the Multistage Two Shaft Compressor Test Facility (M2VP) and connected to the measurement system. Among other things, the RIG 250 includes a blisk rotor, so it is lighter and more efficient due to its optimised blade design. "It takes up to two years to set up the test compressor RIG 250 in its new configuration, to install the instrumentation and connect everything to the existing test facility; connecting the cables to the data acquisition systems alone takes almost a month. With thousands of measurement points, it is necessary to work with complete precision to ensure that the measured values from the sensors can be stored and evaluated in the correct place in the results database", the engineer explains.

Driving such a high-pressure compressor at a maximum speed of close to 15,000 RPM requires a power input of 10 megawatts – equivalent to the output of 135 mid-range cars, each with a 100-horsepower engine. This generates a great deal of noise – similar to the running engines of a large aircraft – and is clearly noticeable in the vibration of the test stand. Proper airflow is required for this test. The air is drawn in by the compressor through an external tower and first passes into a large chamber to reduce the turbulence of the incoming air. This gives rise to a considerable airflow – the same amount of air as the volume of a small, detached house is drawn in every second. It is then accelerated through an inlet nozzle and reaches the compressor almost free of turbulence. Optimal test conditions now prevail. The air is then compressed and reaches a temperature of 240 degrees Celsius. The temperature of the air is reduced using a cooler before it is released to the external environment.

### Data for the development of new design and manufacturing methods

The start of a measurement campaign on the relevant test stand is the moment that the scientists and engineers have been working towards for a long time. Tension also builds in the test facility's control room – will the procedure be successful, and will the long-prepared campaign run smoothly? Even if all does go to plan, the work is still far from over. While the measurements are conducted over a period of several weeks – with the test stand in operation for up to eight hours per day – the detailed and careful evaluation of the

Hundreds of sensors deliver data to the measurement system of the ICD test rig

The team monitors the measurement campaign from the control room

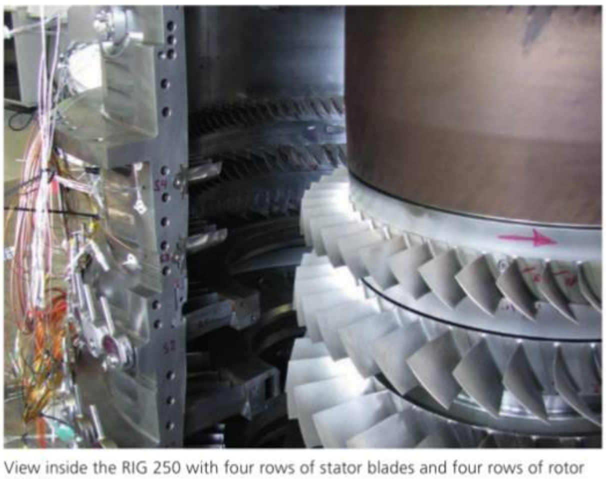
vast quantities of data takes far more time. The researchers therefore need to be patient until the test results are available. Being patient is difficult for both the DLR personnel and the engineers from partner organisations, who may be waiting for them with industrial applications in mind. For this reason, the experiments are planned such that an initial fast evaluation of the tests provides at least a preliminary overview of the results. For example, the most recent measurements, conducted in the summer of 2018, were the culmination of many years of cooperation with Rolls-Royce Deutschland. Their continuation is at the planning stage. The test in question investigated the phenomenon whereby lightweight and thin – meaning reduced-weight – blades can be caused to vibrate by the passing airflow. These results make it possible to accurately predict the stresses that would result from such vibrations, and thus make statements about the operational safety of the engine.

**Compressor components – a glimpse into the future**

Eberhard Nicke, who is head of the Fan and Compressor Department at DLR, believes that the Institute is not working alone on the development of next-generation compressor systems. DLR is involved in the European Union's aviation research programme Clean Sky 2 (CS2), together with MTU Aero Engines and GKN Aerospace. Their joint goal is to coordinate intermediate-pressure compressors, Inter-Compressor Ducts (ICDs) and high-pressure compressors with one another in order to optimise overall engine performance. "This is the first time that cross-module research has been carried out with this level of detail," Nicke explains. In the first phase of the project, the researchers are focusing on the ICD component of the compressor system in order to shorten it as much as possible. "The Institute's third test facility in Cologne – the Transonic Cascade Wind Tunnel (TGK) – will play an important role in this," he continues. "The Transonic Cascade Wind Tunnel has been extended with a special measurement section to be able to test the flow in an ICD under realistic conditions."

This test facility modification has only recently been put into operation. Various computer-based flow studies and optimisations were carried out prior to this. On this basis, a model of a compact ICD was designed. The newly expanded Transonic Cascade Wind Tunnel makes it possible to measure the airflow with unprecedented accuracy. By using the measurement data obtained in this way, the researchers can validate their earlier theoretical models and optimise the engine compressor system. The second phase of the Clean Sky 2 collaborative project can then begin. A compressor system will be tested on the M2VP as part of this initiative. "This kind of test compressor is unique, at least in the western world," Nicke says. "By 2021, optimised compressor technology should have reached a very high degree of maturity." The next-generation engine is now within reach.

Eberhard Nicke heads the Fan and Compressor Department

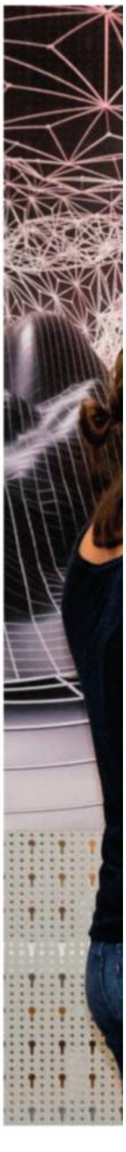


View inside the RIG 250 with four rows of stator blades and four rows of rotor blades

# THE ART OF CONTRADICTION

## The ZKM in Karlsruhe – boundless, like humans

By Peter Zarth



At the very start of our visit to the Center for Art and Media (Zentrum für Kunst und Medien; ZKM) in Karlsruhe, we encounter two surprising statements. "We worship philosophy," is one, dropped casually into the conversation by Christiane Riedel, the Chief Operating Officer, as a matter of course. We also learn that "as a new pairing between gatherings of people and the collection of objects, the museum has the opportunity and the task of transforming itself into a place of knowledge and action together with members of the public, in order to regain access to reality through instruments of thought." This is what Peter Weibel, artistic and scientific director, writes in the 'manual' of the exhibition 'Open Codes': Living in Digital Worlds. This should be fun.

**Regaining reality?**

We are somewhat baffled, as we had expected a place featuring Artificial Intelligence, digitalisation, the world of algorithms, futuristic quantum computers and, of course, art. Admittedly, it is all of these things, but that's just part of what the ZKM is about. Perhaps it really is, paradoxically, striving towards an 'unreachable horizon'. As Riedel continues, we realise that this may well be the case: "What sets us apart? The fact that we don't have any boundaries," she says succinctly, without a hint of pretension. Despite this seeming contradiction in terms, the ZKM is both indescribable and boundless – human. It is as complex as Weibel's words indicate in the second statement mentioned above. After all, his words are complicated, while striving for clarity.

Is the ZKM really trying to "regain access to reality through instruments of thought"? Pay close attention to the wording: 'regaining access to reality' – a precarious foray onto the thin ice of reasoning. Yet there's no doubt that the ZKM is itself a contradiction: its name does not tell the real story, yet it is fitting nonetheless. The ZKM is much more than its name implies. Known until 2016 as the 'Center for Art and Media Technology', it is filled with fascinating contradictions. How else could we hope to get close to reality, let alone 'regain access to it', as Weibel urges us, than by questioning our human understanding of reality, pointing out its contradictions and asking what it really is? Children do it. Art does it. Science attempts to do it. Philosophy does it by formulating the questions and asking them of others. Riedel says something else that only adds to the sense of surprise: "We bring science, technology, art and philosophy together." Is this where classical Bauhaus Modernism meets Renaissance thinking – in a museum that does not see itself as such? In any case, this sounds like an approach that could lead to the future.

**Self-perception – understanding of the world**

But how does it work? Let's leave it to the ZKM to explain: "The ZKM was founded in 1989 with the mission of continuing the classical arts into the digital age. This is why it is sometimes called the 'electronic or digital Bauhaus'– an expression that is traced back to the founding director Heinrich Klotz. From the very beginning, it also took on the task of creating the right conditions for producing works of art – whether by guest artists or employees at the centre. That is why it is called centre instead of museum. It aims to engender a better understanding of the world and thus delves into current themes to make the public aware of questions, contexts and problems. It aims to engender a better understanding of the world and thus looks at current themes in order to make the public aware of questions, contexts and issues. Above all, it seeks to share knowledge. By combining research and production, exhibitions and events, archives and collections, the ZKM is able to aptly illustrate art's development in the 20th and 21st centuries, not least because symposia and other platforms for theoretical discourse between philosophy, science, art, politics and economics accompany the ZKM's collection, exhibition and research activities."

Museum? Centre? The ZKM is you as well.

The light is the focus of attention: room for thought, art and experimentation.

Artistic access – access to art

In the innerworld of the outerworld of the innerworld: augmented reality in the Open Codes exhibition

### Screams and whispers

So how can we describe the indescribable? Perhaps by starting with the biggest contradiction of all to be offered by the sprawling complex on Lorenzstraße: it is a former munitions factory. Today, only a bronze plaque reminds us of its origins. It reveals that Karlsruhe once had 17,000 forced labourers, 12,000 of them from the East. Why, one might wonder, is the East given a special mention here? Because 600 of these people 'met' their deaths here. No clear indication, only obfuscation, as to how this came to pass. This kind of past seeps its way into the present and helps to shape the future. We talk to a supervisor, also from 'the East'. But why, we wonder, does this person 'on no account' want to be named? Her gaze wanders upwards to the almost menacing heights of the surrounding galleries – the ZKM's atriums are 32 metres high. "The guards used to stand there," the person whispers. In our mind's eye, the silhouettes of armed men and women start to appear.

Luckily, the ZKM's 'munitions' (which does justice to the original meaning of the word, namely 'food' or 'fodder') have enough impact on the mind to enable us to overcome such grisly visions to some extent. The ZKM is sustained by its vital nourishment of philosophy, art and science. "We are a membrane, diffusing and connecting many different things," Riedel says.

Reality also means coming to terms with contradictions. While there were still survivors of forced labour, the city council invited them to visit Karlsruhe, including the ZKM. The topic of forced labour has been featured in ZKM events, such as the 2015 conference 'The Tribunal – A Trial Against the Transgressions of the 20th Century', to ensure that the subject remains in the public eye.

### Instigating participatory discourse

You, the visitor, are now expected to make a decisive contribution towards realising the ZKM's mission by getting involved in 'regaining access to reality'. Activities are taking place everywhere you look. Young people write an artistic manifesto with the help of a KUKA robot. A lecturer gives a talk and presents a flow chart with the presumptuous sentence: "I'll just rotate this a little bit more, otherwise it's not art". Gamers gather to play in 'zkm_gameplay. the next level'. Visitors whisper their way through the 'soundproof curtain' in the experimental studio of Polish Radio. People get actively involved in choreography by Sasha Waltz, or listen to the sounds of the Ensemble Modern – whether performed for the theatre experiment 'Gaïa Global Circus', written specially for the centre by the French philosopher, anthropologist and sociologist Bruno Latour, or artists trying out new technologies in the Hertz laboratory. According to Regina Hock, the centre's press spokesperson, the idea is that "workshops, exhibitions, performances, events, concerts and many other things incite us to get involved in intellectual discourse, ideally through direct participation. That is exactly what you can expect here." As such, the ZKM is putting Weibel's exhortation into practice in a multitude of ways, and through groundbreaking exhibitions.

Incidentally, Weibel ranks among the contradictory, inconsistent and well-respected artists of today's scene. His concept of art, and indeed of the ZKM, is vast and all-encompassing: "Of course, this includes music, the mother of all the time-based arts," Riedel explains. "We don't draw distinctions between the arts." Over time, the centre has become just as famous as Weibel. In another contradiction, it does not want to be a museum but claims to be following the lead of others as 'the fourth most important museum' in the world – after the Museum of Modern Art (New York), the Venice Biennale, and the Centre Pompidou (Paris) – as ranked by ArtFacts.net, the world's biggest art database. This ranking is widely known, yet controversial – something that should also please those who have made the ZKM what it is today.

A vanishing future: In the Laboratory for Antiquated Video Systems, Dr Dorcas Müller and her team receive items that were once state-of-the-art technology – along with their artistic content.

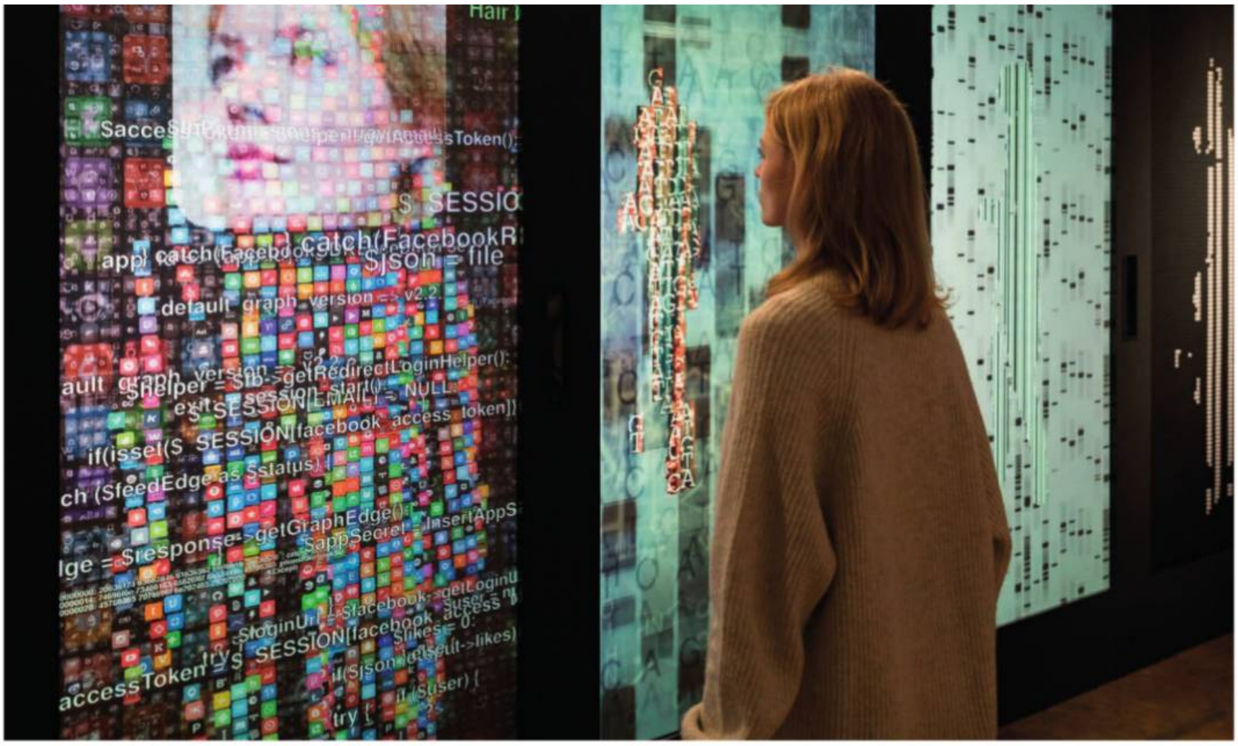
### The archaeology of the future

Let's try to map the genome of this centre for art and media: what makes it unique? We come to an unusual place, which is really unique in this form, where scientists from all over the world – even from the Massachusetts Institute of Technology – flock in order to get technical assistance in Karlsruhe. We pay a visit to Dr Dorcas Müller and her team in the 'Laboratory for Antiquated Video Systems'. It sounds very old-school, but it has a lot to offer: "We save what was the future in the world of the past, and what will be the past not too long from now," she says. "Electronic media die a fast death in the technological sphere. Our laboratory allows people to read, see and experience the past. Our technician can even recreate machines for which no original models survive, in order to play certain material."

This is vital for preserving art: the ZKM maintains and recreates works by early video artists, including Nam June Paik, the pioneer of video art. These would be lost without this 'archaeology of contemporary technology'. Dr Müller explains the principle behind a fossil from the 1960s – the Sony CV, a greyish, unwieldy monster of a tape machine with a screen. "In a sense, this was the original model for the smartphone, the first consumer video device," she says with a smile. "We restored it, and it works. We can play old tapes on it. We restore tape material, too." She also has her eye on the future: "Looking ahead, it is all about preserving today's digital legacy." This critic is quite sure that in 2073 a smartphone from 2019 will look just as outmoded as the Sony CV does today – but they will manage to get it working.

### Mirror worlds – worlds mirror

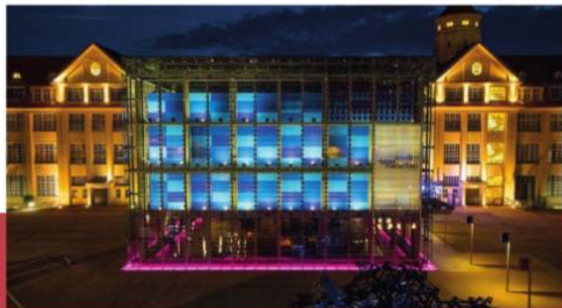
Sometimes the ZKM is downright playful, as mentioned earlier in a more flippant way. It's not often that you find yourself roaring with laughter upon entering an exhibition. The exhibit 'YOU:R:CODE' marks the start of the 'Open Codes' display. The title can be read in two different ways: the interpretation 'your code' indicates that in the installation visitors experience different kinds of digital transformations of themselves. Whereas on entering, a visitor still sees their familiar reflection in a mirror – the most real virtual depiction that we can imagine – the mirror image gradually transforms into a digital databody until finally, the visitor is reduced to an industrially readable code. In the end he/she breaks free from the virtual depiction, and is materialised in a flip-dot display. The second way of reading the piece's title, 'you are code', emphasises that we ourselves consist of code, which amongst other things is manifested in the genetic code. The genetic code constitutes the algorithm of life and from birth it determines what we do. In current research projects synthetic DNA strands even serve as long-term storage for digital data. And for the data analysts and artificial intelligences operating in cloud computing, too, which via smartphones give us our daily instructions for acting, we are only perceived in a mediated way in the form of sensor data and via our electronic traces and expressions – to them we are codes.



Mirror worlds – world mirrors: entering the realms of reality with YOU:R:CODE.

In the 'YOU:R:CODE' mirror exhibit, the ZKM – this munitions factory of the mind – is itself the artist. It also creates its own works of art. Or perhaps you are the ones who are 'regaining access to reality through the instruments of thought'?

Of course, you can simply stroll through the museum collection, currently gathered together in the exhibition 'Writing the History of the Future'. The collection and archives include works and documents from the 20th and 21st centuries. The standout feature of the activities related to the ZKM's collection is its focus towards the electronic arts. The video art collection is one of the largest in Europe, while the computer art collection is the largest of its kind in the world



Modern by tradition: The ZKM with the ZKM Cube (front) and the Klangdom inside.

## ZKM – ZENTRUM FÜR KUNST UND MEDIEN

**Opening hours**

| | |
|---|---|
| Monday and Tuesday | closed |
| Wednesday to Friday | 10 to 18 h |
| Saturday and Sunday | 11 to 18 h |

**Admission fees**

Adults: 6 euro
Concessions and groups of at least 10 people: 4 euro
Children (aged 7 to 17): 2 euro
Families: 12 euro

Prices are subject to change depending on the exhibition.
Entry to all exhibitions is free every Friday from 2 pm.
Entry to the 'Open Codes' exhibition is generally free of charge.

Discounts for groups of 10 or more, students, people with disabilities, federal service volunteers, young people involved in voluntary work, and senior citizens over the age of 65.

**Address**

ZKM Zentrum für Kunst und Medien
Lorenzstraße 19
D-76135 Karlsruhe

**Contact**

Telephone +49 721 8100-0
info@zkm.de

**www.zkm.de**

## MIRACLES OF DUST

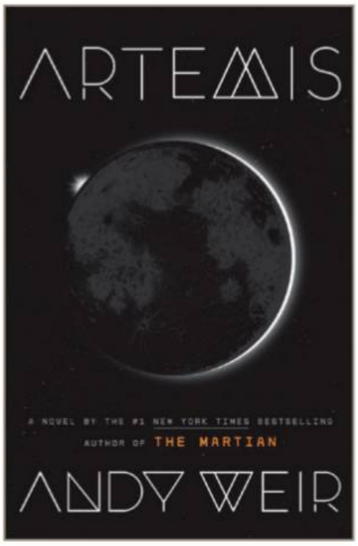

There's something a little bit odd about this scene. A man parks his car in the supermarket car park, sweeps up a little dust from the asphalt, collects it in a jar and, when he gets the chance, goes to see his friend who works in a research laboratory and examines the individual grains of dust under a microscope. That man is Jon Larsen. As he looks, he finds himself transported to colourful, richly varied realm, a microcosm of shapes and hues. What stunning grains of dust! And some of them are not even from this world! In his book **In Search of Stardust: Amazing Micrometeorites and their Terrestrial Imposters**, Larsen looks at a microcosm that is completely invisible to the naked eye.

Cosmic dust particles are formed when objects from space enter Earth's atmosphere and, due to their high speed, produce so much frictional heat that they are almost completely vaporised. A tiny quantity of the leftover molten mass solidifies and cools down to form dust particles. Their luminosity is only visible for a few seconds, as meteors or shooting stars cross the sky. The resulting dust slowly trickles down to the surface of the Earth and can then be collected from all sorts of places, including guttering. With succinct text and a plethora of gorgeous images, Larsen explains what this cosmic dust looks like and how it differs from terrestrial dust. Over more than 150 pages, he describes the different types of spherules (molten globules). Natural processes on Earth such as volcanic activity, lightning, fires and erosion result in some fascinating types of dust, as do human processes like forging, welding, grinding, detonation and the industrial manufacture of mineral wool and many other products.

Each chapter comprises short, concise and informative text. The reader could easily feel somewhat overwhelmed by the sheer number of images (most of them in colour) derived from the electron microscope were they not so meticulously ordered. However, it is a pleasure to explore a realm where the protagonists, measuring only 0.1 to 0.3 millimetres, resemble planets or asteroids in the macro world. Larsen has created a surprising picture book that reveals a stardust-strewn path. An absolute must.

**Christian Gritzner**

## LIVING WHERE THE APOLLO ASTRONAUTS LANDED




Author Andy Weir scored a direct hit with his book The Martian, which was a bestseller before being made into a film. His follow-up novel **Artemis** is not quite up to the standard of The Martian, but is a gripping read all the same. Once again, Weir manages to come up with a science fiction novel that plays out in the not-too-distant future: the Moon is settled, and millionaires, scientists, tourists and workers live in its five huge bubbles, named after the Apollo astronauts. Jazz Bashara, the main character, keeps herself afloat with the odd bit of smuggling and black-market business. Pleasantly rotund, like Mark Watney in The Martian, and with a loose tongue and flippant manner, she's beholden to no one. When Jazz is hired to sabotage an aluminium factory on the Moon and her client is murdered a short time later, we embark on a thriller that makes skilful use of the space setting. Everyday life is not too far removed from that on Earth, but elegantly adapted to conditions on the Moon with a myriad of intricate details. Trips to the surface of the Moon are a tourist attraction, while the Apollo landing site has become a place of pilgrimage and one of the must-see stops on any visitor's itinerary. Goods arrive in regular trips from Earth to the Moon. Items such as lighters or cigarettes are prohibited due to the danger that they pose in such an environment, and they change hands as contraband.

Andy Weir is a science enthusiast who loves carrying out factual research and making it pivotal in his stories. Readers of Artemis will enjoy the thrilling action, the chase scenes and the tales of racketeering, while also getting a taste of how a city on the Moon might be.

**Manuela Braun**

# FIRST MAN

Image: Universal Pictures International

1961, Mojave desert: a test pilot bounces off the atmosphere and has trouble re-entering his flying contraption. His officers doubt his capacities as a pilot. He seems distracted. Is he reliable? Cut to a family scene where the same pilot sits by his sick daughter's bed. What will happen to his career? Did he make a mistake?

If I did not know better, I would probably have agreed with the officers in command. But this pilot will one day become the first man on the Moon, thanks to his extraordinary piloting skills, his calm demeanour and his persistence, even when faced with the most death-defying odds.

**First Man** is the compelling story of an extraordinary man, a dedicated father, husband and friend, who perseveres through the rigorous training, survives disasters, and is prepared to make sacrifices. The film shows Neil Armstrong's struggles – both in his career and personal life – his path filled with 'small steps' towards the human exploration of the Solar System, and the ticking clock of the space race between two nations.

Although Ryan Gosling plays his role convincingly and the friendship among space pioneers is enthralling, I was glad to have a firm background knowledge of that era, the programmes that preceded Apollo, and the disasters and the triumphs that led to that ultimate moment in 1969 when the 'Eagle' landed. The film is definitely worth watching: the suspense on the Gemini 8 launch day, the alarms blaring when the spacecraft starts to spin uncontrollably, Neil's calm response when things turn for the worst – the drama on the ground as well as in the air kept me on the edge of my seat throughout most of the film.

The strongest role for me was that of Janet (Neil's wife, played by Claire Foy). During the entire all she displays tremendous courage. She is a strong woman who won't take no for an answer. Despite how much she struggled with her husband's job she always supported her fellow pilot wives when their partners were never coming home again, and insisted on Neil saying goodbye to his boys before his trip to the Moon.

'First Man' is an excellent film for space enthusiasts and lay people alike. We all know Neil's famous words when he stepped off that ladder, but it was another one of his lines that struck me more: "We need to fail down here, so we don't fail up there." Maybe we should all take that to heart a little more?

**Linda Carrette**

## RECOMMENDED LINKS

MARS24 – TIME ON MARS
www.giss.nasa.gov/tools/mars24/
Check out the local time on Mars – at the location of your favourite mission or landmark. Choose from among the spacecraft that have landed on the Red Planet or 50 well-known craters and other landmarks to show on a Sun clock map. Various different Mars maps and projections are available for the clock, together with orbit diagrams, computed panoramas and an analemma. A separate window shows UTC and your time zone on Earth, together with spacecraft event time for your chosen missions.

TRACKING FLIGHTS LIVE
www.flightradar24.com
Is your airplane on time? What does air traffic look like in a certain region? Flightradar24 is a global flight tracking service that provides you with real-time information about thousands of aircraft around the world. Flightradar24 tracks more than 180,000 flights, from over 1200 airlines, flying to or from more than 4000 airports around the world in real time. They currently provide services online and for iOS or Android devices.

SPACE WEATHER LIVE
www.spaceweatherlive.com
SpaceWeatherLive is an international website and app that provides the latest space weather data, news, and updates from the Sun to aurora on Earth! By subscribing to SpaceWeatherAlert you will receive mail alerts when there is significant activity. These are also automatically posted on Twitter.

ACCELERATAR
acceleratar.uk
A particle accelerator of your own? This is now possible thanks to a new app – and augmented reality. To play, you will need some physical markers, in the form of paper cubes. Once you've downloaded the app and the cubes, access the instructions on the AcceleratAR website to understand how it works. With this app you will learn about the physics of particle accelerators and electromagnetic fields.

YOUR OWN SPACE CENTRE
youtu.be/wGHICSMGO04
Anyone who dreams of designing and flying rockets, operating manned space stations or launching missions to alien planets can do so in the computer game Kerbal Space Program. The type of animation is reminiscent of children's toys – but it is highly complex and makes spacecraft sometimes mercilessly burn up in the atmosphere.

VIRTUAL CONTROL ROOM
www.musc.dlr.de/hp3/en/
The InSight mission is on Mars, and the 'Mole' has been deployed and has already begun hammering into the surface. But how deep is it into the surface, and what is the temperature on Mars? The DLR Microgravity User Support Center (MUSC) has created a virtual control room that allows you to follow the Mole's progress.

## 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, security and digitalisation 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 two project management agencies for research funding.

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DLR Department of Public Affairs and Communications
Linder Höhe, D 51147 Köln
Phone +49 2203 601-2116
E-mail kommunikation@dlr.de
Web DLR.de
Twitter @DLR_en

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**Cover image**
The fastest computer used exclusively for aeronautics research in Europe is at the DLR site in Göttingen. The computer is the heart of the simulation center C²A²S²E (Center for Computer Applications in Aerospace Science and Engineering).
Image: DLR / Thomas Ernsting

**Deutsches Zentrum für Luft- und Raumfahrt**
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