DLRmagazine

of DLR, the German Aerospace Center · No. 171 · November 2022

AWAKENING THE SLEEPING GIANT

DLR CONDUCTS RESEARCH FOR THE HEAT TRANSITION

More topics

- **LEAGUE OF EXTRAORDINARY ROBOTS**
  Robots on the move on Mount Etna
- **A POLAR HOT SPOT?**
  A research team investigates global warming

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About DLR

DLR is the Federal Republic of Germany's research centre for aeronautics and space. We conduct research and development activities in the fields of aeronautics, space, energy, transport, security and digitalisation. The German Space Agency at DLR plans and implements the national space programme on behalf of the federal government. Two DLR project management agencies oversee funding programmes and support knowledge transfer.

Climate, mobility and technology are changing globally. DLR uses the expertise of its 55 research institutes and facilities to develop solutions to these challenges. Our 10,000 employees share a mission – to explore Earth and space and develop technologies for a sustainable future. In doing so, DLR contributes to strengthening Germany's position as a prime location for research and industry.

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German Aerospace Center

EDITORIAL

DLR STATEMENT

What is it like to coordinate ESA astronaut Matthias Maurer's mission from Earth? What challenges do our researchers face when they spend several days on a huge glacier in the Alps to determine snow cover?

DLR's blogs portal takes readers behind the scenes of our research. Scientists share their personal take on missions and projects, providing insights that cannot be found in press releases. The **DLR.de/blogs/en** pages are also the right place to go for a deep dive into science, for example to understand exactly how the radiation measuring device on board NASA's Artemis I lunar mission works. As well as exploring a wide range of topics from aeronautics, space, energy, transport, digitalisation and security, the platform offers informative posts full of facts and context. Its articles cover a diverse range of topics, from an upcoming meteor shower or imminent solar eclipse to a review of historical events such as the lunar landings of the Apollo missions.

Dear reader,

Until now, the energy transition has largely revolved around electricity; sustainable heat has been sidelined for quite some time. However, current uncertainty over energy supply is beginning to change this. For a while now, DLR scientists have been working on this sleeping giant, conducting research into various technologies and concepts for climate-friendly heat using renewable sources, including heat pumps, thermal wind energy, energy systems analyses and the use of lime for heat storage. The cover story of issue 171 of the DLRmagazine gives an overview of the different aspects and potential of heat. We also interview Christian Sattler, Divisional Board Member for Energy and Transport, to understand whether we are facing a 'heat problem'.

Incidentally, an entirely different issue with heat has been developing in the Arctic, a region that is warming up much faster than the rest of the world. An international research team has travelled to the North Pole to study the phenomenon of Arctic amplification and the effects that this warming could have on the rest of the planet.

It is not just human researchers who are busy at DLR. In the ARCHES project, a team of robots journeyed to one of the most inhospitable areas in Europe – Mount Etna. In this issue, you can read about why they explored this Sicilian volcano and the special skills each individual team member brought to the project.

Other highlights of this issue include a focus on Mars' two moons – Phobos and Deimos – which are finally to be explored in detail with a new mission, and an interview with DLR transport researcher Laura Gebhardt, who investigates whether e-scooters, e-bikes and pedelecs are environmental saviours or mere nuisances. You can also discover how artificial intelligence integrates the reactions of a concert audience into a musical piece, and much more.

We hope you enjoy reading this issue.

Your Editorial Team

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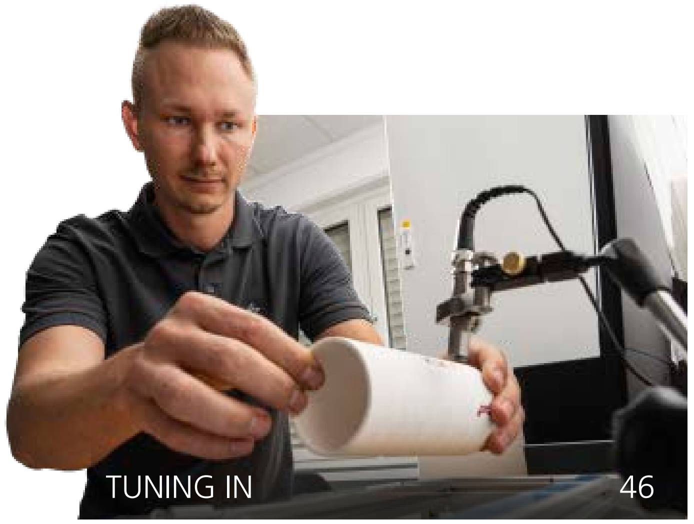
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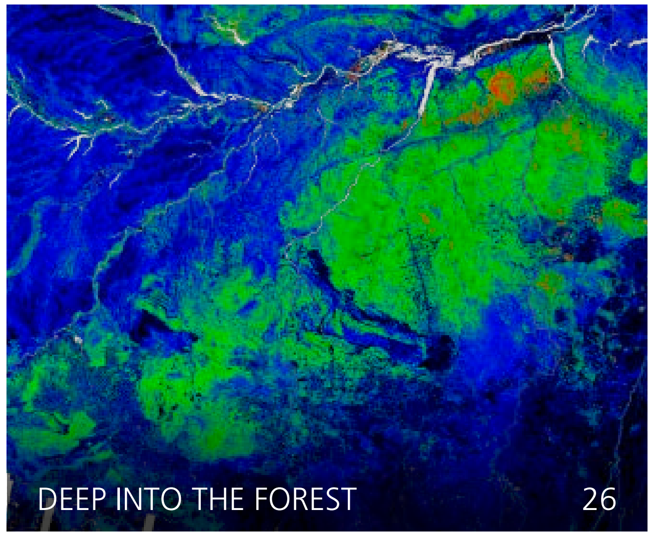
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EUROPEAN INDEPENDENCE IN WEB SEARCH

In the OpenWebSearch.EU project, DLR is working with 13 research and computing centres to facilitate effective web searching in compliance with EU regulations. Over the next three years, they will develop the core of an Open Web Index (OWI) for Europe. To this end, data centres will make their computing capacities available for this purpose and work together to index the Internet. In addition, the project partners are devising an open and expandable European infrastructure for web search and analysis, based on European values, standards and legislation. Web search is currently dominated by a few search engine providers. Information and knowledge are not truly accessible as public assets at the moment, according to the project partners. OpenWebSearch.EU aims to strengthen Europe's digital sovereignty and promote an open and fair search engine market.

openwebsearch.eu/Source: NASA/Unsplash/Pixabay

The OpenWebSearch.EU project is developing a web index that will form the basis for new forms of Internet search.

Researchers from the DLR Institute of Vehicle Concepts have developed a hydrogen expansion machine that can also be used in heavy construction vehicles

HYDROGEN-POWERED CONSTRUCTION SITE VEHICLE

In the future, heavy construction site vehicles could also be able to handle longer tasks with hydrogen. This will be made possible by a hydrogen expansion machine. This machine takes the high pressure of the hydrogen from the storage tank and reduces it for the fuel cell. The energy released in the process is converted into electricity by a generator. The electricity can in turn be used in an electric motor to power the hydrogen vehicle. This idea was developed by researchers at the DLR Institute of Vehicle Concepts and received the DLR.IDEA AWARD. It is intended to make fuel cell technology more competitive with purely battery-electric mobility and to increase the range of fuel cell vehicles.

MEASURING FLIGHT DATA WITH LASERS

Laser-based instruments can provide accurate and reliable flight data. DLR scientists demonstrated this in practical tests in August and October 2022 with the Falcon research aircraft. On board the aircraft were a laser Doppler anemometer, a scatterometer and a laser spectrometer. This new approach to collecting flight data using lasers makes it possible to acquire information such as flight altitude, speed and rate of climb and descent more reliably and considerably reduces the time and effort required to set up and calibrate the sensors. One advantage of laser sensor technology is that it is possible to tell immediately from the measurement signal whether the sensor is working properly. This is not always the case with conventional sensors; for example, they can be dirty or iced up and still deliver a measured value, which is incorrect. Until now, aircraft have often still used mechanical methods, which have changed little since the beginning of aviation. During the flights, the researchers were able to obtain large amounts of data and show that the principle of this technology works.

The sensors for laser absorption spectroscopy are located on the rear of DLR's Falcon research aircraft. They investigate how strongly the oxygen molecules in the atmosphere absorb the laser beam between the sensors.

THE ROTOR BLADES OF THE FUTURE HAVE 1500 SENSORS

Testing the vibration and load behaviour of the rotor blades

In order to operate wind turbines more efficiently in the future and in locations that are less wind-intensive, their rotor blades must be larger and at the same time lighter. DLR is working with partners from research and industry to find out how this can be achieved and what technical challenges are involved. To this end, DLR's WiValdi (Wind Validation) Wind Energy Research Farm is being built in Krummendeich in Lower Saxony. Step by step, both the wind turbines and the measuring masts are being installed. The rotor blades of the wind turbines are equipped with around 1500 sensors to measure the vibration and load behaviour as well as the aerodynamics and statics of a wind turbine on a full-size device and during actual operation.

CONTROLLED COSMIC COLLISION

NASA/Johns Hopkins, APL/Steve Gribben

The DART spacecraft collided with an asteroid 11.6 million kilometres from Earth, diverting it from its orbit.

Can we protect Earth from asteroid impacts in the future? NASA's DART (Double Asteroid Redirection Test) mission could partially answer this question. On 27 September 2022, the spacecraft, which was launched on 24 November 2021, collided with the 160-metre moonlet Dimorphos 11.6 million kilometres from Earth. This moonlet orbits asteroid Didymos, which is five times larger. In a controlled impact at 22,000 kilometres per hour, the spacecraft created a crater several tens of metres in diameter and the asteroid's orbital period changed measurably, by a few minutes. This is the first time humans have succeeded in deflecting a natural body in the Solar System.

REGIONAL NEWS

AUGSBURG: The DLR_School_Lab Augsburg opened at the end of July. Here, children and young people can carry out experiments that reflect current research work at the university, as well as at the DLR facilities in Augsburg, the Center for Lightweight-Production-Technology and the Institute of Test and Simulation for Gas Turbines. There are now 15 DLR_School_Labs across Germany, which are visited by around 40,000 schoolchildren each year.

BRAUNSCHWEIG: DLR conducted flight tests with the Dornier 228 research aircraft to collect data on how motor vehicles interact with cyclists and pedestrians. Based on the data, the researchers are developing technologies that improve cooperation between road users and thus contribute to Vision Zero in road traffic.

COCHSTEDT: The International Forum for Aviation Research is the world's aviation research establishment network. This year, delegations from all member organisations were invited to visit DLR at its most important aeronautics research sites. The visit to DLR's National Experimental Test Center for Unmanned Aircraft Systems in Cochstedt was followed by a visit to the DLR Institute of Composite Structures and Adaptive Systems and DLR Flight Experiments in Braunschweig.

COLOGNE: The former head of the Department of Radiation Biology and deputy head of the DLR Institute of Aerospace Medicine, Gerda Horneck, was awarded the William Nordberg Medal by COSPAR (Committee on Space Research) for her pioneering work in the field of astrobiology, radiation and biology. Since 2018, the International Astronomical Union has named a minor planet after all COSPAR awardees.

JENA: The DLR_School_Lab Jena opened in September. Here, children and young people can experiment on topics related to spaceflight and digitalisation and discover exciting career opportunities. In terms of content, the lab is primarily oriented towards the research activities of the DLR Institute of Data Science.

JÜLICH: At DLR's solar tower in Jülich, the company Synhelion has successfully tested a solar thermal process for the production of synthesis gas on a larger scale for the first time. Liquid fuel can then be produced from synthesis gas. This is climate-neutral and thus a promising technological approach for achieving climate protection goals in the mobility sector.

OLDENBURG: DLR, OFFIS and the University of Oldenburg are jointly building an innovation quarter on the site around Escherweg, Fritz-Bock- and Industriestrasse. The goal is joint research in the IT sector for the fields of production and the energy industry, health and care, mobility of the future as well as the environment and sustainability. The building provides urgently needed space and, above all, laboratories for transport research at the DLR Institute of Systems Engineering for Future Mobility.

DLR.DE/EN
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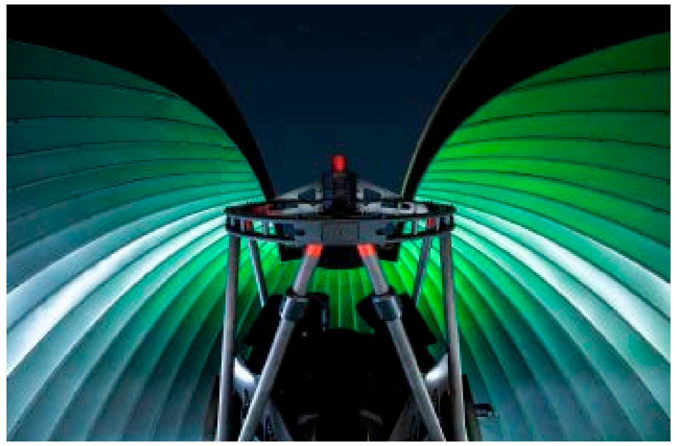
All articles can be viewed online in the news archive with images or videos.

DLR.de/news

QUICK AND PRECISE DETECTION OF SPACE DEBRIS

The inauguration of DLR's Johannes Kepler Observatory was celebrated at its location on the Empfingen innovation campus on 20 June 2022. The unique research and development station houses the largest telescope of its kind in Europe and will contribute significantly to the safe use of space. Using state-of-the-art laser technology, it can determine the trajectory and composition of objects 10 centimetres across in Low-Earth Orbit. Named after the pioneering German astronomer Johannes Kepler, the observatory will help protect active satellites from dangerous collisions by enabling evasive manoeuvres to be planned more efficiently and detecting previously unknown orbital objects. To do this, DLR researchers carry out spectral analyses – they examine the colour composition of the sunlight scattered by the observed objects. This allows for conclusions to be drawn, for example about the type of object, its composition, size, rotation and orbit.



The telescope of the Johannes Kepler Observatory is housed in an almost 15-metre-tall round tower with a rotating dome

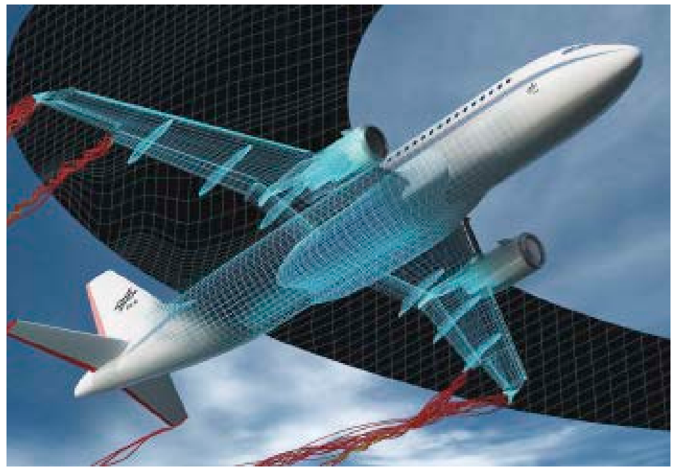
HALO on the approach to Edmonton Airport

HALO ANALYSES GREENHOUSE GASES OVER CANADA

Flying low over a river delta and then high into the north. As part of the CoMet 2.0 Arctic mission the German HALO research aircraft flew over Canada. The Hudson Bay Lowlands are the second largest wetlands in the northern hemisphere. Their exact methane emissions are one of the great unknowns in the struggle for more precise climate forecasting. HALO's long range is crucial for performing such flights. Using the aircraft and its capabilities, researchers are investigating the greenhouse gas emissions of individual sources and how natural and anthropogenic sources can be analysed more distinctively. Innovative instruments are being tested as part of the mission. This includes the CHARM-F lidar measuring device developed at DLR. It enables the measurement of methane and carbon dioxide independently of sunlight, from a great distance and with a high degree of accuracy. The aircraft also carries the MAMAP2DL imaging spectrometer from the University of Bremen, which records methane and carbon dioxide from local sources. The research flights will also help to better calibrate data from already active satellite missions such as Sentinel-5P and EnMAP.

DESIGN, PRODUCTION, TESTING – LINKED TOGETHER DIGITALLY

DLR's Virtual Product House (VPH) initial project for the digitalised development of control surfaces for future aircraft wings has been successfully completed. For the first time, design, production and test phases have been fully linked together digitally, using the example of a wing flap. Now that the VPH process has been successfully implemented in the initial project, wing and flap concepts can be designed more efficiently through advanced simulations of production and testing. This in turn will help develop climate-friendly aircraft faster. Possible complications and shortcomings in later development phases can be anticipated early on and avoided by altering the design. The simulation-based test procedures are also intended to replace some of the physical tests. This is an important step towards 'digital twins' – fully functional, digital representations of real aircraft components – which will be one of the focal points of the follow-up project VPH2.0 already underway.



Vision of the 'virtual product' as a guiding concept at DLR and for digitalised product development

CELEBRATING 15 YEARS OF TERRASAR-X

83,050 orbits around Earth – TerraSAR-X offers an impressive collection of data after 15 years in space. The DLR satellite was originally designed to operate for five years. Thanks to its robust design, however, the impressive piece of technology remains in perfect shape and continues to provide researchers worldwide with insights into the changes happening on Earth. Since its launch from Baikonur in 2007, the satellite has collected over 400,000 radar images and 1.34 petabytes of outstanding Earth observation data – regardless of weather conditions, cloud cover or daylight. Not only does the range of TerraSAR-X applications encompass the full spectrum of geosciences, including geology, glaciology, oceanography, meteorology and hydrology, but the radar data are also essential for environmental research, land use mapping, vegetation monitoring, and urban and infrastructure planning. In addition, cartography, navigation, logistics, crisis management and defence and security also rely on TerraSAR-X data.

The TerraSAR-X and TanDEM-X satellites in formation flight

The NGT FuN research infrastructure

A SMART CHASSIS FOR THE TRAIN OF THE FUTURE

DLR is working on a new design as part of its Next Generation Train (NGT) concept. The wheels are driven individually and controlled with smart technology, meaning each wheel has its own control computer within the car body and its own sensor system. This approach offers significant and wide-ranging advantages as it could reduce noise pollution by making the train quieter as well as reducing the wear and tear on wheels and rails. The structures and materials used in this high-tech chassis have also been optimised to lower the weight, which in turn lowers the energy consumption and allows for larger load capacities. It also opens up new possibilities regarding the construction and design of the interior of the train. The concept has already shown promise in simulations and experiments with a 1:5 scale model of the NGT chassis. DLR researchers are now building a full-scale functional model and test stand.

SEARCHING FOR LIFE ON MARS

The search for fossil or living organisms on other celestial bodies is one of the great driving forces of current planetary research. Life has only been found on Earth so far, but it is conceivable that it once developed on Mars, or perhaps even exists there today. The BIOMEX experiment investigated whether the biological compounds that are important components of terrestrial organisms can withstand extreme environmental conditions. The 469-day long-term experiment, led by DLR, was conducted with biomolecules on the exterior of the International Space Station ISS. The station offered ideal conditions much more similar to the situation on the surface of Mars. This stress test in space revealed that the biomolecules would survive almost unchanged in Martian soil and that they could be identified using Raman spectroscopy on Mars. The experiment therefore is essential in the current and future search for biosignatures.

ESA/Roskosmos

EXPOSE-R2 experiment platform on the ISS

AWAKENING THE SLEEPING GIANT

DLR conducts research for the heat transition

by Denise Nüssle

The Test Facility for Thermal Energy Storage in Molten Salt (TESIS) of the DLR Institute of Engineering Thermodynamics in Cologne is the first facility for molten salt storage and technology research on this scale in Germany. Here, industry can test components for molten salt storage under real operating conditions.

In public discussions about the energy transition, the field of sustainable heat use has long been in the shadows. The focus has been on electricity from renewable energy sources, and how best to generate and distribute it in large quantities. For those outside a relatively closed circle of house builders and renovators dealing directly with heating technology, building insulation and heat pumps, the 'heat transition' has passed largely unnoticed – until now.

Due to the current uncertainty of supply, especially of natural gas, citizens, politicians and businesses must face the question of how industrial processes, which often require a great deal of heat, can be kept running. The same dilemma looms over heating for public and private buildings. Meanwhile, the political and social consensus to put a stop to global climate change demands a new look at our heat supply, with a view to adopting more sustainable and sometimes completely new technological solutions. Fortunately, DLR has its finger on Germany's heat pulse with its energy systems analysis. Together with partners from science and industry, DLR is researching innovative technologies for climate-friendly heat from renewable energy sources and also supporting spin-off projects.

A look at the numbers – the energy giant we call heat

More than half of the energy consumed in Germany is used to provide heating and cooling – including process heat for industrial processes. Forty percent of energy-related carbon dioxide emissions are generated in this context. Heating and hot water in private households also have an enormous impact, being responsible for around 80 percent of energy consumption. In view of recently rising gas prices, the financial burden has grown enormously.

"Compared to the 'energy transition', however, attention to the 'heat transition' has been rather modest until now," says Evelyn Sperber from the DLR Institute of Networked Energy Systems. She works in the Energy System Analysis department and researches the interactions between the heat supply of buildings and the electricity supply of the future. The share of heat provided by renewable energies is around 15 percent. The lion's share comes from biomass, with wood being the principal energy source. However, biomass is only available in limited quantities, is not necessarily climate-neutral and its cultivation can compete with food production. Buildings of all kinds are still primarily heated with fossil fuels – natural gas or oil – often using outdated systems. "If we succeed in intelligently linking technologies for climate-friendly heat supply with the electricity sector, with its heavy use of wind and photovoltaics, the heat transition could make an immense contribution to the energy transition as a whole," says Sperber, looking to the future.

A small drone surveys buildings in terms of their geometric, physical, energetic and functional properties.

"If we succeed in intelligently linking technologies for climate-friendly heat supply with the electricity sector, with its heavy use of wind and photovoltaics, the heat transition could make an immense contribution to the energy transition as a whole."

Evelyn Sperber

Energy-efficient building renovation – DLR expertise for analysis and evaluation

In Germany, the building of new housing is not matched by the demolition of old structures. Thus, even if new buildings emitted no carbon dioxide whatsoever, net emissions would not be reduced significantly, with the result that legally-mandated climate targets cannot be achieved. Refurbishing old buildings to improve their energy efficiency is therefore a critical strategy, but in Germany such refurbishment proceeds too slowly and is not sufficiently extensive. Owners and investors shy away from the costs and risks associated with comprehensive renovation, which are often difficult to predict. Quality assurance is difficult because objective testing technologies are lacking or are expensive and time-consuming.

To break these barriers to transformation, DLR is working with an interdisciplinary team on a range of new technologies. In the future, they should allow buildings and districts to be analysed and evaluated objectively, quickly and cost-effectively. "We want to create a precise knowledge base for planning and construction companies, owners and investors. They will be able to call upon this base to derive sensible energy- and cost-efficient refurbishment measures, and also check them qualitatively after completion," says Bernhard Hoffschmidt, who heads the DLR Institute of Solar Research and has successfully initiated, supported and managed several spin-off projects.

Researchers at the DLR Institute of Networked Energy Systems are developing models for coupling the heat and power sectors

DLR's Integrated Positioning System (IPS DLR OS), here carried by Boston Dynamics robotic dog SPOT, measures the interior building and room geometry.

The jump from research on solar thermal power plants to the analysis of buildings is not as great as one might think. Hoffschmidt and his colleagues have developed a measuring system mounted on a small drone that monitors the status of the often gigantic heliostat fields of solar-thermal power plants. Similar approaches can be used in the future to analyse and evaluate buildings and entire city districts. "At DLR, we already have most of the knowledge, technologies and experience in place," he says.

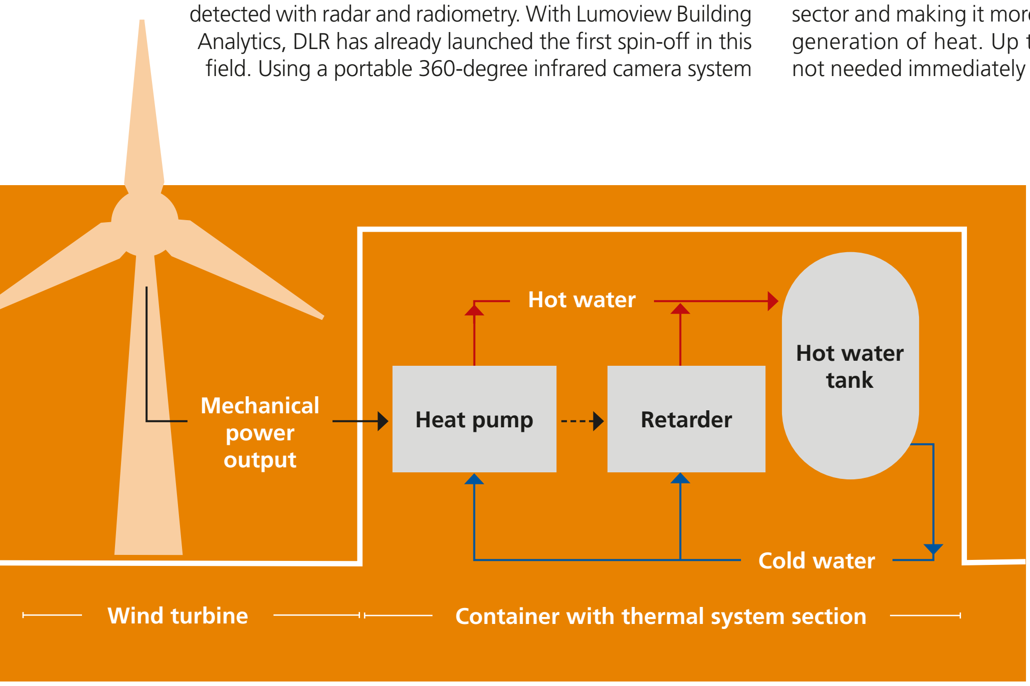
For example, analysis methods from the fields of Earth observation, security and energy research already use sensors that automatically take measurements aboard satellites, aircraft or drones. Many of these sensors could be adapted for use in the building sector. DLR researchers are also testing a special camera system which rides on board a robot dog, from where it can determine the inner geometry of rooms or entire buildings using 3D scans – and can also detect gaps and holes. Hidden wall structures such as cavities, conduits and shafts can be detected with radar and radiometry. With Lumoview Building Analytics, DLR has already launched the first spin-off in this field. Using a portable 360-degree infrared camera system and special software, the spin-off creates three-dimensional building models. These images show thermal properties at a glance, identifying the places where external walls lose the most heat and finding damp spots. The operation can be completed in just minutes, easily and with little training

Heat for neighbourhoods, business and industry – a networked approach

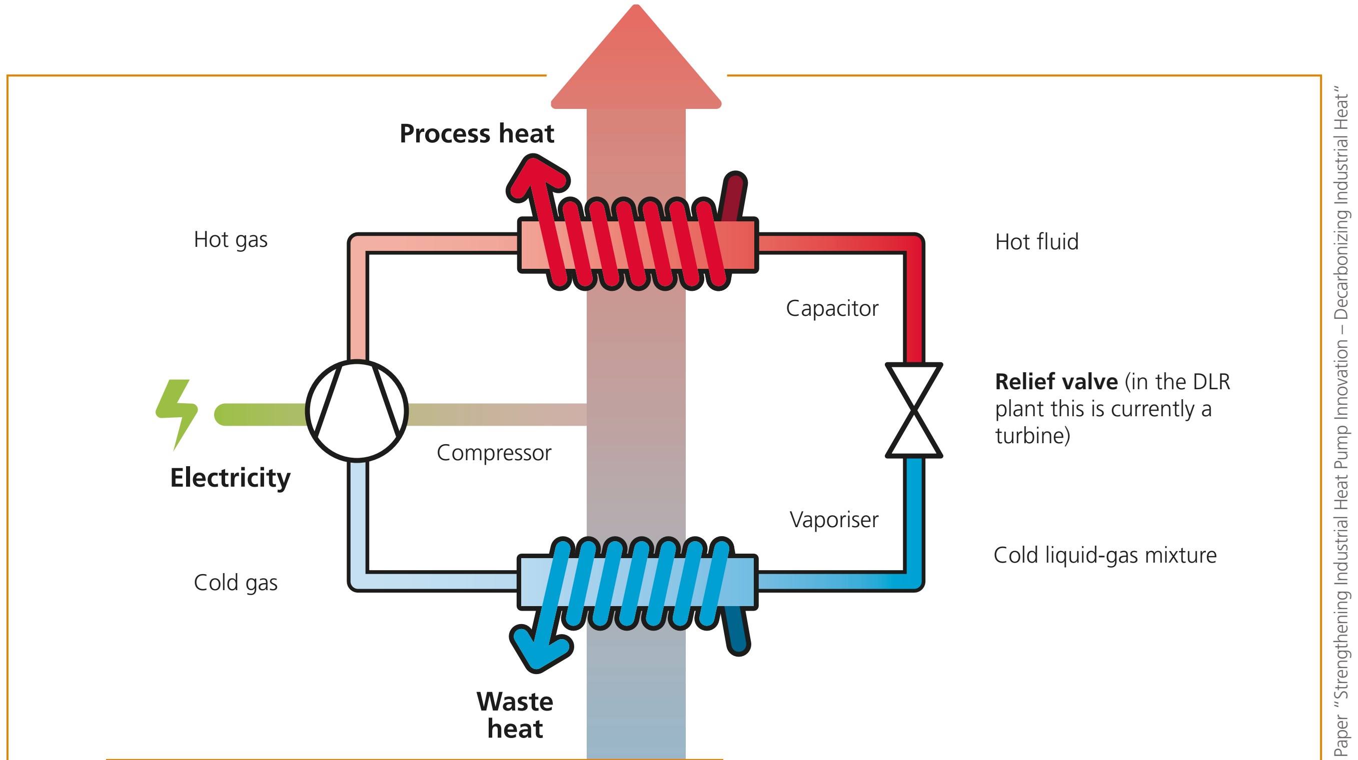
For the energy transition to be successful, the heating sector needs to be thought of in a more networked manner, with existing resources better and more flexibly managed – at all levels and across sectors. This means looking at individual buildings in the context of their surroundings, and coupling air conditioning systems to electricity from photovoltaic panels and thermal collectors. Waste heat from industry and commerce must be used as efficiently as possible, on-site where it is available, while thermal insulation and the expansion of heating networks must be better coordinated. The fields of electricity, heat, industry and mobility will be much more closely linked in the future. In the Wärmewende Nordwest (Northwest Heat Transition) research project, scientists from the DLR Institute of Networked Energy Systems and its partners are investigating the heat transition in the Oldenburg and Bremen regions. The aim is to record and optimise the heating requirements of buildings, neighbourhoods, business and industry in a transparent manner. To this end, the researchers are further developing an existing simulation model to add depictions of heat flows and the different components of the heating network alongside electricity flows.

Heating and energy storage – generating heat directly from wind

Wind energy is one of the main pillars of the energy transition. It already accounts for around 20 percent of electricity generation. But heat can also be generated directly from wind – without carbon dioxide emissions and therefore in an environment-friendly manner, relatively easily and inexpensively. Under the heading of 'wind thermal energy' the DLR Institutes of Flight Systems, Engineering Thermodynamics and Networked Energy Systems are researching this previously little-known technology to assess its economic potential and identify possible uses. A first test facility already exists. It consists of a small wind turbine and all the components necessary for heat generation, all packed inside a standard shipping container to be compact and transportable. "Wind thermal energy is one approach to decarbonising the heating sector and making it more flexible. The decisive advantage is the direct generation of heat. Up to now, electricity from wind energy that is not needed immediately has been used to generate heat and store it.



DLR's wind thermal energy facility in Celle



HOW DOES A HEAT PUMP WORK?

Heat pumps transport heat from a place with a low temperature to a place with a higher temperature and vice versa. This usually takes place in a closed system in which a heat transfer medium flows. Pumping heat from cold to hot requires energy in the form of electricity – and the greater the difference between the temperature levels, the more energy is needed. A well-known example is the refrigerator, where a heat pump transports the heat from the interior to the exterior.

This involves an extra step and correspondingly high losses in the conversion from kinetic energy into electricity and then to heat," describes project manager Malte Neumeier of the Institute of Flight Systems. The DLR researchers see potential uses for wind thermal energy wherever heat is required at low and medium temperatures, up to around 300 degrees Celsius. This temperature range covers local and district heating for buildings and many industrial processes.

XXL heat pump – sustainable heat for industrial processes

Heat pumps are used to cool or heat. These processes require energy in the form of electricity. "Heat pumps are becoming an increasingly interesting technological component for both private households and for industry. They provide a solution to electrifying the heating sector and thus avoiding emissions – provided that the electricity used comes from renewable energy sources," explains Panagiotis Stathopoulos of the DLR Institute of Low-Carbon Industrial Processes. "This is because heat pumps produce several times as much heat per unit of electricity consumed. This is significantly more efficient than electric heaters or burning green hydrogen. However, heat pumps are complex systems with high installation costs."

DLR's research work is primarily focussed on high-temperature heat pumps. These are intended to provide sustainable heat for industrial processes up to 300 degrees Celsius, for example for drying or steam generation. More than 80 percent of emissions from the industrial sector come from burning fossil fuels to generate process heat. "This technology has the potential to

This prototype of a special high-temperature heat pump called CoBra is located at the DLR Institute of Low-Carbon Industrial Processes in Cottbus. The system can provide heating and cooling for industrial processes on a demonstration scale.

Panagiotis Stathopoulos from the DLR Institute of Low-Carbon Industrial Processes at the CoBra plant.

The DLR Institute of Networked Energy Systems is researching the 'H2-ready technology' to heat buildings. In the long term, hydrogen from renewable energy sources could also be used directly in fuel cell cogeneration plants.

save a quarter of all industrial carbon dioxide emissions. Currently available heat pumps can provide heat up to a maximum of 150 degrees Celsius. With our development work we are closing the technological gap and, above all, developing the components and cycle processes required for this," says Stathopoulos. The scientists hope to use special heat pumps to boost the temperature of existing waste heat at the highest possible temperature.

"This technology has the potential to save a quarter of all industrial carbon dioxide emissions."

Panagiotis Stathopoulos

To this end, one-of-a-kind pilot plants are being built at the DLR sites in Cottbus and Zittau. The 'CoBra' prototype was inaugurated in the summer of 2022 and works with dried air as a heat transfer medium. The name CoBra comes from Cottbus, the location of the plant, and the Brayton thermodynamic process, which describes the basic principle of the facility. Here, the researchers want to demonstrate the basic principle of heat pumps in the high-temperature range. New compression systems that can withstand relatively high temperatures and do not require expensive materials, as well as compact, efficient and inexpensive heat exchangers are the next development goals. The second pilot plant is scheduled to go into operation in Zittau next year. This plant works with the Rankine Cycle, in which water is the working fluid – unlike the Brayton Cycle, which works with air. The operating strategy – that is, the right temperature and pressure at the right time – is central in this process to increase heat very efficiently to a higher temperature level.

© DLR

DO WE HAVE A HEAT PROBLEM?

Three questions for Christian Sattler, Divisional Board Member for Energy and Transport at DLR and Director of the DLR Institute of Future Fuels

Why has heat been out of the spotlight for so long? Do we have a heat problem?

: No, we don't have a heat problem, but we do have a demand for heat, both for heating buildings and for industrial processes. The problem lies in carbon dioxide emissions – heat is primarily generated by burning fossil fuels. Another aspect is security of supply.

How can research and technology help?

: For example, by developing efficient energy conversion processes and storage systems to provide renewable energy as heat whenever it is needed.

Could Germany or indeed Europe become self-sufficient in heat?

: It is possible, but that might not be the best solution. Unlike electricity or fuel, heat cannot be transported over any distance, and the use of renewable energy sources to generate heat requires a lot of space. Sector coupling is therefore a necessary principle, especially in conurbations, where residues and stored energy can be used in addition to electricity and waste heat. This could be sourced from other regions where more renewable energy is available per unit area, which can therefore be stored more efficiently.

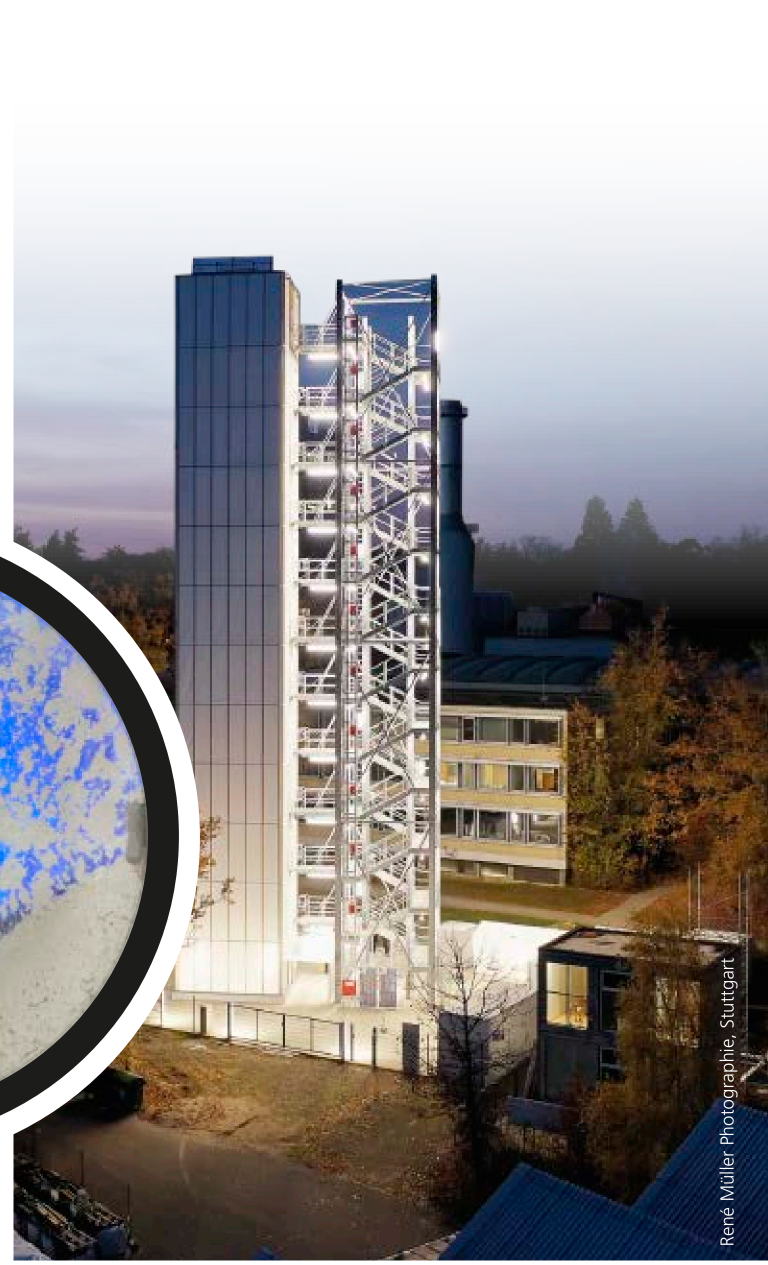
Heating with lime – the art (and science) of heat storage

The use of electricity from renewable energy sources for heating alongside the electrification of heat generation offers the opportunity to decarbonise the heating sector and thus massively reduce its carbon dioxide emissions. However, since the availability of renewable electricity is dependent on the weather and the season, energy systems of the future will also need heat storage. At the DLR Institute of Engineering Thermodynamics, teams are developing innovative storage solutions based on different materials for a temperature range of 100 to 1000 degrees Celsius, with storage periods of up to several months. A wide variety of storage media are used, from liquids such as molten salt and thermal oil to compressed air and solids such as cement, ceramic particles and lime.

The lime powder is heated in the reactor. The mixing tool supports the thermochemical reaction.

A team led by Marc Linder and Matthias Schmidt has been working successfully for several years on climate-neutral ways to heat buildings with a heat storage system using quicklime: The DLR researchers are currently testing a pilot facility together with the University of Stuttgart and are using this technology for the first time and on a larger scale outside of the laboratory. Lime storage tanks use the chemical reaction of quicklime and water to generate heat. They first heat lime powder,

Various lime samples



René Müller Photographie, Stuttgart

From 2023, the thermochemical lime storage system will be tested under real conditions in the world's first adaptive high-rise, which opened in Stuttgart at the end of 2021.

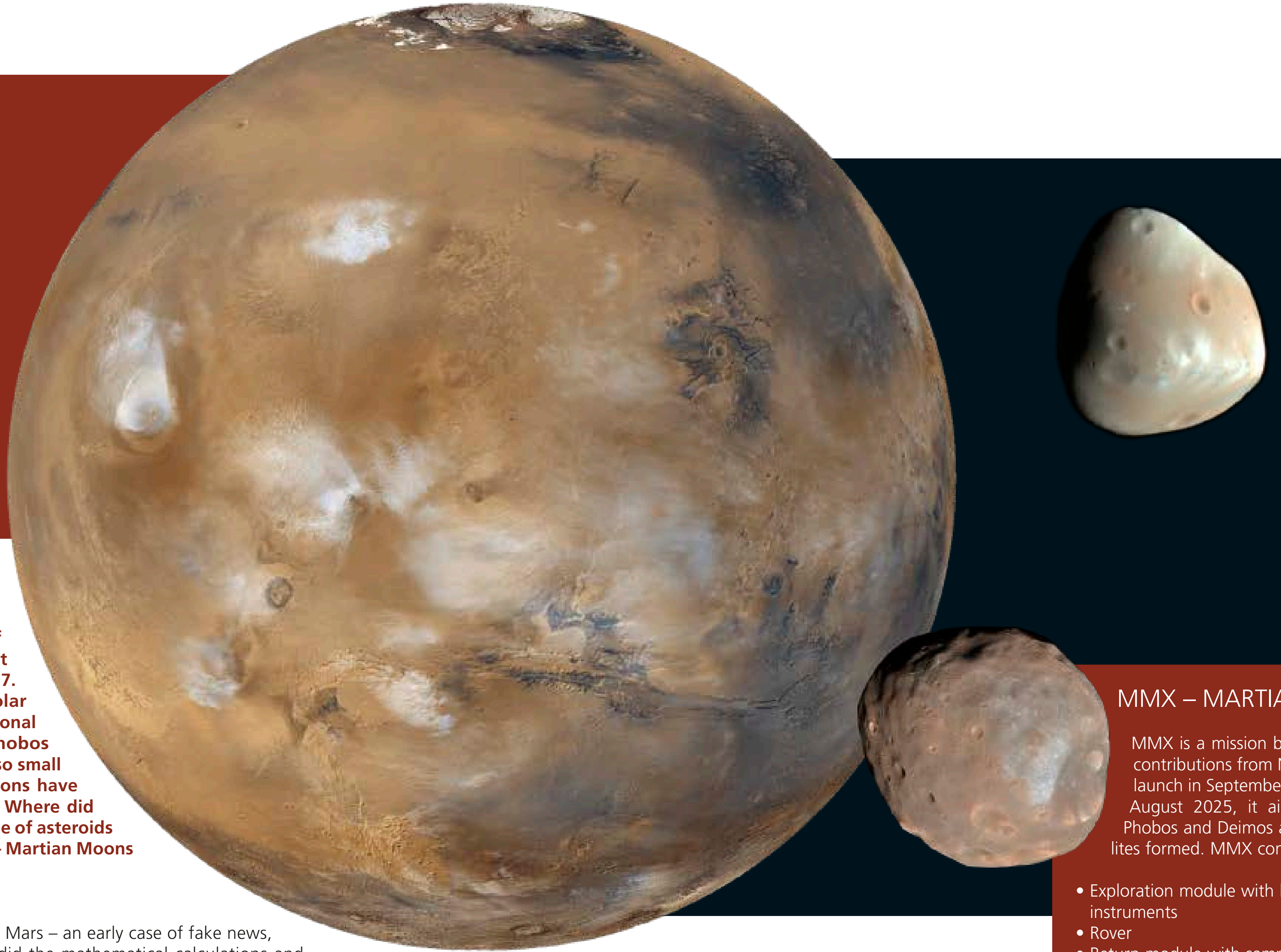
called slaked lime, in a furnace to over 450 degrees Celsius using energy from renewable energy sources. The water bound in the lime escapes and quicklime is produced. This can be stored relatively easily and for months without loss. When heat is required, water is added to the quick lime. The two substances react and slaked lime is produced again alongside a temperature of over 100 degrees Celsius. "The heating output can be regulated by the quantities of lime and water introduced," explains Schmidt. "If the slaked lime is burned again, it can be reused to store energy. This process can be repeated as often as desired." With this principle, renewable energy can be stored in summer and used for heating in winter. With the operation of the pilot plant, the researchers want to gain important insights into how such a heating system can best be controlled and thus get closer to its practical application. Lime storage tanks would be particularly interesting for private households because lime is inexpensive and available in large quantities. Entire residential areas could also be supplied in this way – so perhaps in the near future a tanker will no longer bring oil for heating, but a container full of lime.

Denise Nüssle is an editor at DLR's Media Relations department.

ON NO MOON'S LAND

The Martian Moons eXploration mission aims to solve the mystery of how the Red Planet's moons formed

by Ulrich Köhler



Mars with its two moons, Deimos (above) and Phobos.

NASA/JPL-Caltech/MSSS/University of Arizona/Photomontage: DLR

In Roman mythology, Fear and Terror were the frightening companions of Mars, the god of war. This is powerful imagery. In Homer's Iliad, Phobos and Deimos were two brothers who belonged to the entourage of the Greek god of war, Ares. These names were given to the moons of our neighbouring planet when they were discovered by the US-American astronomer Asaph Hall in 1877. Apart from Earth's Moon, they are the only two satellites in the inner Solar System. They are much smaller than the Moon, and due to the low gravitational forces, they are irregular in shape rather than spherical. At its largest, Phobos measures almost 27 kilometres across and Deimos just 15 kilometres. They are so small that telescopes on Earth cannot make out any details of them, but both moons have been observed from up close by Mars probes. This leaves one big question: Where did these diminutive moons come from? Their spectral properties are similar to those of asteroids and hardly like those of Mars. A very special mission could provide the answer – Martian Moons eXploration mission, or MMX.

The history of the discovery of the moons reads like an astronomical thriller. Asaph Hall, born in 1829, took his first post at the Harvard Observatory, where he earned a meagre three dollars a week. He later picked up some more work at the US Naval Observatory in Washington DC. As far as Hall was concerned, the textbooks were correct in stating that Mars had no moons. However, he became sceptical when his mass calculations for Mars, derived from the orbital disturbances of Earth and Jupiter, did not make sense. He began to doubt Mars' moonless status and planned some observations for August 1877, when the Red Planet would be at opposition just 56 million kilometres from Earth.

Persistence pays off

Hall was worried that his colleague and rival, Henry D Holden, would use the large refractor, the Great Equatorial Telescope, on the best nights for observation during autumn 1877, but fortunately his fears proved unfounded. There came a point when Hall was tempted to abandon his search due to poor atmospheric conditions, but his wife Angeline encouraged him to keep looking. And it paid off! On the night of 12 August 1877, Hall noted a faint 'star' near Mars, before it clouded over again. On 16 August he spotted the point of light again, travelling with Mars. He had discovered Deimos. Two days later, he found Phobos. Simon Newcomb, the director of the observatory, brazenly claimed the discovery as his own in the New York Times of 20 August. Henry Holden even claimed to have discovered three more moons orbiting Mars – an early case of fake news, perhaps? Hall did the mathematical calculations and found that these new moons violated Kepler's orbital laws and were repeated observations of Phobos and Deimos. Ultimately, Hall emerged with an impeccable reputation in professional circles for the accuracy of his calculations.

Moons for a limited time only

Phobos orbits Mars in just over 7.5 hours, about 6000 kilometres above its surface. This means that the satellite is rotating faster than the planet, which takes 24.5 hours. In other words, a potential Martian would see Phobos rise in the west and set in the east. No other moons in the Solar System orbit their planet from such a close range. Deimos orbits Mars at an altitude of 23,500 kilometres and has an orbital period of 30 hours.

Measurements by spacecraft and repeated observations by DLR's High Resolution Stereo Camera (HRSC) on the European Space Agency (ESA) Mars Express orbiter have shown that Mars is exerting tidal forces on the two small celestial bodies, altering their orbits. Deimos is moving away from Mars and is likely to be lost to the planet in the distant future – a fate it shares with Earth's Moon. Meanwhile, Phobos is gradually spiralling in towards Mars and is likely to break up when it reaches a proximity of 5500 kilometres – known as the Roche limit – as the tidal forces will be greater than the moon's force of internal cohesion. This is expected to happen in about 40 million years. When this occurs, the rock debris will give Mars a temporary ring.

NASA's Mariner 9 probe sent the first close-up images of the moons back to Earth in 1972. The two US Viking orbiters followed from 1976 to 1980. Then came photos and measurements from NASA's Mars Global Surveyor, Mars Reconnaissance Orbiter, 2001 Mars Odyssey and ESA's Mars Express orbiter. The former USSR and Russia also launched three missions exclusively to study the Martian moons: Phobos 1 and 2 in the late 1980s, which lost radio contact after the transmission of a small amount of data; and the Phobos Grunt mission, which was lost shortly after its launch in 2011. Despite having been photographed, measured and characterised to a limited extent in terms of their geological, mineralogical and geochemical properties, Phobos and Deimos continue to be uncharted territory for planetary research.

MMX – MARTIAN MOONS EXPLORATION

MMX is a mission by the Japanese space agency JAXA, with contributions from NASA, ESA, CNES and DLR. Scheduled for launch in September 2024, and an expected arrival at Mars in August 2025, it aims to characterise the Martian moons Phobos and Deimos and clarify how and where the two satellites formed. MMX consists of the following:

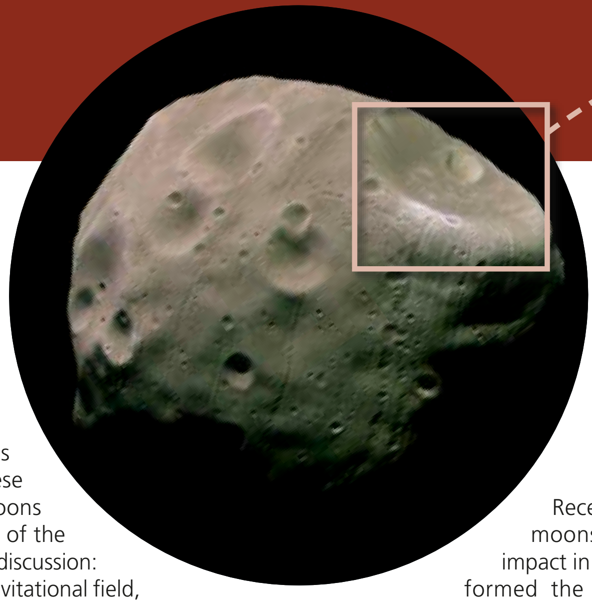
- Exploration module with landing legs and sampler with eight instruments
- Rover
- Return module with sample recovery capsule and three instruments
- Propulsion module with fuel tanks and thrusters for Mars orbit insertion

The rover was developed in a joint project by CNES and DLR. It weighs almost 25 kilograms, including four kilograms of components on the mother craft. For DLR, the institutes of Space Systems, of Composite Structures and Adaptive Systems, of System Dynamics and Control, of Optical Sensor Systems, of Planetary Research and the Microgravity User Support Center (MUSC) are also involved under the leadership of the DLR Institute of Robotics and Mechatronics.

The goal is to study the geological, physical and mineralogical properties of Phobos' surface and demonstrate low-gravity mobility. The data will also be used to calibrate the orbiter measurements and will support the landing of the exploration module. Data exchange with Earth will take place via the orbiter. The rover's operations will be controlled from the control centres of CNES in Toulouse and at DLR's Microgravity User Support Center (MUSC) in Cologne. It has:

- Stereo camera (NavCAM)
- Wheel cameras on the chassis (WheelCAM)
- Radiometer (minRAD)
- Raman spectrometer (RAX)

Since the first detailed images of Phobos, the less-than-30-kilometre-across martian moon has been a mystery of planetary research. Its formation is as mysterious as the origin of the linear grooves on its surface.



NASA/JPL-Caltech/MSSS/ University of Arizona

Captured or ejected?

Two big questions remain: how did the two moons form, and what are they made of? Both bodies are extremely dark, reflecting only five percent of the sunlight that reaches them – almost like charcoal. Mars, on the other hand, reflects about four times as much on average. Given these facts, it is hard to see how the planet and its moons could share a common origin, but this is still one of the theories. Essentially, there are three theories under discussion: that the moons are asteroids captured by Mars' gravitational field, that they were formed as a result of a massive impact on the planet, or that they formed at the same time as the Red Planet.

The 'capture theory' is supported by the fact that the colour spectrum of both moons resembles that of D-type asteroids: like these celestial bodies, the moons are dark and homogeneously reddish, low in water and rich in carbonaceous and siliceous molecules. Such asteroid moons could have come from beyond the orbit of Neptune. However, this hypothesis is contradicted by the fact that both moons orbit Mars near the ecliptic plane on which all planets and most of their moons move around the Sun. In addition, both orbits are almost circular. Such a coincidence would be difficult to account for under the 'captured asteroids' theory. The orbital parameters lend weight to the third theory, although this is contradicted by the fact that the specific density of the moons, at 1.87 grams per cubic centimetre, is not even half that of Mars.

Recent research suggests that the moons are remnants of a major impact in Mars' early history, which also formed the planet's extensive northern lowlands. The impacting body could have been as large as 2000 kilometres across and knocked out trillions of tonnes of light crust and dark mantle from the young planet. The debris would have formed a ring around Mars, 'giving birth' to Phobos and Deimos, and perhaps even more moons that were either lost or re-impacted on Mars. This theory explains the relatively low and barely elliptical orbits quite well.

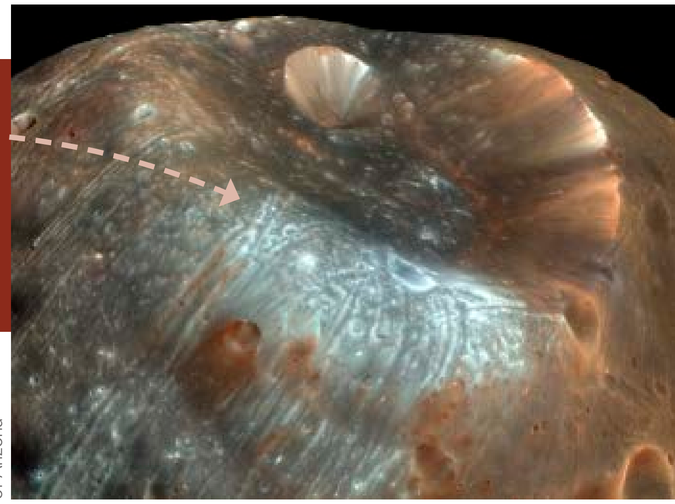
Investigating on site takes the cake

Only a spacecraft can help to clarify the origin of Phobos and Deimos, and help us understand the role of small celestial bodies in the development of the planets. This is the purpose of the MMX mission by the Japanese Aerospace Exploration Agency (JAXA). It will be the third JAXA mission to collect samples and bring them to Earth, following the two Hayabusa missions to the asteroid belt. NASA, ESA, the French space agency CNES and DLR are also involved in the mission.

We can look forward to exciting events from 2025 onwards, when the spacecraft observes Phobos and Deimos from orbit. Scientists are currently searching for a suitable landing site for the mothercraft and the small MMX rover. The rover is being developed jointly by CNES and DLR. The Institute of Robotics and Mechatronics in Oberpfaffenhofen is leading the project on behalf of DLR. The vehicle, weighing 25 kilograms, will be dropped gently onto the surface of Phobos from a height of around 50 metres. On Phobos, the gravitational pull is one two-thousandth of that on Earth, so the rover will come to rest after bouncing several times. It will then autonomously manoeuvre itself into an upright, ready-to-launch position. The rover will move around Phobos and explore it with instruments including a radiometer and a Raman spectrometer, in the development of which DLR is playing a major role. A little later, it will take samples that are scheduled to reach Earth in 2029. Regardless of how Phobos and Deimos formed, it is likely that later impacts from Mars also ejected material at Phobos. In any case, the samples from this moon will also contain traces of the planet, which will make MMX the first mission to bring Mars samples to Earth.

CNES

Back to Mars, this time to its moon Phobos with the MMX rover.



NASA/JPL/University of Arizona

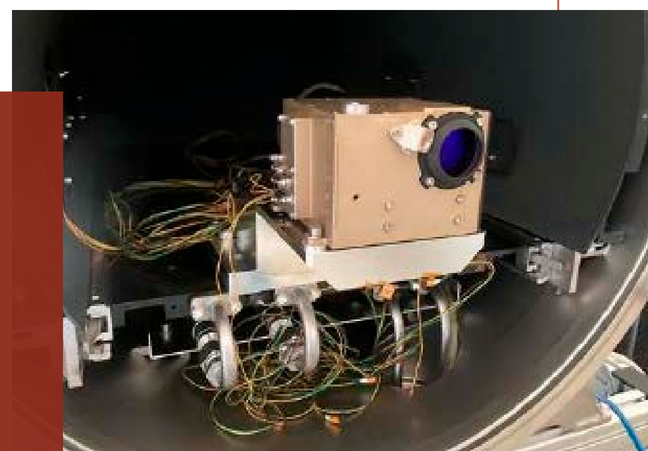
Stickney crater is the most prominent structure on the Martian moon Phobos. It was named after Chloe Angeline Stickney Hall, the wife of the moon's discoverer Asaph Hall.

Phobos' most striking surface structure is a nine-kilometre-wide impact crater that almost destroyed the moon when it formed. It was first photographed by Mariner 9 in 1972 and given the name Stickney by the Naming Committee of the International Astronomical Union as a tribute to Asaph Hall's resolute wife, Chloe Angeline Stickney Hall, who persuaded her husband to continue with his work. Stickney was her maiden name. In 1878, Asaph Hall wrote, "I would have given up searching for the moons of Mars had my wife not encouraged me to keep looking." What a story!

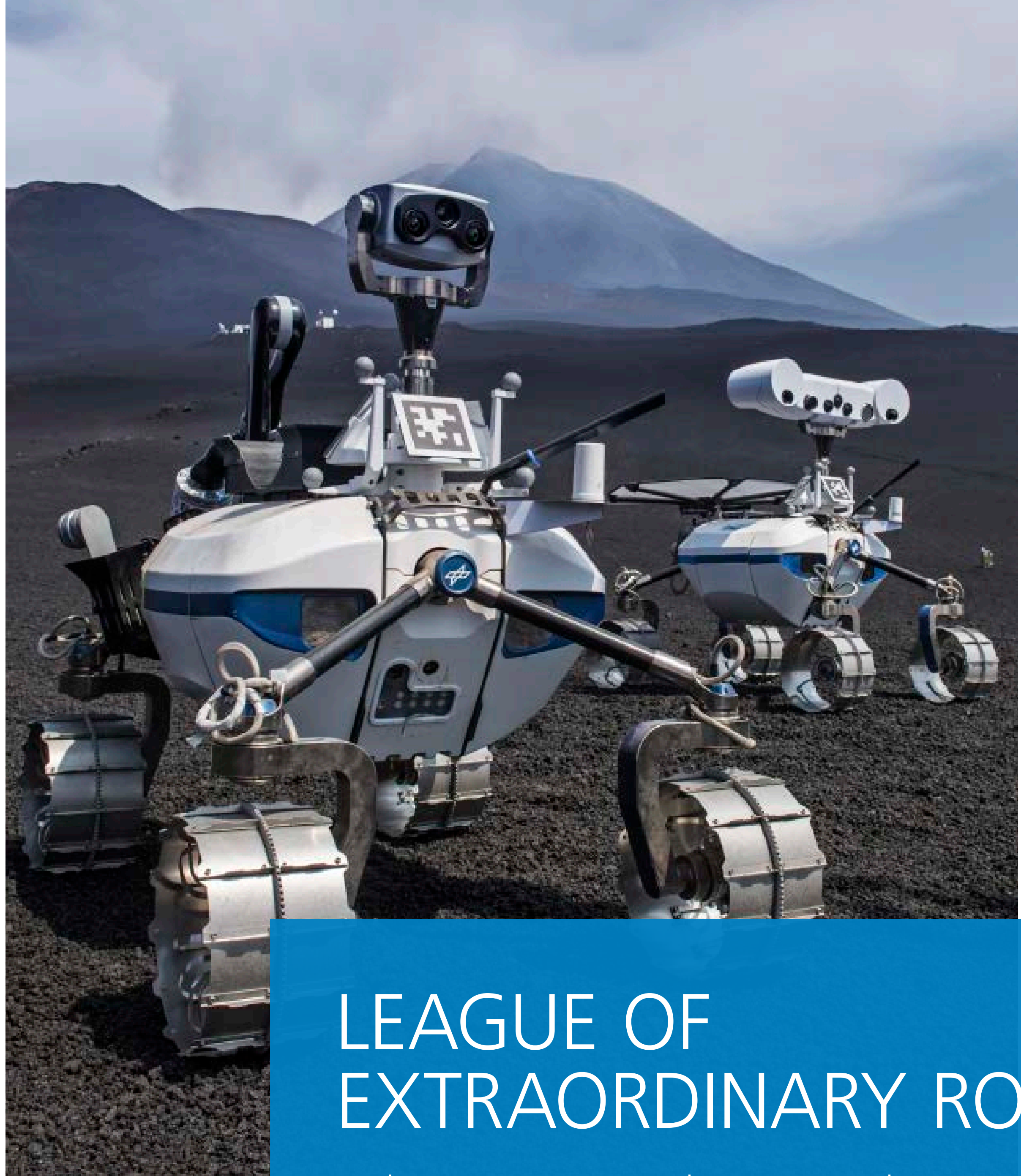
Ulrich Köhler is a geologist at the DLR Institute of Planetary Research and has been fascinated by Mars and its two moons since he first got his hands on the iconic yellow National Geographic magazines in the 1970s, featuring photos from the US Viking missions to Mars.

More information about the MMX mission will follow in the next edition of the DLRmagazine. Stay tuned!

The miniRAD radiometer from the DLR Institute of Planetary Research will measure surface radiation at six thermal infrared wavelengths. This gauges the surface temperature, which depends heavily on the thermal properties of the surface materials, in addition to the irradiation conditions. Measuring the radiation makes it possible to draw conclusions about the material properties. The thermal properties also give an indication of the porosity, enabling direct comparison between measurements for asteroids and comets, as well as asteroid and meteorite samples.



The Raman spectrometer RAX (RAman spectroscopy for MMX) was developed by the DLR Institute of Optical Sensor Systems, JAXA (under the leadership of the University of Tokyo), and Spain's National Institute of Aerospace Technology (INTA). RAX will characterise the mineralogical composition along the rover's path to help us understand the processes that Phobos could have undergone. The Raman measurements on Phobos will be compared with measurements taken by other rovers on Mars to evaluate the different formation hypotheses. Comparison with the measurements from the samples returned to Earth by MMX will show how representative the samples are.



Scientist and assistant: LRU1 (Lightweight Rover Unit 1, right) and LRU2 during their joint mission on Mount Etna in Sicily.

LEAGUE OF EXTRAORDINARY ROBOTS

Today Etna, tomorrow the Moon – robots explore together

by Katja Lenz

The scientist, the assistant, the pathfinder, the supplier, the cave explorer – the roles are clear. LRU1, LRU2, Ardea, Rodin and Scout share the common goal of exploring uncharted territory. They all do what they are best at, and they always work as a team. The robots and the lander have now practised doing just that in one of the least hospitable places in Europe – Mount Etna.

Blackened soil, porous lava rocks that crunch with every step and smoke that rises in the distance. This volcano, on the Italian island Sicily, has been active almost continuously for 60,000 years. On its southern flank, Mount Etna's volcanic activity has created a barren landscape with hills and depressions as far as the eye can see. Here, scientists find similarities between the volcano and the Moon.

"The landscape is highly suitable as a test environment," says Armin Wedler of the DLR Institute of Robotics and Mechatronics in Oberpfaffenhofen. "The loose, coarse-grained surface and the solidified lava layers pose remarkably realistic challenges for reconnaissance missions." The Etna mission marks the culmination of the ARCHES project (Autonomous Robotic Networks to Help Modern Societies), which has been developing networked robotic systems since 2018. The time has come for them to show what they can do.

The scientist

LRU1 (Lightweight Rover Unit 1) takes off. Turning its four wheels into position, it starts rolling along. People have difficulty keeping up with it on foot because the ground is so soft, and, at 2600 metres, the air gets noticeably thinner. Humans do not see as well as LRU1, either, as it has seven 'eyes' in its flat, broad head. In fact, there is not much need for people here at all: LRU1 works independently within its robot team, makes decisions and carries out its mission. A person is still responsible for the process, however: "The robots are and will continue to be an extension of the human arm and eye," says Wedler, who manages the project. Humans and the robots could end up very far apart: the Moon is 384,400 kilometres from Earth, while Mars is more than 50 million kilometres away.

© DLR

The final preparations at Base Camp on Mount Etna before robot LRU1 starts its mission. Several camera systems are mounted on its head. With the exterior filter wheels it recognises different frequency ranges.

In this team, LRU1 is the scientist. It begins a mission by looking around, seeking out promising positions. The three cameras in the middle of its head perform a task similar to human eyes. Two of them form a greyscale stereo camera system, while the other is a colour camera. LRU1 uses them to see in three dimensions and pinpoint its location. "One particular challenge is recognising previously visited places in the grey volcanic landscape and orienting itself accordingly," explains Martin Schuster of the Institute of Robotics and Mechatronics.

A fourth camera has a telephoto lens for longer distances, while a thermal camera measures temperature differences. The two exterior cameras enable LRU1 to perceive different frequency ranges using filter wheels. "For instance, it can distinguish between rock types that look the same to humans," Schuster says. The large filter wheels give the LRU1 its characteristic head shape.

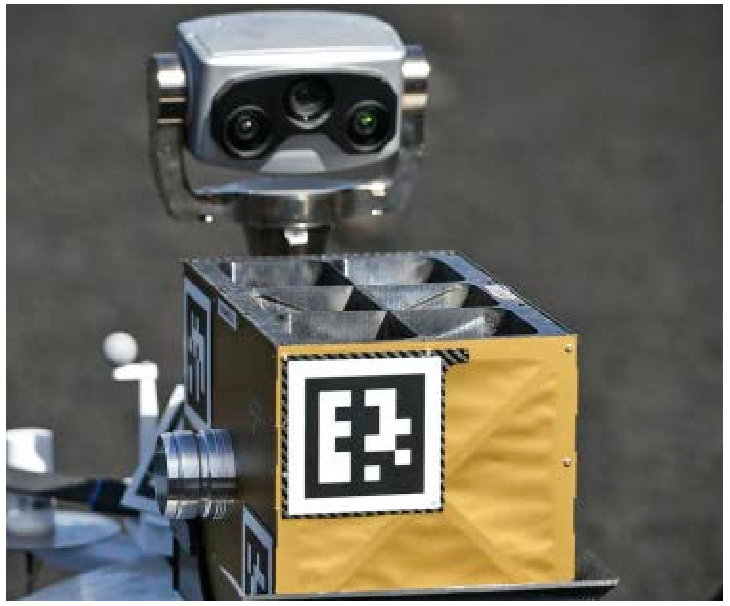
"The robots act as a team, but remain independent. Having several smaller systems has the advantage that the entire team can go on functioning even if one part fails."

Peter Lehner

While working, it travels at up to four kilometres per hour. It controls its four light wheels individually with flexible titanium spokes, allowing it to tilt its body and maintain its balance on slopes. Everything that needs to be decided immediately on site is calculated using the onboard computer. Although LRU1 has no arms, it sometimes appears to be waving merrily thanks to the black antenna at its front. The robots connect to each other via WiFi. "They act as a team, but remain independent," says Peter Lehner of the Institute of Robotics and Mechatronics, adding: "Having several smaller systems has the advantage that the entire team can go on functioning even if one part fails."

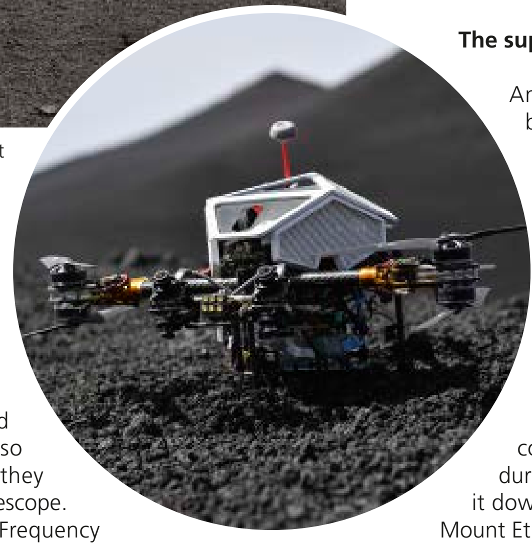
Mount Etna's barren landscape bears a resemblance to the surface of the Moon. LRU2, Ardea, Rodin, LRU1 (from left) and Scout were deployed here. In the background is DLR's Base Camp, which was set up for the mission.

The LRU2 assistant uses its arm to perform analyses or handle payload boxes



The black-and-white markings serve as name tags. The robots recognise each other and identify their payload. Here LRU2 is carrying a box to hold rock samples.

Ardea, the pathfinder, completes a test flight in strong winds, exceptionally secured on a hook.



The assistant

LRU2 – Lightweight Rover Unit 2 – is a bit tougher. It has the same structure as LRU1, but is more powerful, with sturdier titanium wheels. It has an arm with six degrees of freedom – just one less than a human arm – allowing for a considerable range of movement. Its joints can rotate indefinitely. LRU2 carries instruments or rock samples on its back and can decide whether to use a hand, a gripper or a shovel for a task. It always has a tool at hand. "One factor in reconnaissance missions is the ability to deal with limited resources," says Andreas Dömel of the Institute of Robotics and Mechatronics. "The biggest challenge is to give the robot as many different skills as possible on a mission. You never know exactly what you will be dealing with."

LRU2 works with a kind of modular system. Whatever it needs, it gets from the Rodin lander: battery packs, payload boxes for rock samples, elements of an antenna system or the laser-induced breakdown spectroscopy (LIBS) system. LIBS is 'hot stuff'.

"The biggest challenge is to give the robot as many different skills as possible on a mission."

Andreas Dömel

When LRU2 points the LIBS box at a rock, the pulsed laser shoots a mini hole a few micrometres wide and deep. The material vaporises, creating a small amount of plasma for a fraction of a second. "The steam is ionised, which means that the atomic nuclei lose one or more electrons due to the laser energy," says Fabian Seel of the DLR Institute of Optical Sensor Systems. "When the released electrons collide with atoms, ions or molecules in the plasma, they can excite them to glow, and a distinctive colour appears." The colours can be registered by a spectrometer. As different elements produce different colours in the plasma, the researchers learn which elements are in the rock.

The LIBS instrument picked up signals for potassium, calcium, sodium and silicon in Etna's lava rock. The colours of the elements are known and always the same whether on Earth, the Moon or Mars, so LIBS can be used to examine the elemental composition of unfamiliar and remote places. NASA rovers are already using LIBS instruments on Mars to study the local geochemistry and thus the history of the planet's formation. "We can also use LIBS to search for specific elements during missions," adds Susanne Schröder of the Institute of Optical Sensor Systems. Knowing what is particularly common where is important if, for instance, people are ever going to stay on the Moon for long periods and use locally available resources. In the future, LIBS could go much farther than the Moon and Mars, as the optical technology is suitable for use on any planetary body – even the icy moons of Jupiter or Saturn.

Although it looks like LRU2 is waving, the black rod on the right is actually an antenna.

All the robots wear 'name tags' consisting of small black and white squares, which they use to recognise each other and know exactly where the others are at any given time. They placed boxes with antenna elements so precisely on Mount Etna that they could be combined to form a telescope. This set-up is called LoFar (Low Frequency array). The boxes are also equipped with the appropriate labels. LRU1 analysed the area, while LRU2 distributed the boxes. "Telescope units could be arranged over a large area on the far side of the Moon," says Emanuel Staudinger of the DLR Institute of Communications and Navigation. "From there, they could scan the radio portion of the electromagnetic spectrum for possible signs of extraterrestrial civilisations."

The pathfinder

The Ardea drone is the fastest team member in the exploration of uncharted territory. It likes to fly at a height of two to three metres, mapping and analysing whether the route is suitable for the large robots. It processes data in real time – if Ardea gives the OK, the team follows. Consulting with people would be impossible on a mission to Mars. "It would take far too long to send the data to Earth, evaluate it and then send back commands," says Marcus Müller of the Institute of Robotics and Mechatronics. In the meantime, there might be an obstacle, or in the worst-case scenario, one of the team members could become an obstacle in the flight path. That is why Ardea works completely autonomously. It 'sees' with four cameras that work in stereo pairs, and has a 240-degree vertical angle of view. "It's not just useful for examining surfaces – Ardea can even find its way in caves or lava tubes and create 3D maps there," Müller says. The drone's range is limited, but it always has a safe place to land – LRU1's back doubles as a landing platform.

"Rodin is like the big brother who takes care of everything. It's the 'rock' and heart of the team."

Bernhard Vodermayer

The supplier

And when the mission has been completed, when batteries are drained and the rock sample box is full, Rodin stands ready and waiting. The lander unfolds its solar panels, provides energy and communications, and stores the boxes. "Rodin is like the big brother who takes care of everything," says Bernhard Vodermayer of the Institute of Robotics and Mechatronics. "It's the 'rock' and heart of the team." Indeed, it is quite literally at the centre of the team – when exploring, the robots orientate themselves to Rodin to stay in contact. The lander maintains contact not only with the team, but also with the scientists on Earth or at a base camp. A comparable model could be used on a space mission, during which the nozzle beneath the lander would slow it down as it touched down on extraterrestrial terrain. On Mount Etna, however, Rodin arrived in a container, thanks to a lot of (human) muscle power.

The lander Rodin has everything that the robots need. In addition, it is in contact with the people on Earth and in the base camp.

The cave explorer

Scout, that's its name. It looks like an insect and moves like a kangaroo. It does not jump very high, but the principle is the same: spring elements in its legs store energy and actively support movement. Some observers on Mount Etna exclaimed how cute Scout looks 'hopping about'. Roy Lichtenheldt of the DLR Institute of System Dynamics and Control, who is responsible for the robot, acknowledges that "Sometimes it is as though Scout was a pet." That was not planned – the technical possibilities and the functions were always at the forefront during development.

In some ways, however, the design was influenced by nature: Its tripartite, six-legged body "is heavily inspired by insects," according to Lichtenheldt. Its flexible 'spine' is more mammalian. Scout is in its element in hazardous situations. If it falls and lands on its back, it simply turns over or keeps going. It can climb over obstacles up to 40 centimetres high and drag or haul loads of up to six kilograms. These abilities make Scout an excellent robotic cave explorer. On Etna it had another special assignment: in one experiment, it wore a WiFi repeater and positioned itself autonomously so that the other robots could stay in touch constantly without any issues. In other words, a real team player.

Katja Lenz is a Media Relations editor at DLR.

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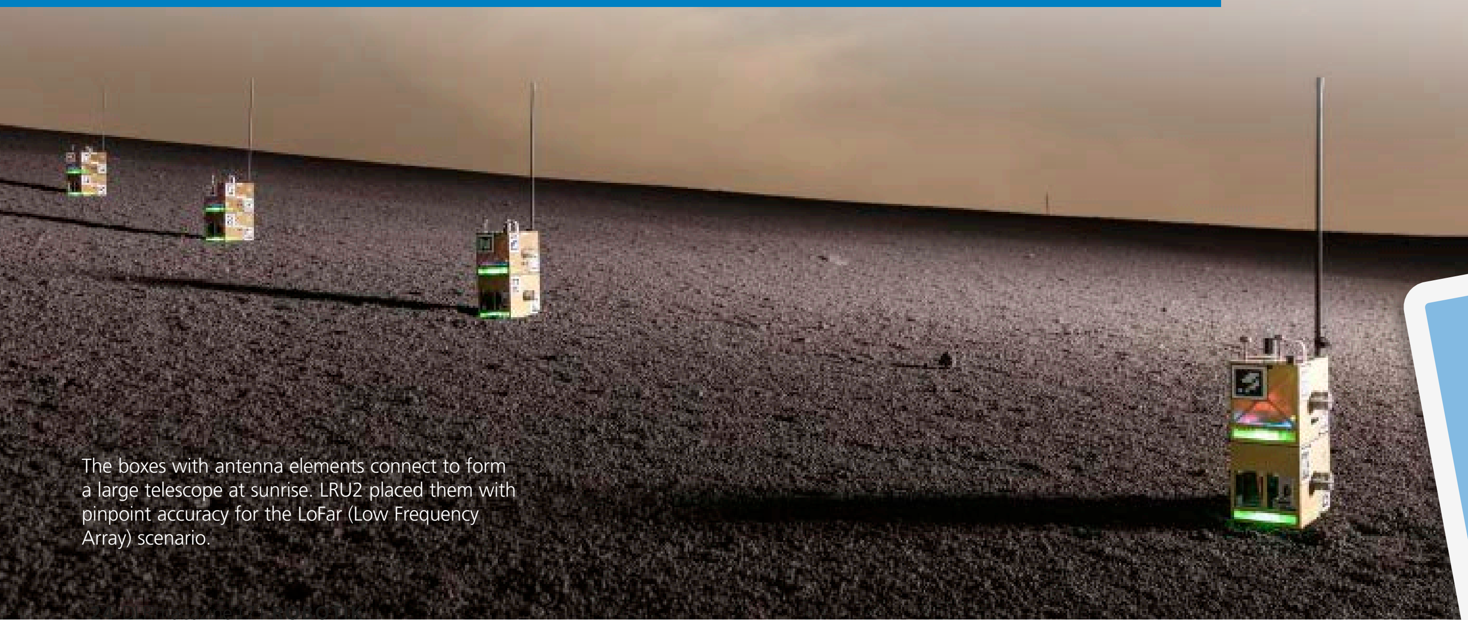
Six legs with three feet each make Scout bounce. The feet are equipped beforehand – depending on the surface on which the robot is moving.

THE ARCHES MISSION AT A GLANCE

Heterogeneous, autonomous, networked robotic systems have been developed since 2018 as part of the Helmholtz future project ARCHES (Autonomous Robotic Networks to Help Modern Societies). This involves an array of robots and fields of application. In addition to exploring the Solar System, the project paves the way for environmental monitoring of the oceans and disaster relief on Earth. The space demonstration mission, which took place on Mount Etna in June and July 2022, had been postponed several times due to the COVID-19 pandemic.

DLR carried out the mission with the Karlsruhe Institute of Technology (KIT) and the European Space Agency (ESA). The other ARCHES project partners are the Alfred Wegener Institute (AWI, Helmholtz Centre for Polar and Marine Research) and GEOMAR (Helmholtz Centre for Ocean Research Kiel). ARCHES builds upon the insights gained from ROBEX (Robotic Exploration of Extreme Environments), a demonstration mission that took place on Mount Etna five years ago.

In addition to the DLR Institute of Robotics and Mechatronics, the institutes of System Dynamics and Control, Communications and Navigation and Optical Sensor Systems are all involved in ARCHES. With the MORABA mobile rocket base, DLR Space Operations and Astronaut Training established a communication link between the 'ground station' and Mount Etna and operated the network infrastructure.



The boxes with antenna elements connect to form a large telescope at sunrise. LRU2 placed them with pinpoint accuracy for the LoFar (Low Frequency Array) scenario.

THE ROBOTS, DRONE AND LANDER

LIGHTWEIGHT ROVER UNIT (LRU1 AND LRU2)

LRU is the prototype of a mobile robot for exploration in unfamiliar, inaccessible or difficult-to-access terrain.

Dimensions: 114 x 74 x 94 centimetres
Weight: approximately 30 kilograms
Payload: 5 kilograms
Speed: 4 kilometres per hour

SCOUT ROVER

Overcoming rough terrain is still a major challenge for mobile robots. The rover Scout has an innovative, flexible spoked wheel and malleable rear elements to overcome obstacles that other rovers cannot.

Dimensions: 105 x 51 x 30 centimetres
Weight: 18 kilograms
Payload: > 6 kilograms at 5-litre volume
Speed: 7.2 kilometres per hour

ARDEA

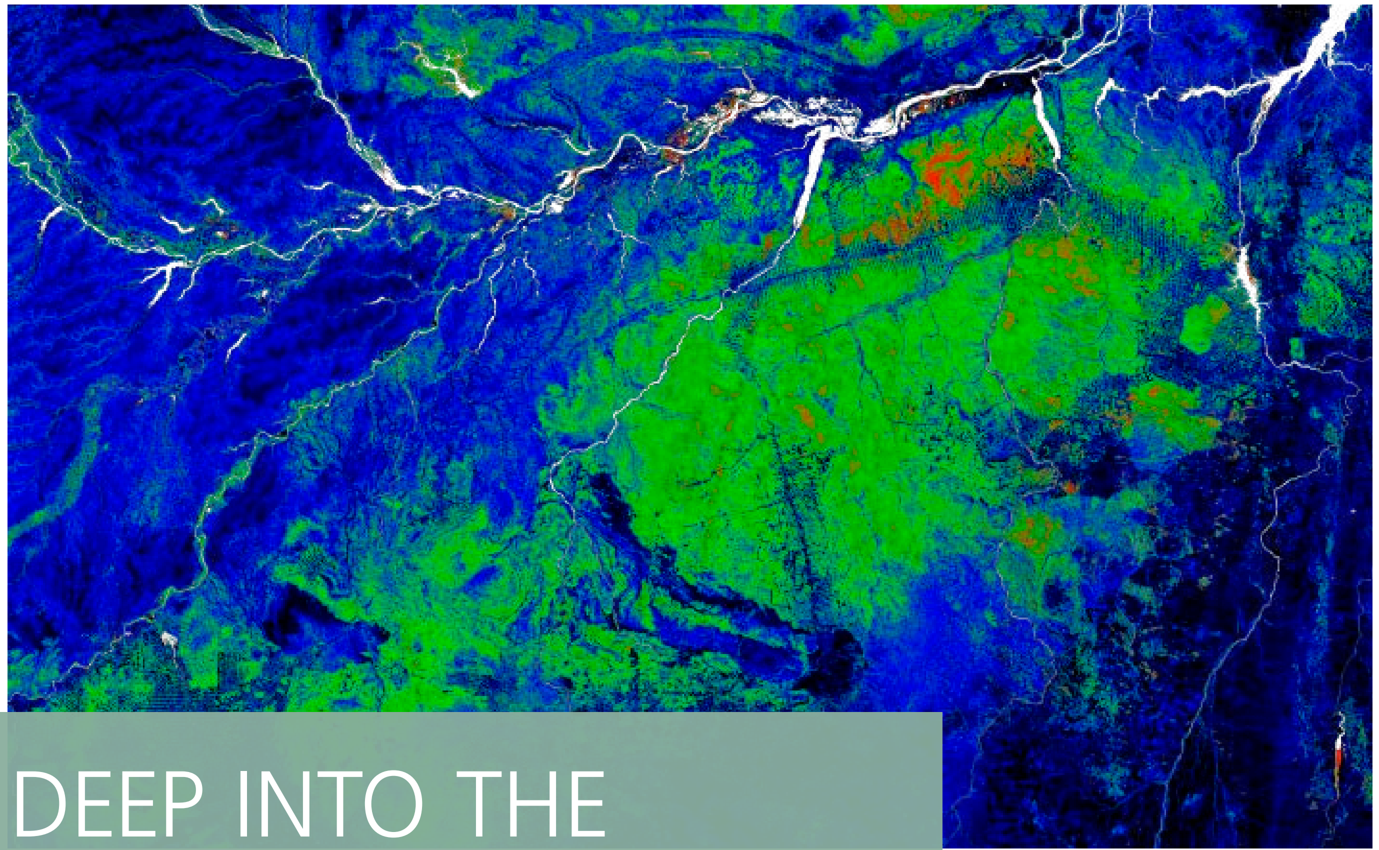
Ardea is a micro aerial vehicle (MAV) equipped with four cameras with ultra-wide-angle lenses that cover a vertical image area of 240 degrees. This allows Ardea to see above and below at the same time, making it much easier to carry out navigation and mapping activities in tight spaces such as caves.

Dimensions: 68 × 68 × 30 centimetres
Weight: 2.4 kilograms
Payload: 0.5 kilograms
Speed: 4 kilometres per hour

RODIN

In the ARCHES scenario, a stationary unit that is responsible for the energy supply and for data exchange between the control centre, rover and sensor boxes.

Dimensions: approx 210 x 280 x 280 centimetres (ground to top of the lander body, excluding the antenna)
Weight: 500 kilograms
Payload: approximately 80 kilograms (on Mount Etna)
Speed: 0 kilometres per hour



DLR researchers used TanDEM-X measurements to calculate forest density of this region of the Amazon rainforest. The map has a resolution of 100 metres.

DEEP INTO THE FOREST

A combination of remote sensing data grants new insights into the structure of forests

by Konstantinos Papathanassiou

Forests are gigantic carbon reservoirs – they store half of the terrestrial carbon. They also control the water and carbon transport between the ground and the atmosphere. As such, they play an important role in climate change. Changes in temperature and precipitation and the intensification of extreme weather pose major threats to forests and their role. For this reason, knowing the condition of Earth's forests and how their spatial structure is changing is especially vital. To this end, DLR researchers have combined data from various remote sensing missions. But that's not all: a future satellite mission has the potential to reveal the spatial forest structure and its change over time with unprecedented detail.

Mapping the structure of forests by means of remote sensing techniques is particularly challenging because of its strong spatial variability, which is the result of natural, climatic and anthropogenic processes. As a result, the vast majority of remote sensing data cannot provide reliable information about key parameters such as vegetation structure, height or biomass.

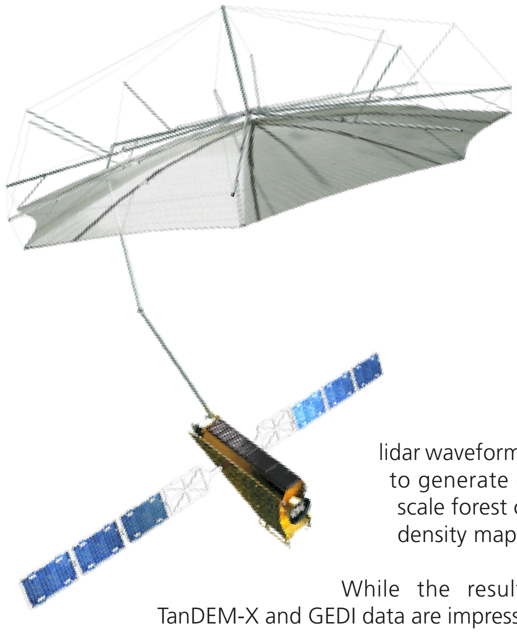
Twin satellites characterise Earth's forests

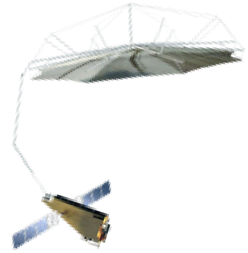
The German TanDEM-X mission was the first to capture elements of vertical forest structure. It consists of two X-band synthetic aperture radar (SAR) satellites flying in formation and has been mapping Earth since 2010. TanDEM-X uses interferometric and tomographic SAR measurements. Their data have given researchers an initial impression of the potential that the 3D forest structure offers for characterising forests.

When radar waves penetrate into forest, a complex interaction occurs. To make it computable, physical models are used that make it possible to determine relevant forest structure parameters from the radar measurements, even if they cannot be measured directly. However, in the case of TanDEM-X the amount of radar measurements is not sufficient to provide enough information to determine the forest structure parameters of the model.

To get around this problem, the researchers used measurements from NASA's Global Ecosystem Dynamics Investigation (GEDI) mission. GEDI is a waveform lidar system on board the International Space Station ISS. Since it entered operations in late 2018, the system has provided more than 10 billion lidar waveforms to date along its designated ground track between 51.6 degrees north and 51.6 degrees south. Combining the interferometric TanDEM-X measurements with GEDI's lidar waveforms makes it possible to generate continuous large-scale forest canopy height and density maps.

While the results of combining TanDEM-X and GEDI data are impressive, this is rather a demonstration project that merely hints at the potential of dedicated interferometric or tomographic SAR configurations for mapping 3D forest structure. At X-band the foliage penetration is limited, making the determination of forest canopy heights in dense forests often imprecise. Furthermore, TanDEM-X has a rather limited acquisition capability that restricts the collection of dense time series. To complicate matters further, the limited spatial coverage provided by the GEDI data only allows measurements to be conducted at a few locations and at different times. Both factors limit the ability of the researchers to measure changes to forest structure over time.



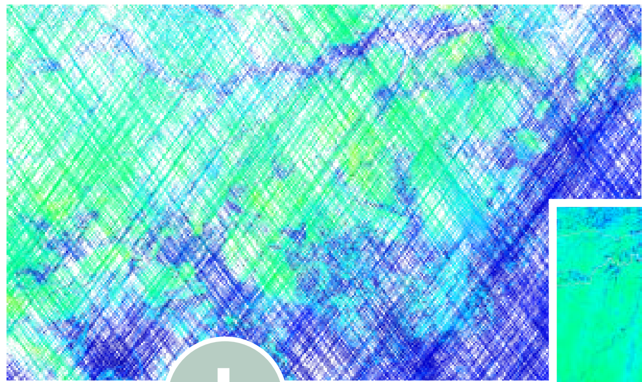


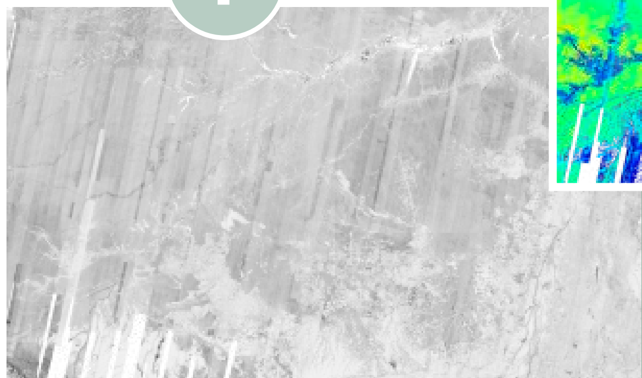
The twin satellites of the Tandem-L mission could deliver an up-to-date, 3D image of Earth's entire landmass on a weekly basis. This would enable the visualisation of dynamic processes taking place on Earth's surface.

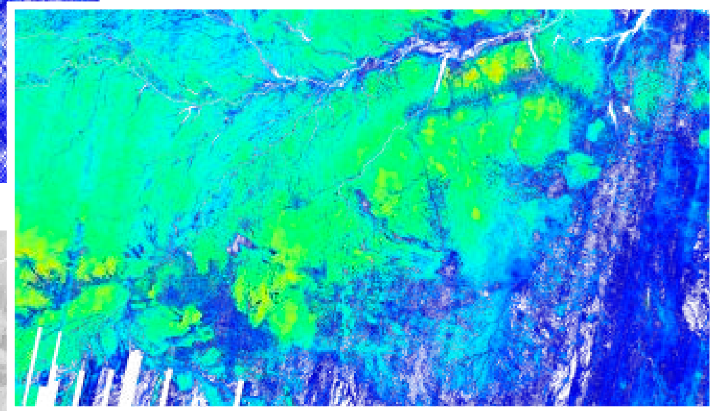
Tandem-L – looking deep into forests

The satellite duo Tandem-L has the potential to measure the spatial and temporal variation of the 3D forest structure with unprecedented accuracy and resolution. Tandem-L is an innovative radar mission proposed by DLR. It would be the world's first mission capable of carrying out global 3D forest structure measurements using innovative tomography technology. The foundation for the 3D forest structure image is the polarimetric SAR tomography technique developed by DLR. This can record and document the extent and degree of disruption to the global forest and how it is changing. Based on reconstructions of the 3D forest structure, researchers can go on to create ecological growth models that allow statements to be made about the biomass and productivity of the forests. The Tandem-L measurements could also be integrated into forest ecology and climate modelling, making it possible to address aspects far beyond biomass and productivity. This would transform global forest and climate research over the long term.

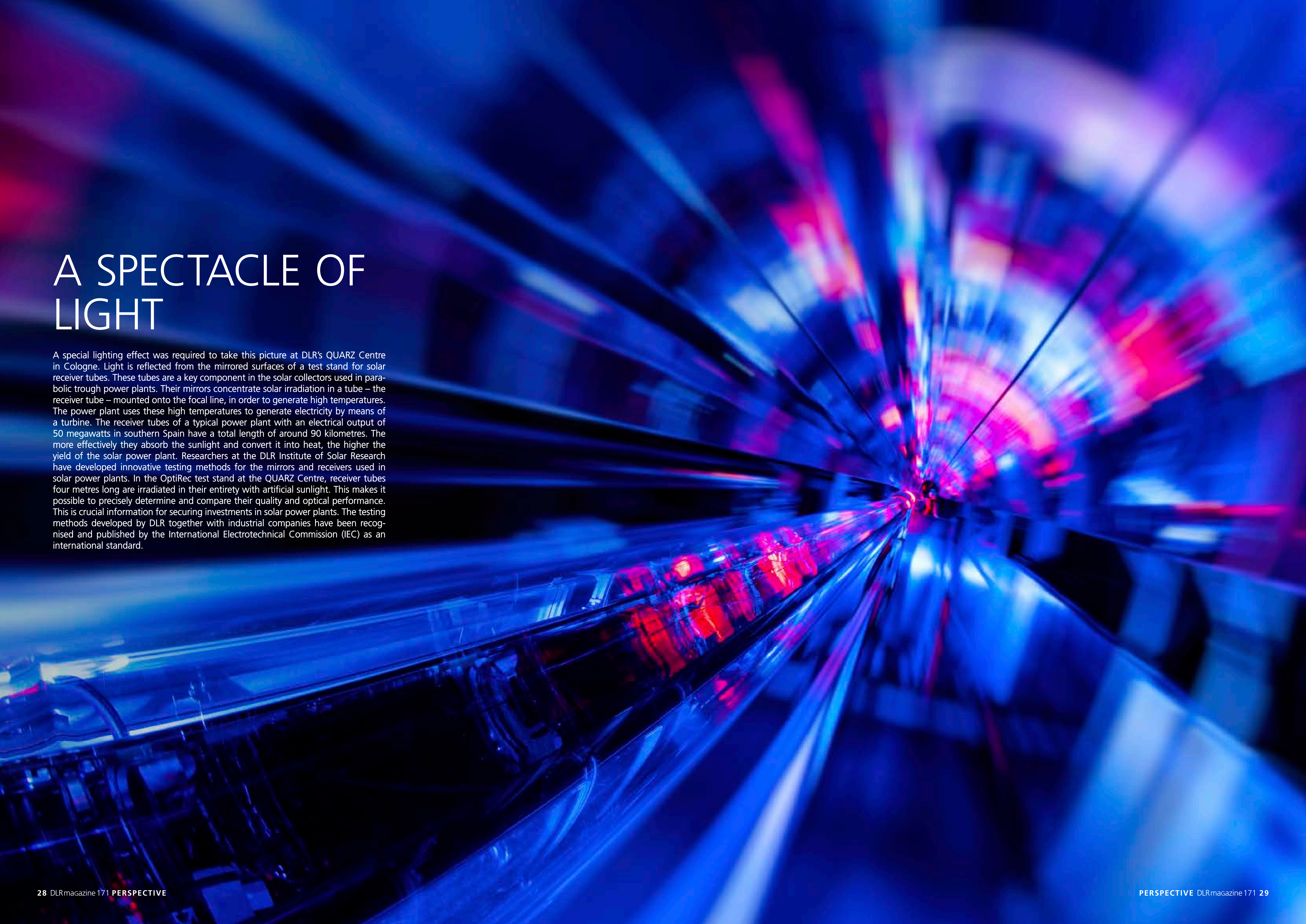
Konstantinos Papathanassiou works in the Radar Concepts department at DLR's Microwaves and Radar Institute.







The map on the right was generated using a combination of TanDEM-X and GEDI data. It shows forest heights with a spatial resolution of 25 metres. At the top left are the GEDI forest height measurements – 60 million have been used in total. Since GEDI does not provide continuous imaging, there are large measurement gaps between its ground tracks. Below are the TanDEM-X measurements of the same region of the Amazon rainforest – a total of 12,000 TanDEM-X images.



A SPECTACLE OF LIGHT

A special lighting effect was required to take this picture at DLR's QUARZ Centre in Cologne. Light is reflected from the mirrored surfaces of a test stand for solar receiver tubes. These tubes are a key component in the solar collectors used in parabolic trough power plants. Their mirrors concentrate solar irradiation in a tube – the receiver tube – mounted onto the focal line, in order to generate high temperatures. The power plant uses these high temperatures to generate electricity by means of a turbine. The receiver tubes of a typical power plant with an electrical output of 50 megawatts in southern Spain have a total length of around 90 kilometres. The more effectively they absorb the sunlight and convert it into heat, the higher the yield of the solar power plant. Researchers at the DLR Institute of Solar Research have developed innovative testing methods for the mirrors and receivers used in solar power plants. In the OptiRec test stand at the QUARZ Centre, receiver tubes four metres long are irradiated in their entirety with artificial sunlight. This makes it possible to precisely determine and compare their quality and optical performance. This is crucial information for securing investments in solar power plants. The testing methods developed by DLR together with industrial companies have been recognised and published by the International Electrotechnical Commission (IEC) as an international standard.

A POLAR HOT SPOT?

The Arctic is warming more quickly than the rest of the planet – a research team is trying to find out why.

by Andreas Ellmerer

Anthropogenic climate change is threatening particularly vulnerable ecosystems such as those in the Arctic. Here, the Earth's surface is warming at almost three times the global average. The reasons for this so-called Arctic amplification are not yet known, so an international research team flew five aircraft in and above the Arctic clouds to collect data that might help answer this question.

In Kiruna, Sweden's northernmost city, the summers are short and cool while the winters are long, freezing and snowy. Tourists are drawn there for the unspoiled nature, sled dog tours and the northern lights, while researchers come to launch data-collecting rockets or balloons and study climate change in the Arctic. The HALO-(AC)³ campaign saw DLR's HALO research aircraft take off from here for 17 nine-hour Arctic flights, each time fully equipped with the latest measurement technology. The campaign was accompanied by one French and one British research aircraft, also stationed in Kiruna, as well as two polar aircraft from the Alfred Wegener Institute (AWI), which took off from Svalbard near the North Pole. Together, these flights examined the properties of the Arctic atmosphere. The researchers involved are united by the goal of better understanding the Arctic climate and the particularly marked warming observed there.

On the trail of Arctic amplification

An important phenomenon of change is what is known as Arctic amplification – the above-average temperature increase in the region compared to the global average. By way of comparison, the global climate has warmed by approximately one degree Celsius since 1971. In the Arctic, this increase is around three degrees, and it is possible that this differential will continue to widen due to feedback mechanisms. The change in the temperature gradient between the mid-latitudes and the Arctic could lead to more warm air intrusions flowing towards the North Pole, with colder air moving southward. These warm air intrusions could in turn accelerate the melting of sea ice. The resulting uncovered darker ocean surface would absorb and store thermal energy more effectively than a white ice surface, which reflects solar radiation. This would accelerate the melting of the sea ice, further intensifying the warming of the Arctic.

The Polar 6 research aircraft of the Alfred Wegener Institute

When white, reflective clouds move over the ocean the picture changes, because cloud cover can have a major impact on the atmospheric radiation budget. Clouds behave differently over the open ocean and over sea ice. This, among other effects, is what the scientists hoped to investigate with aircraft measurements. "It is a privilege to be able to see and experience this unique part of the Earth. Its preservation is so important to us," says Christiane Voigt. The cloud physicist led a team from the DLR Institute of Atmospheric Physics in Svalbard.

A variety of measurement technologies

"Our HALO research aircraft allow us to fly high above the clouds, from where we can measure them and track the movement of the warm air masses," explains Silke Groß of the DLR Institute of Atmospheric Physics. HALO stands for High Altitude and Long Range Research Aircraft. With a range of over 8000 kilometres and a maximum altitude of 15 kilometres, the aircraft is perfectly suited to work in the Arctic.

> *"It is a privilege to be able to see and experience this unique part of the Earth. Its preservation is so important to us."*
> **Christiane Voigt**

Before take-off, the runway at Kiruna airport must be cleared of snow.

HALO is rolled onto the runway

By contrast, a modern airliner like the Airbus A320neo can fly at a maximum altitude of just under 12 kilometres with a range of 3200 kilometres.

During the HALO campaign, the scientists used remote sensing measuring instruments such as radar and lidar to investigate what types of clouds form over the cold Arctic Ocean when warm air hits them. Along the way, the team on board HALO released numerous probes at high altitude. As they descend through the atmosphere, these 'dropsondes' acquire measurements of temperature, humidity, wind and pressure. Wind and pressure are also recorded by measuring probes attached to the aircraft. The data provide a good picture of the local meteorological situation.

DLR's HALO research aircraft

With the Polar explorers on Svalbard

In Svalbard, the DLR researchers flew directly through low clouds with their cloud probes aboard the P5 polar aircraft. The flight followed a sawtooth pattern below 600 metres altitude through cold, boundary layer clouds. Using high-resolution cloud measurement instruments,

The DLR research aircraft HALO taking off from Kiruna airport

The dropsondes are ejected from the research aircraft via this chute

Video about HALO-(AC)³

HALO-(AC)³ FACTS AND FIGURES

Flight distance covered	approx. 107,700 kilometres
Flights	17
Flight hours	140 hours
Dropsondes released	347
Messages sent on Slack	23,163

the team studied the influence of the Earth's surface – including sea ice, broken sea ice and open ocean – on the formation of clouds as well as their composition, particle size distribution and particle shape. "Initial results from HALO-(AC)³ and the previous campaigns MOSAIC and AFLUX show that the low clouds that form over the ocean in the spring have a higher water content and larger particle diameters than those that form over the sea ice," says Voigt.

From space, white clouds over ice can hardly be distinguished from the bright surface. However, over the dark ocean, low ice clouds alter the radiation balance significantly. The researchers were also interested in the different cloud properties in the warm air intrusions and the cold air outbreaks; the latter lead to a characteristic comb-like line cloud pattern that forms in the cold air overflowing the ocean beyond the edge of the sea ice. But flying in the turbulent boundary layer and in clouds is no easy task. "It's extremely exciting to fly just 60 metres above the ice shelf. The research aircraft used are well suited for the flight manoeuvres involved, and the AWI has many years of expertise in polar flight," adds Voigt. Due to the absence of hangars, HALO could not be stationed in Svalbard over winter, although the polar aircraft and pilots stayed on the apron even in the freezing cold.

A second polar aircraft equipped with remote sensing instruments carried out coordinated measurement flights directly above the P5 to collect data on the effects of radiation high above the clouds. In particularly interesting conditions, HALO, FAAM or the ATR flew in from Sweden to work with the P5 and P5 polar aircraft to investigate changes in the atmospheric radiation flux in the Arctic, the particularly sharp rise in temperature and the influence of clouds.

Cold and complex objects of research

High ice clouds, known as cirrus, are the most common cloud type in the Arctic and immensely influence the global climate. In general, cirrus clouds have a warming effect because they reflect thermal radiation back to Earth. Meanwhile, because they are so cold, they themselves emit little heat into space. At the same time, they also reflect solar radiation. "The interaction of the different effects makes it incredibly complicated to study this type of cloud," says Groß. In addition, there is a difference in the temperature of the surface radiation over ice and over water, the reflection of solar radiation depends on the position of the Sun – whether it is polar night or polar day – and the properties of the clouds, such as their size, shape or the number of ice crystals in turn depend on external conditions such as temperature and humidity. All of these factors influence how cirrus clouds react to solar and terrestrial radiation, and in turn have an effect on the Earth's heat balance.

The researchers are currently evaluating data from the campaign. "The initial results indicate that the distribution of moisture in arctic cirrus clouds differs from that at lower latitudes," says Groß. Relative humidity is an important factor in cloud formation. The researchers assume that it also influences the microphysics and the radiation balance of the clouds. If the warm air intrusions into the Arctic increase, for example, this could have an impact on the radiative effect of the region. "We want to use data from the campaign to investigate the way in which global warming will change," adds Groß.

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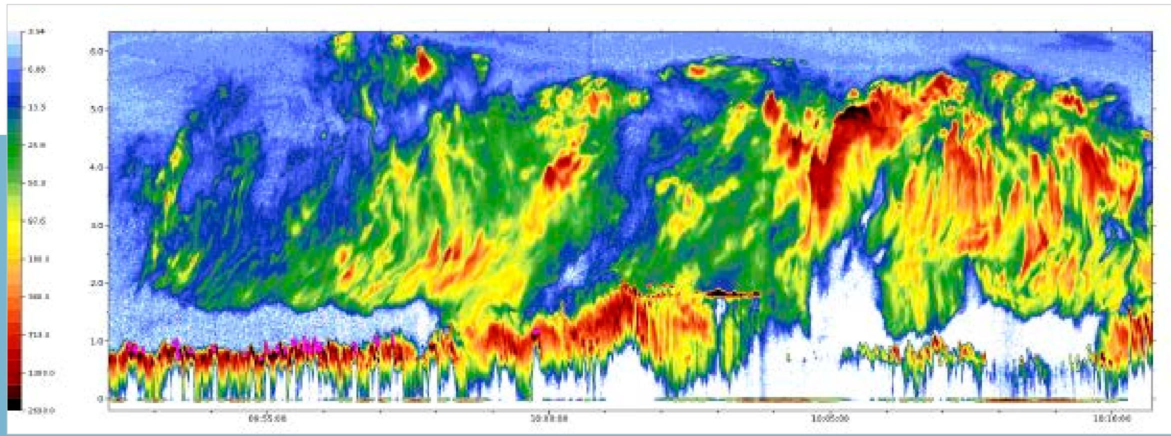
The DLR team in Svalbard. In the centre, Christiane Voigt.



Lidar measurements at a wavelength of 532 nanometres. They show the 2D cloud structure below the research aircraft. Cloud-free areas are shown in light blue and white. Everything from dark blue shows the clouds along the flight path, with the intensity of the backscattered light increasing from dark blue to dark red. The illustration highlights the complex structure and interplay of low clouds over the open ocean and ice clouds above. At the beginning of the flight path, the low clouds (height up to approximately two kilometres) are clearly separated from the ice clouds (lower edge at approximately 2.5 kilometres). However, as the flight progresses, the upper edge of the deep clouds increases so that they are now directly connected to the overlying ice clouds.

"The fact that we were able to carry out the campaign so successfully was a combination of luck and risk, because forecasting small-scale weather phenomena in detail is anything but simple."

Manfred Wendisch

Weather simulation as a basis for the flights

Weather simulations from the University of Cologne and the Ludwig Maximilian University in Munich served as the basis for flight planning. Data from the European Centre for Medium-Range Weather Forecasts (ECMWF), such as temperature and air pressure, can precisely predict when and at what altitude clouds will form. HALO flew in these areas together with the polar aircraft to examine how accurately the simulations predicted real developments. In this way, modern weather and climate models can be improved. This task will keep researchers busy for years to come. "The fact that we were able to carry out the campaign so successfully was a combination of luck and risk, because forecasting small-scale weather phenomena in detail is anything but simple," says Principal Investigator Manfred Wendisch of the University of Leipzig.

For Wendisch, another vital element for the success of the mission is the team, with some 20 doctoral students working on the project. "Young people come up with ideas that you would never think of yourself. We all benefit from that and I'm glad they were involved. The mix of young researchers was the key to success!" adds Wendisch.

Andreas Ellmerer is an editor at DLR's Media Relations department.

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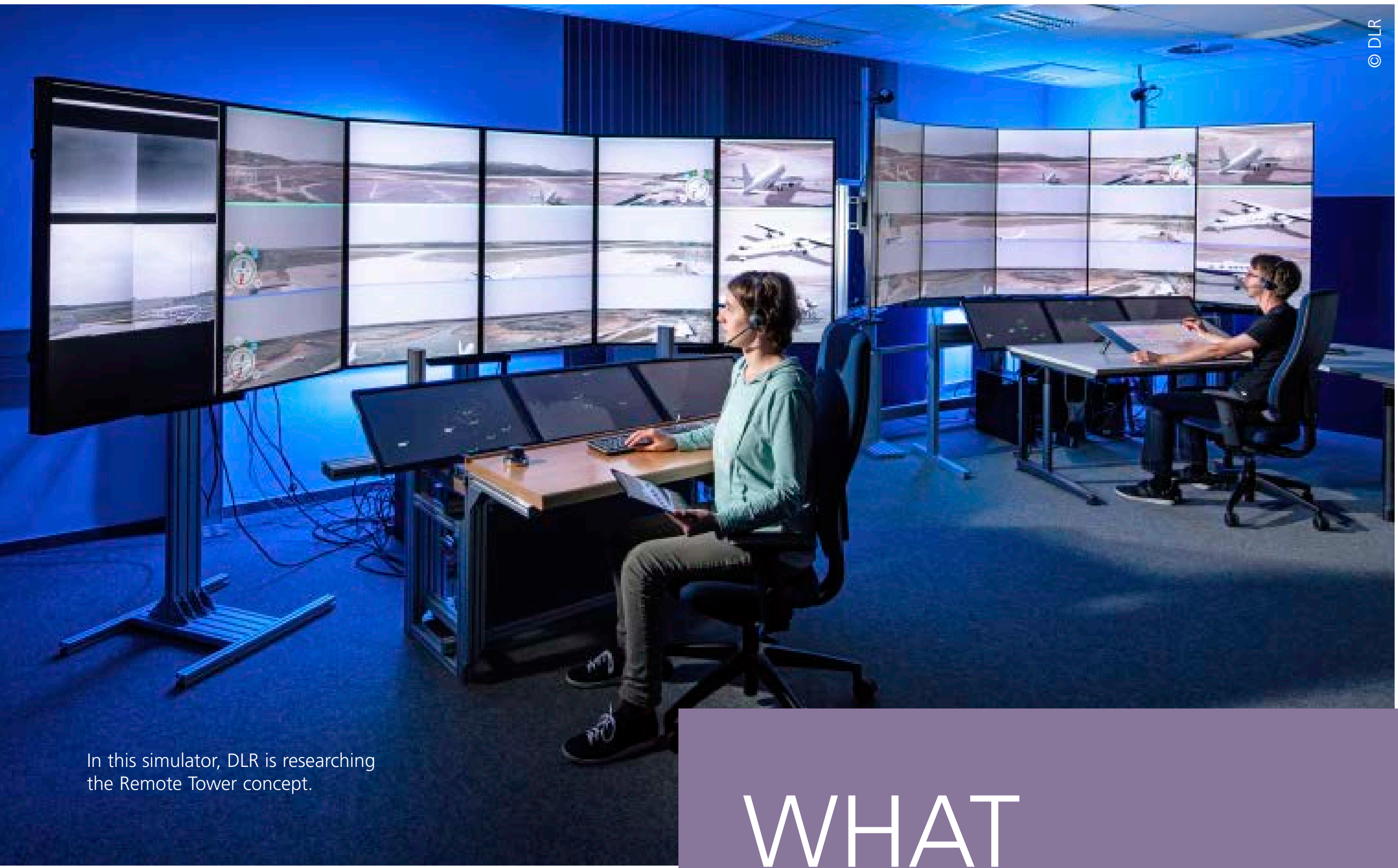
Manfred Wendisch from the University of Leipzig, Principal Investigator of HALO-(AC)³.



In this simulator, DLR is researching the Remote Tower concept.

WHAT TOWER?

Remote Tower – a DLR success story

by Michael Drews and Julia Heil

The air traffic control tower is often the most striking structure of any airport. From its commanding position, air traffic controllers have everything in view – well, almost everything, because there are blind spots, which is why larger airports in particular are now monitored using a wide variety of sensors. But the 'Remote Tower' concept goes further – it uses optical sensors to deliver video images that replace the direct view from the tower window. These video images do not necessarily have to be displayed where they are captured, meaning that airports can be controlled remotely. In a 'Remote Tower Centre' it is even possible for the sensor data from several airports to come together, which can make air traffic control (ATC) much more efficient and flexible. The first Remote Tower Centre was opened in Sweden in 2015. Since 2018, airports have also been monitored from afar in Leipzig, while in the year after next a centre is scheduled to open in Braunschweig, in the immediate vicinity of the place where the concept originated 20 years ago – the DLR Institute of Flight Guidance.

This prototype remote tower workstation from 2007 was developed at the DLR Institute of Flight Guidance

The story of the Remote Tower began in 2001, when a team from the Institute of Flight Guidance entered the idea of a remote or 'virtual' tower from which air traffic control at an airport could be operated, to an internal DLR competition. The concept drew upon work by the NASA Ames Research Center, which had already conducted research into the use of virtual and augmented reality applications for air traffic. The idea, visionary at the time, won the competition and received an award. The team then set about developing an initial prototype to show how the concept might work in reality. Since 2005, the system was tested at Braunschweig-Wolfsburg Airport. At the same time, the world's first remote tower simulation was created at the DLR Institute, in the form of a live 180-degree digital video panorama. National and international research and development activities followed, prompting numerous air traffic control organisations such as the Swedish Civil Aviation Authority and the German air navigation service provider Deutsche Flugsicherung (DFS) to express their interest.

During the test setup of the DFS Remote Tower Centre Leipzig with three airports, researchers investigated how air traffic controllers cope with the technology.

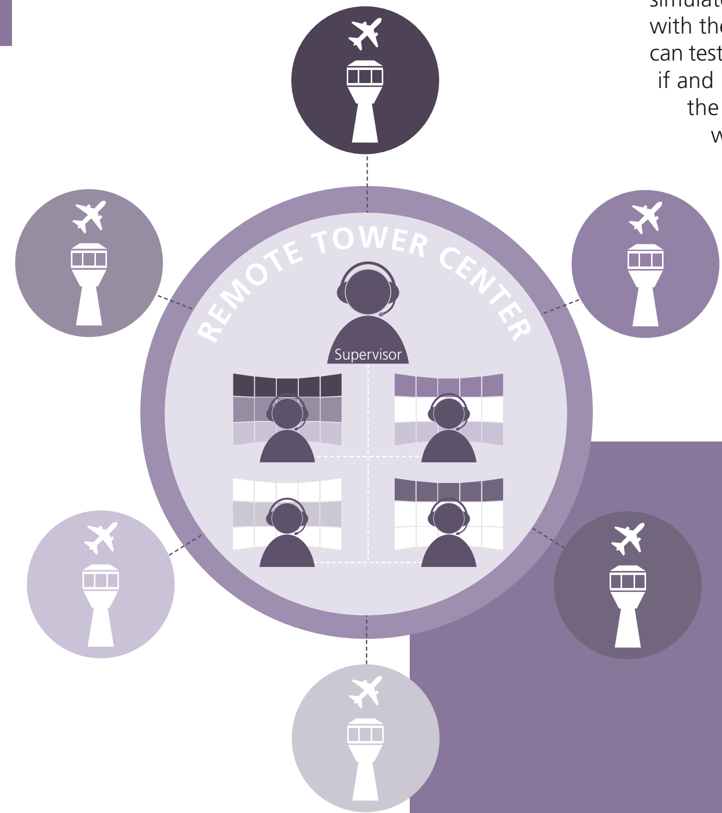
An idea that works

In 2014, DLR was able to transfer the technology to industry. The team not only made advances in technology, but also developed methods to examine and improve the interaction of ATC personnel with the new technology. The first Remote Tower finally went into operation in Sundsvall, Sweden in 2015. Since then, all air traffic control operations for Örnsköldsvik Airport have been operated from Sundsvall. "This success helped us to think further. If we can control one airport remotely, it should also be possible to control several airports from a single working position," says Jörn Jakobi of the Department of Human Factors at the DLR Institute of Flight Guidance. This was the birth of the Multiple Remote Tower concept, the core idea of which is that a single air traffic controller can monitor several airports simultaneously. This is now to be tested at the new Remote Tower Centre (RTC Lower Saxony) in Braunschweig, which is being set up by DFS Aviation Services (DAS) and is scheduled to go into operation in 2024. To this end, DAS and DLR will work together in an affiliated research cluster to further develop the concept. "Of course we'll start with one controller working at a maximum of one airport," says Jakobi. In the next step, low-traffic airports will be interconnected on a trial basis. In this way, the controllers will be able to gain hands-on experience with the new technology and adapt to the new situation.

A panoramic view, despite the distance

Then, as now, the high-resolution video panorama is the heart of the Remote Tower. This is where the controllers sit and survey the various airport areas. An array of cameras installed in a row generates the panorama on site. In addition, pan and tilting zoom cameras bring every detail into view.

In order to investigate various scenarios, the DLR Institute has set up a Remote Tower laboratory that realistically depicts this working environment. "We can just as easily simulate large international airports with several controller workstations, as smaller airports or airfields. We can also deliberately simulate emergency situations such as a burning engine, a problem with the landing gear or deviations from clearances. In doing so, we can test whether or not the controller notices the critical situation and if and how it can be resolved," says Jakobi. For RTC Lower Saxony, the 'twin' of a real workstation is also being set up at DLR, fed with all the important operational data from the airport. This makes it possible for new techniques and processes to be researched in parallel with real operations.



The sensor data from several airports and airfields come together in a remote tower centre. The centre is home to a pool of controllers who are responsible for air traffic control. In the Single Remote Tower concept, one person controls one airport; with Multiple Remote Towers, one person can control several airports. A supervisor monitors and distributes the workload.

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The panorama provides a direct view of the airport

"When such small airports join together in a RTC, they can save resources and offer more qualified ATC services at a reasonable cost."

Jörn Jakobi

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Thanks to a new suite of tools, the supervisor has an overview of the controllers' workload.

Safety comes first

Before innovations are tested in live operation, extensive simulation trials are carried out. During the tests, different controllers work on the same traffic scenario one after another in the simulator, alternating between the old and new technology. The researchers study the workload to see if it has increased or decreased, and observe how well the participants have grasped the situation in which they find themselves. They are asked whether they can predict how traffic conditions will develop and whether they have the necessary tools to handle critical situations. "We need to ensure that the new system will add value, meaning that it is either safer or more efficient, before we even consider bringing it to market. Under no circumstances should it be less safe than the original system," says Jakobi. A psychologist, he is the project manager responsible for the Remote Tower concept. Acceptance is also of great importance; if the users aren't behind the concept, it will probably not become established practice. For this reason, the scientists seek out practical feedback at an early stage.

"We need to ensure that the new system will add value, meaning that it is either safer or more efficient, before we even consider bringing it to market."

Jörn Jakobi

A matter of balance

Stress levels are an important indicator for evaluating the safety of the system. A high workload is nothing unusual, especially in air traffic control. In the long run, however, it can lead to negligence and errors. Meanwhile, an under-load can also have fatal consequences. "Someone who is only observing and doesn't have much operational work to do may well be unprepared when something critical does happen and unable to react appropriately," says Jakobi.

Normally, controllers work according to the four-eyes principle, meaning there are always two people on duty to support each other. In a Remote Tower Centre, several air traffic controllers, each monitoring an airport alone, are supported by a supervisor. If necessary, this supervisor provides the second pair of eyes.

The supervisor also plays a crucial role in the Multiple Remote Tower concept, by monitoring and distributing the workload. To this end, the DLR team is researching a suite of new digital planning tools that allow everything to be kept in view. If the workload is poorly balanced or becomes critical, the system issues warnings and helps to find suitable support. The system was put to the test at the end of 2021. Here, DLR, together with industrial partner Frequentis, set up a Remote Tower Centre prototype from which Lithuanian and Polish air traffic controllers monitored a total of 15 simulated airports remotely. "This is particularly interesting for airfields with very little traffic or at night, when no air traffic control is currently provided for financial reasons or staff shortages, and those airfields close," explains Jakobi. In future, a controller could be on duty at the centre in such situations to monitor the airports during this time, thus extend their operating times and increasing their attractiveness to passengers and cargo customers. This in turn could increase demand and thus generate more revenue. "The result is a needs-based air traffic control service for the entire airport network and synergy for aviation," adds Jakobi.

Enabling more traffic at smaller airports

The German air navigation service provider DFS coordinates operations at Germany's 15 international airports. But there are a total of around 400 airfields in Germany. At small airfields, there are often Aerodrome Flight Information Service officers who provide information but do not carry out air traffic control. Here, pilots have to fly according to Visual Flight Rules and mainly coordinate amongst themselves. Commercial instrument flying cannot take place. "When such small airports join together in a RTC, they can save resources and offer more qualified ATC services at a reasonable cost," says Jakobi.

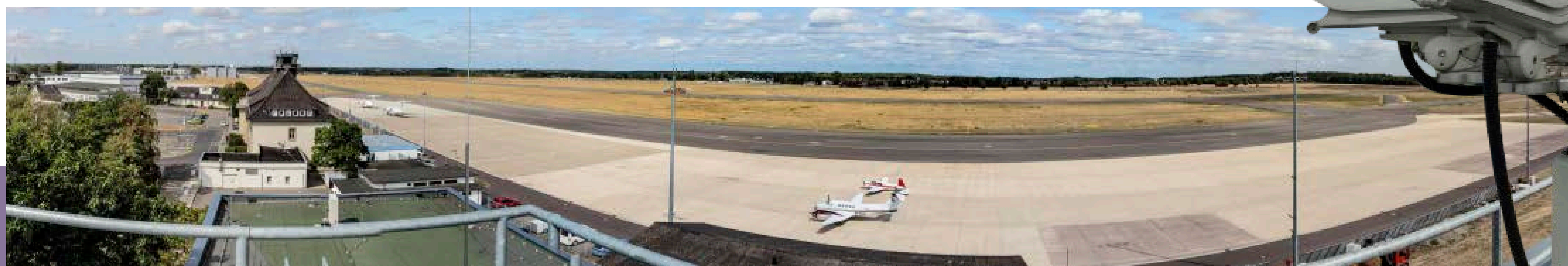
This will also be tested by RTC Lower Saxony. Certified air traffic controllers will sit next to Aerodrome Flight Information Service Officers (AFISO) serving Emden Airport. A first research question will be to examine whether air traffic controllers and AFIS personnel can be flexibly switched between the workstations, and which problems still need to be solved. Jakobi sees a key advantage of the technology in the fact that it makes aerodrome air traffic services much more flexible: "With quick availability and flexible working, the entire air traffic service system becomes more versatile and adaptable to current conditions."

What will the future bring?

So will the airports of the future be towerless? "At many small airports, remote towers will sooner or later become the norm," says Jakobi. Rather than investing in expensive new buildings or maintaining existing towers, investment could be redirected to sensor technology, which is much more economical. This was a decisive argument for Saarbrücken Airport, where the tower was going to be renovated at great expense. Today it stands empty, and coordination takes place at the Remote Tower Centre in Leipzig. The Scandinavian Mountains Airport near Rörbäcksnäs, Sweden, which opened in 2019, was planned and built with no tower at all. However, already existing towers would not have to be demolished. For example, they could serve as a fallback option if problems arise in the centre. In addition to such alternative options, the Remote Tower concept has redundancies built into to it to cope with failures.

For Jakobi, the success of the Remote Towers has a lot to do with close cooperation: "Users, research and industry must come together as early as possible – one providing the requirements, another the research expertise, and the third the ability to develop and sell the marketable product." In Germany, a fourth player is the Federal Supervisory Authority for Air Navigation Services (BAF). This office is tasked with examining and approving new concepts, and DLR remains in close contact with it. Before the opening of the Remote Tower Centre in Leipzig, DLR experts contributed research results to a report, on the basis of which the BAF approved the operation. DLR is also represented on international committees for the standardisation of Remote Tower concepts, helping to continue this success story and a start a new chapter in aviation history.

Michael Drews is responsible for communication at the DLR Institute of Flight Guidance. **Julia Heil** is an editor in DLR Communications.



View of a DLR camera system at Braunschweig Research Airport

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Research on the move – the DLRmagazine keeps its readers up to date on the latest topics our scientists are working on in aeronautics, space, energy, transport, security and digitalisation. The social relevance and innovative power of the research and activities presented here are just as important to us as good writing style, comprehensibility and beautiful images. We want to hear from you: What do you like about the DLRmagazine? What can we improve?

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The number of people that read the DLRmagazine regularly is growing steadily. It is distributed well beyond the specialist community – in Germany and abroad. Of course this motivates us to improve continuously, not only in terms of content, but also in terms of design – we aim to be up to date and always aware of new developments. We count on your support for this: We have created an online survey for DLRmagazine readers – it only takes a few minutes to complete. Please take this opportunity to give us your feedback. You can do so until **15 January 2023**. The short link and QR code on this page will take you directly to the survey. Your information will not be linked to personal data. If you would also like to take part in the prize draw, please enter your e-mail address – this will be treated separately from the survey data and will be deleted after the draw has been completed.

There are a total of ten T-shirts from the brand new DLR Campus Collection to be won. The black and white T-shirts and high-quality hoodies in grey, blue, black and pink are available now and exclusively in DLR's Space Shop at the DLR site in Cologne, or online at sozialwerk-spaceshop.de. The lettering, in the classic campus design along with the embroidered DLR logo, make the collection a real eye-catcher. Other items and colours from the DLR Campus Collection will follow soon. The T-shirt draw is supported by the Society of Friends of DLR (GvF). We are grateful for their support!

The new DLR Campus Collection

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IN BRIEF

DLR EXAMINES DUST FROM THE ASTEROID RYUGU

Between June 2018 and November 2019, the Japanese Hayabusa2 spacecraft explored the almost one-kilometre-diameter asteroid Ryugu. The spacecraft also collected samples from the asteroid's surface. In December 2020, the capsule containing the samples acquired by Hayabusa2 during its flyby landed safely on Earth with its cargo of just over five grams of material. Following the Japanese space agency JAXA's approval of DLR's request in July 2022, the Berlin-based Institute of Planetary Research was sent a small portion of the sample. Its scientists are currently examining spectral differences between original and analogue material. The findings will prove important for future remote sensing missions in which spacecraft explore planets or other bodies from afar.

JAXA

Dust particle A0112 from the asteroid Ryugu. It is three millimetres across and has a mass of 5.1 milligrams. Scientists are currently examining the valuable particle in the laboratories of the DLR Institute of Planetary Research in Berlin.

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Several systems are being tested in the project: on the left, a haptic input station with two lightweight arms (HUG); in the centre, the humanoid, two-armed mobile home assistance robot Rollin' Justin; and on the right EDAN, a wheelchair with a lightweight robotic arm and a hand.

ROBOTS FOR PEOPLE IN NEED OF CARE

Although robots cannot replace human caregivers, they can provide support so that caregivers have more time to provide the personal, human touch. In the SMiLE project (Service Robotics for People in Living Situations with Limitations; Servicerobotik für Menschen in Lebenssituationen mit Einschränkungen), scientists from the DLR Institute of Robotics and Mechatronics are researching which activities robots will be allowed to take on in care in the future, how to ensure that people and their needs are always at the heart of technological advances, and how robotic assistance systems can be used in retirement homes, private households and hospitals. Although these robots were developed for spaceflight, they can also help with essential tasks on Earth.

'PARKING' ASSISTANCE FOR SHIPS

Together with Niedersachsen Ports, sensor specialist SICK and IT company Humatects, the DLR has developed an assistance system to help ships during docking, transit and lock manoeuvres. SmartKai integrates robust maritime Lidar (light detection and ranging) sensors into the quay and jetties. These capture their surroundings. Lidar sensors use laser technology to perform tasks such as determining distances and speeds quickly and precisely. The SmartKai system processes the data and makes it available to skippers in real time, giving them a complete overview of the surrounding conditions and helping them to navigate their ships safely.

Ships and quay facilities are often damaged in ports due to high traffic density, changing environmental conditions and time constraints.

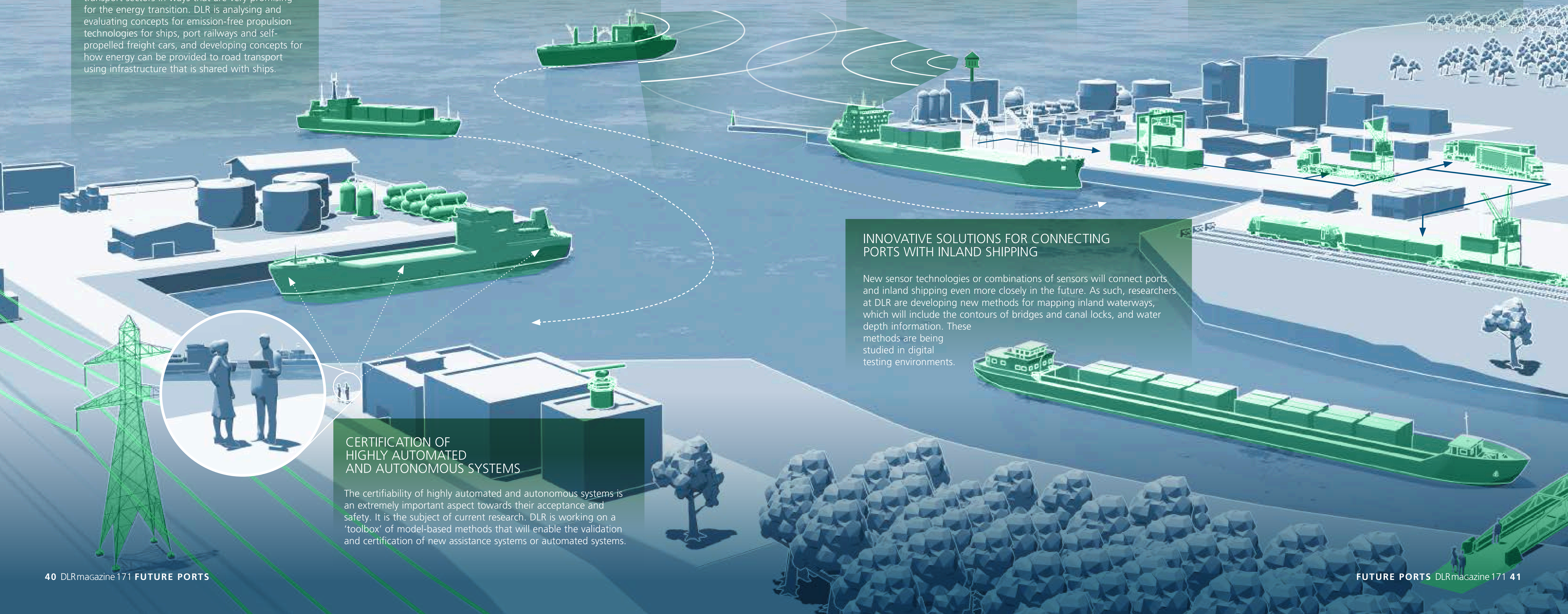
SMART HUBS

Research for the ports of the future

Ports are among the most important conduits and transshipment hubs for global trade and transport. All major ports are currently undergoing transformation to achieve higher levels of digitalisation, automation and networking. These processes should help ensure safe, secure and efficient supply chains in the future.

DLR is supporting such activities as part of the FuturePorts project, which is being funded by DLR's Transport Programme and will run until 2025. Here, researchers are actively working to shape the port of the future in terms of digitalised and automated processes and procedures. The 10 participating DLR institutes are focusing on optimising traffic management, driving forward emission-free shipping, developing highly automated assistance systems and improving the coordination of intermodal transport chains via the port as a transport hub.

For more information on the project (German only):
s.dlr.de/FuturePorts



INNOVATIVE TRAFFIC MANAGEMENT IN PORTS AND FOR PORT APPROACH

Managing port arrivals and departures is essential for a seamless logistics chain. To this end, DLR is developing a system for the operational management of traffic flows based on automated decision-making processes. Researchers are also testing whether maritime navigation assistance systems can compensate for any failure of satellite navigation systems in ports.

SECTOR COUPLING IN ENERGY AND TRANSPORT

Maritime transport interfaces with the energy and transport sectors in ways that are very promising for the energy transition. DLR is analysing and evaluating concepts for emission-free propulsion technologies for ships, port railways and self-propelled freight cars, and developing concepts for how energy can be provided to road transport using infrastructure that is shared with ships.

DEVELOPMENT OF MANOEUVRE ASSISTANCE SYSTEMS

Ships often have to navigate very narrow channels when entering, leaving and travelling within port areas. DLR is developing and testing new assistance systems that will enable ships to reliably monitor the traffic situation and carry out specific manoeuvres autonomously.

END-TO-END DIGITALISATION OF THE TRANSPORT CHAIN

Data and digital models are essential for efficient logistics in ports. DLR is developing a demonstrator for a fully digitalised transport chain. All of the processes involved, such as the loading and unloading of containers, are reproduced in this digital model of the port, allowing changes to structures and processes to be tested and evaluated easily and effectively.

INNOVATIVE SOLUTIONS FOR CONNECTING PORTS WITH INLAND SHIPPING

New sensor technologies or combinations of sensors will connect ports and inland shipping even more closely in the future. As such, researchers at DLR are developing new methods for mapping inland waterways, which will include the contours of bridges and canal locks, and water depth information. These methods are being studied in digital testing environments.

CERTIFICATION OF HIGHLY AUTOMATED AND AUTONOMOUS SYSTEMS

The certifiability of highly automated and autonomous systems is an extremely important aspect towards their acceptance and safety. It is the subject of current research. DLR is working on a 'toolbox' of model-based methods that will enable the validation and certification of new assistance systems or automated systems.

HERE TO STAY?

DLR is investigating new forms of transportation

Interview with Laura Gebhardt

Trendy transport, saviour of the environment or a public nuisance? The explosion of e-scooters, e-bikes and pedelecs on our streets shows that micromobility has arrived, expanding our range of options for getting from A to B. Although expectations are high, early opinion is divided. Laura Gebhardt from the DLR Institute of Transport Research has been involved in this relatively young field since its inception and is one of its few experts. In this interview she looks at this new way of getting around.

Ms Gebhardt, what exactly is micromobility?

: Well, that is an exciting and difficult question. There's no clear or widely-agreed definition, either in science or in the public domain. As a rule, it includes small and light vehicles for travelling relatively short distances with a maximum speed of between 25 and 45 kilometres per hour, depending on the definition. These include e-scooters, e-bikes, Segways and electric scooters. Some have been around for a long time, but above all, the electric drive and the principle of sharing – hiring instead of buying – have given micromobility a boost. In Germany, for example, e-scooters hit the streets almost overnight in 2019. E-bikes appeared a little earlier in the sharing market.

What opportunities does this form of mobility offer?

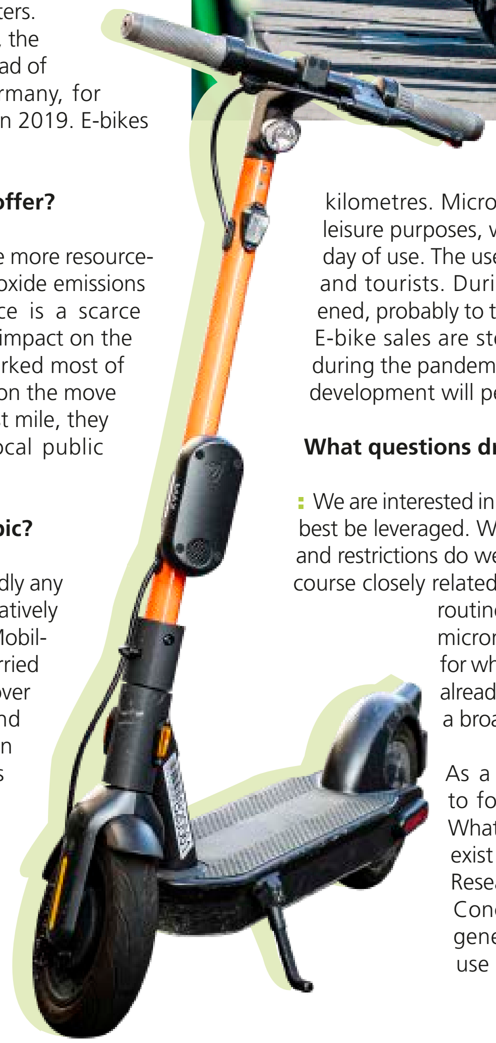
: One motivation, of course, is the obvious need to be more resource-efficient in the future. This applies to both carbon dioxide emissions and land use. In constantly growing cities, space is a scarce commodity. Its availability and use have a significant impact on the quality of life. Cars take up a lot of space and are parked most of the time. Micromobility devices – shared and always on the move – offer an alternative. As a feeder for the first and last mile, they can also help to increase the attractiveness of local public transport.

What are the challenges for research on this topic?

: The biggest challenge at present is that there are hardly any empirical and comparable data. Micromobility is a relatively new phenomenon. Large statistical surveys such as 'Mobilität in Deutschland' (Mobility in Germany) are only carried out every five years or so, and therefore do not yet cover this phenomenon. Although individual studies and projects have been carried out, sometimes giving an insight into usage data from the service providers, it is not always possible to understand exactly how the data was collected or evaluated.

What are the findings so far?

: Three years of research have shown that the average distance travelled is around two



kilometres. Micromobility devices are mainly used for leisure purposes, with Saturday being the most popular day of use. The users in cities tend to be younger people and tourists. During the pandemic, distances lengthened, probably to the detriment of local public transport. E-bike sales are steadily increasing and really took off during the pandemic. We are curious to see whether this development will persist.

What questions drive you and other researchers?

: We are interested in how the potential of micromobility can best be leveraged. What framework of conditions, funding and restrictions do we need for this? These questions are of course closely related to our general mobility patterns and routines. How will these change? Who uses micromobility devices for which routes and for what reason? In France and Spain, we can already see a shift from leisure and tourism to a broader group of users.

As a researcher, it is exciting to be able to follow these developments so closely. What reasonable and sustainable scenarios exist for the use of micromobility devices? Researchers at the DLR Institute of Vehicle Concepts are investigating the emissions generated during the manufacture and use of micromobility devices and their carbon-dioxide reduction potential compared to other vehicles. Personally, I'm also interested to see if these new modes of transport have a role as a status symbol for certain groups, such as young people.

Is this new form of mobility actually good for the environment?

: If they are going to have a benefit, the vehicles must be manufactured, distributed and deployed adequately. Some e-scooter

service providers are already paying more attention to sustainability. To achieve the best possible environmental balance, robust and durable vehicle models and replaceable batteries are as important as, for example, ensuring that e-scooters are collected with e-cargo bikes instead of diesel vans. Users should also ask themselves which routes and means of transport they are going to replace with the micromobility solution. Riding an e-scooter, instead of walking or cycling for example, is not in the interest of sustainability. The data show that around 30 million car journeys made each day cover less than two kilometres. In one DLR study, we calculated that 13 percent of car journeys in Germany could be replaced with e-scooters. The potential, then, is clearly there, and the question now is how it can be realised, at least in part.

Light electric vehicles can reduce greenhouse gas emissions from the transport sector by up to 40 percent. This was shown in a study by the DLR institutes of Transport Research and Vehicle Concepts.

Laura Gebhardt
studied geography and sociology with a focus on the city and urban development processes, and then worked at the Geographical Institute of the University of Bonn. She has been a research associate at the DLR Institute of Transport Research in Berlin since 2014. Her research focuses on everyday mobility behaviour, what people need to be mobile, and the question of how civil society can be involved in the development of future mobility concepts. This was the topic of her thesis.

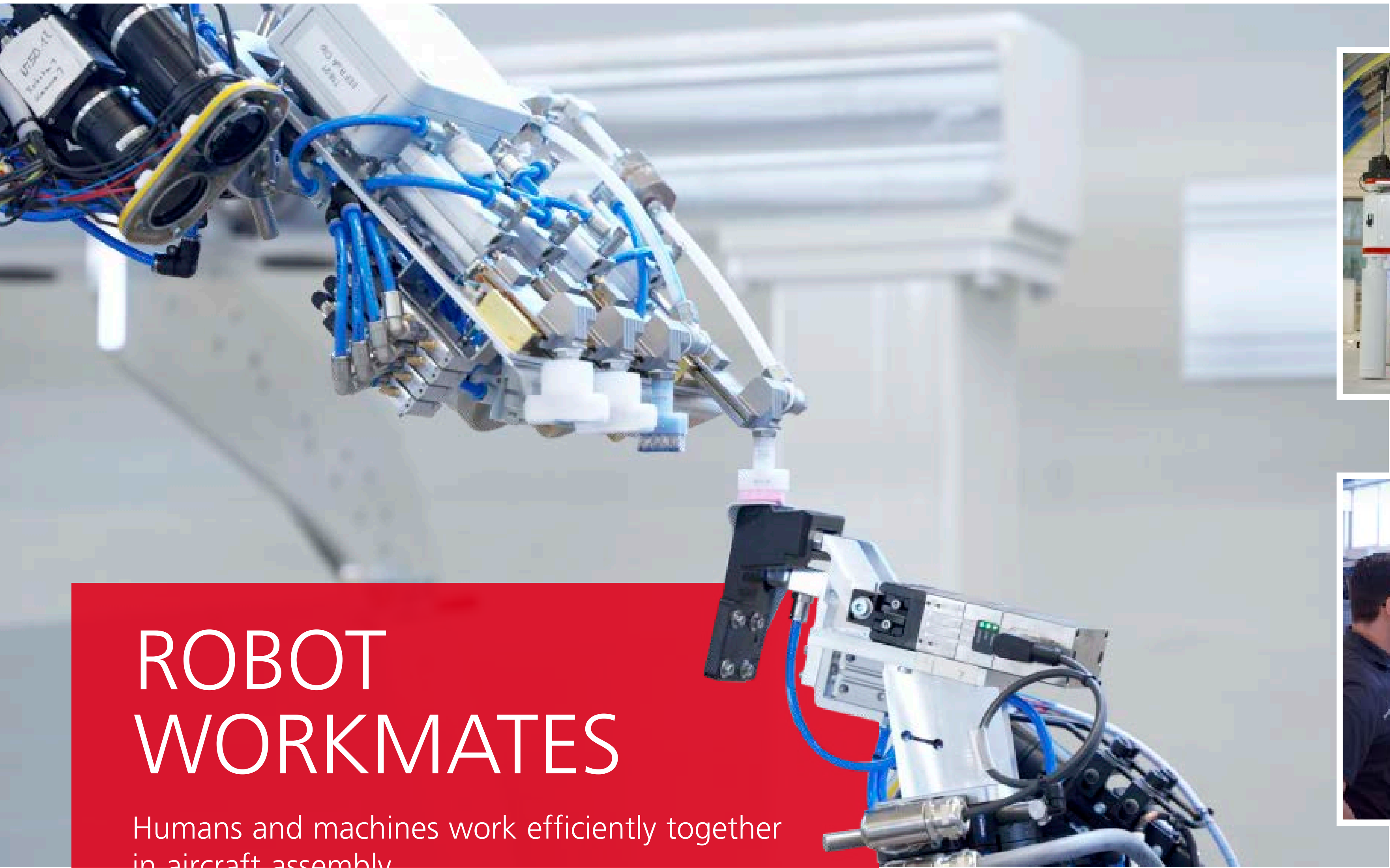
© DLR

"Driving an e-scooter instead of walking or cycling is not in the interest of sustainability."
Laura Gebhardt

What does the future of micromobility hold?

: At the moment, micromobility devices are perceived as yet another, often disruptive means of transport. This can and does lead to conflicts, for example when e-scooters are parked on cycle paths or footpaths. If an energy transition is to be implemented, such as moving away from private cars, we will also need a conversation about the redistribution of urban space. Fewer cars will free up space to be redistributed and used by more diverse, different and shared modes of transport. We will undoubtedly see differentiation within the sphere of micromobility: e-skateboards and hoverboards will remain more of a niche product. E-scooters will form a piece of the jigsaw in a sustainable transport system, for distances of two to three kilometres, and as a feeder. A lot will probably also happen with e-cargo bikes. These could be used more and more for deliveries, city cleaning and other services. The potential and role of micromobility stands or falls on the framework conditions. We will not only require innovative vehicles, but also the will to make driving cars less attractive and less necessary.

Interview by **Denise Nüssle**, Media Relations editor at DLR.



ROBOT WORKMATES

Humans and machines work efficiently together in aircraft assembly

by Marcin Malecha and Julia Heil

Building an aircraft takes time. In contrast to the automotive industry, where over 1000 vehicles can leave a factory on any given day, Airbus builds only around 60 aircraft per month. Manual work is still involved – structures must be cleaned and stiffening elements pre-assembled and fastened in place. The processes involved require a high level of accuracy and are time-consuming. New concepts and technologies can help increase the amount of work that can be automated. Together with partners from industry and research, DLR is investigating what cooperation between human and machine might look like.

The fuselage of a medium-haul aircraft such as the Airbus A320 consists of several segments, called sections, which are made up of several shells. To prevent the metal outer skin of a shell from buckling, it is held in place by a support structure, similar to that of a ship. Before a worker can assemble the elements of the support structure, which can be up to seven metres long, the outer skin must be cleaned and an activation liquid and sealing compound applied. Only then is the support element fitted and pre-assembly completed. During the final assembly, highly skilled workers must fasten up to 1000 rivets per segment to firmly connect the components. This is followed by a final quality inspection.

Automation in pre-assembly and final assembly

These two process steps – the pre-assembly and final assembly of a shell – formed the core of a research project called 'Agreed'. DLR was the commissioning party for the project and worked together with the aircraft manufacturer Premium Aerotec to digitalise and automate the processes involved. Premium Aerotec manufactures fuselage parts for various types of Airbus aircraft. Pre-assembly takes place in Augsburg and final assembly in Nordenham, Lower Saxony. "A huge benefit for us was the fact that we had access to the data and were working with components that would fly on real aircraft. These are normally confidential," says Marcin Malecha, who works at the DLR Center for Lightweight-Production-Technology (ZLP) and led the project for DLR. "We also worked together with experts from production, which has enormously increased levels of acceptance for the technologies developed. The results will greatly benefit our future research."

> *"A huge benefit for us was the fact that we had access to the data and were working with components that would fly on real aircraft."*
> **Marcin Malecha**

Mobile transport units bring the robots to their workstations. They are equipped with sensors that register movements. If a person gets too close to them, they stop until the path is clear.

Digital twins were developed for the pre-assembly and final assembly of the aircraft shells, representing every step in production.

THE AGREED PROJECT AT A GLANCE

Agreed was an internal DLR project. The aim was to develop automation solutions for flexible and expandable shell assemblies using digital intelligence. In addition to technological research, DLR also assumed the administrative and planning roles. The work was coordinated in cooperation with the general contractor Premium Aerotec GmbH. Other participants from industry and science were subcontracted for extensive research work: Broetje-Automation GmbH, Viscotec GmbH, University of Wuppertal, Fraunhofer IFAM, Fraunhofer IFF and Capgemini.

s.dlr.de/Agreed1
s.dlr.de/Agreed2

Planning and development in the digital factory

The team started by developing what are known as 'digital twins' for pre-assembly in Augsburg and final assembly in Nordenham. This accelerated process development, as all tools could be tested prior to prototyping and the robotic movements programmed before the equipment was physically built. The virtual environment represented every step of production. The digital twins were the basis for the daily work plan, showing how many workers and robots would be in use. The experts themselves were equipped with augmented-reality headsets. These displayed the work steps and assistance options, and controlled the distribution of tasks between humans and robots. Artificial intelligence was used in some process steps, taking over the programming, for example, in the complex threading movements of clips during pre-assembly. At other points, the robots moved completely autonomously, such as during drilling and completeness inspections. The drilling and riveting tools were specially developed and brought to their respective stations together with lightweight robots on mobile transport units. Their routes were also controlled using the digital twin.

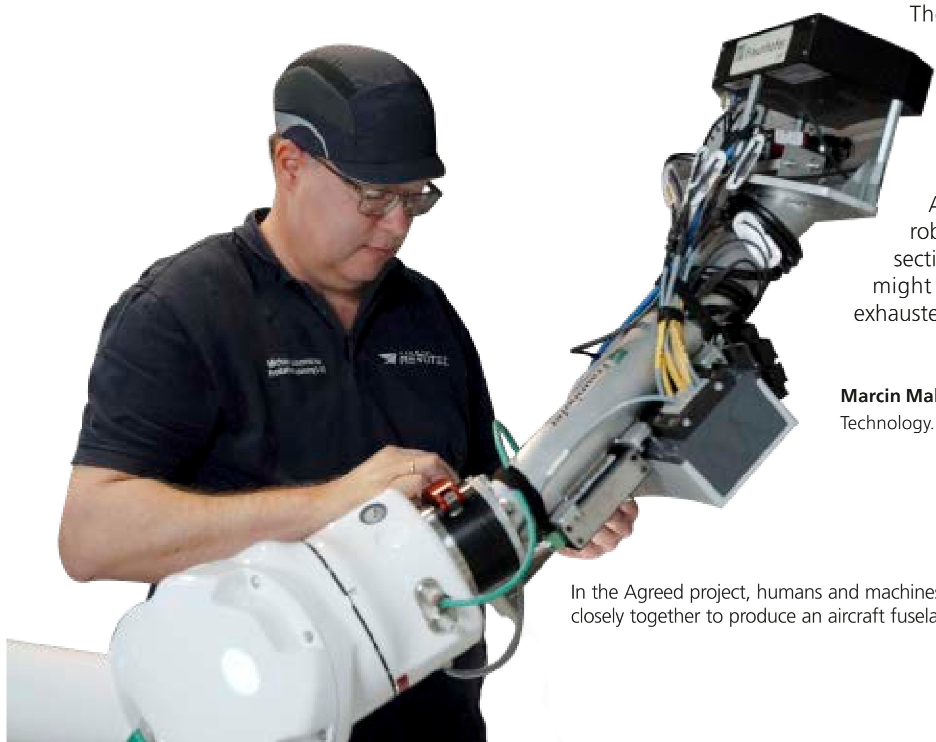
In parallel, the researchers designed the robots and tools needed to clean the outer skin and fix the support structures. Here, too, the experts benefited from the digital twin. "The program showed us directly whether our tool was the right size or in the right place, and where we still needed to make adjustments. This saved us from having to build many prototypes," adds Malecha.

Two successfully tested concepts

During the project, the team was able to completely automate the pre-assembly process – it ran entirely without human intervention. Human and machine worked closely together during the final assembly. A robot took over quality assurance, comparing the position of the rivets and drill holes with the digital construction plans using images from mounted cameras. A specialist only intervened to assess whether corrections should be made if a position did not match up.

The systems are currently running on Premium Aerotec's research facilities. "It will probably take another two to three years before the first automated or cooperative station is used in production. However, there is a lot of interest from industry in the technologies developed in the Agreed project," Malecha says. And if he has his way, the project will not end here. Together with Premium Aerotec, a concept is set to be developed for a station where robots work on several components in parallel and follow the section assembly. Malecha is confident of success: "Automation might not be suitable for all processes, but we have not yet exhausted our possibilities."

Marcin Malecha is a project manager at DLR's Center for Lightweight-Production-Technology. **Julia Heil** is an editor at DLR Communications.



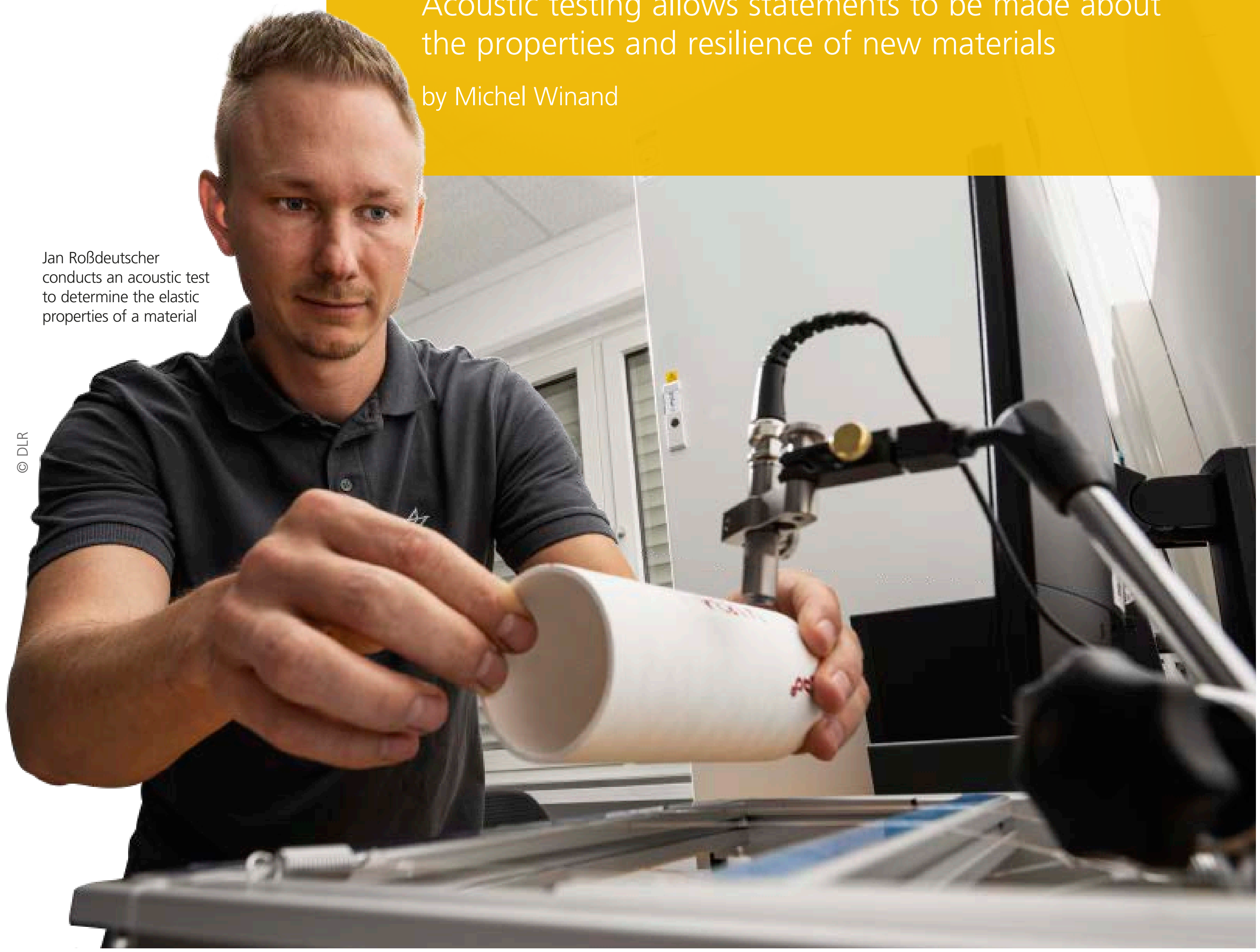
In the Agreed project, humans and machines worked closely together to produce an aircraft fuselage.

Images: Tobias Blaser/Lichtwerk

TUNING IN

Acoustic testing allows statements to be made about the properties and resilience of new materials

by Michel Winand



Jan Roßdeutscher conducts an acoustic test to determine the elastic properties of a material

When materials are exposed to stress and strain or harbour small defects, their sound changes. Tensile- and compressive stress also influences the vibration behaviour of materials. This phenomenon is used, for example, when strumming a guitar. Even in ancient times, potters would use a sound test after firing their clay vessels – damaged vessels produced a duller sound. Today, sound is still used to inspect the quality of clay or porcelain in industrial series production and to quickly identify damaged components. What is more, researchers at the DLR Institute of Materials Research are also using this method to develop new high-performance materials for aviation, spaceflight and the energy sector.

"Until now, we always had to test our materials to destruction to determine whether their load-bearing capacity had changed. Since these materials are used in a wide temperature range, a large number of samples had to be tested, which was a time-consuming and expensive process. With the non-destructive acoustic test, this is no longer necessary," says Jan Roßdeutscher, a researcher at the DLR Institute of Materials Research, describing the process.

Stability, even at high temperatures

Fibre-reinforced ceramic components are used, for example, in high-temperature combustion chambers. Conventional combustion chambers made of metal alloys have a temperature capability of approximately 1200 degrees Celsius. Combustion chambers made of fibre ceramics are far more resistant to high temperatures, which is beneficial for the combustion process, and allows them to run more cleanly and efficiently. Due to their fibre-based structure, these ceramics are less fragile than their well-known cousins in tile form, although they have a similar level of hardness.

The sound of materials

With the impulse excitation technique, material samples can be examined in a temperature range from room temperature to 1600 degrees Celsius. During these tests, the sample is placed in the apparatus, where it is tapped with a small projectile. A microphone records the resulting vibrations. Roßdeutscher's team uses the recording to determine both the resonance frequency of the sample and its damping – in other words, the extent to which it transmits the vibration energy. The measurement curves recorded provide information about how the material behaves during use, and if necessary, how it will change under different circumstances.

The researchers can also identify possible material transformation effects, such as the sintering of ceramics and chemical reactions occurring in the material. "We save an enormous amount of time and materials in contrast to the tensile test we have been using up to now. We no longer have to examine a new material sample for each temperature, but can record any number of measuring points with one sample. This enables us to better describe temperature-dependent behaviour of the materials," adds Roßdeutscher.

The researchers are currently using the impulse excitation technique to determine the properties of materials. These are important in order to be able to realistically simulate and design larger components to be manufactured using those materials. With the results of the acoustic test, fibre-composite ceramics can be produced more efficiently and economically, as scientists can check the quality at each individual production step and detect defective components at an early stage.

From turbine blades to brake discs

The results are used to develop materials that are even more resistant to high temperatures, while having high strength and damage tolerance. The acoustic test also provides information on whether entire components made of fibre-reinforced composite ceramics, such as new types of turbine blades or ceramic brake discs, have weak points. The resonant frequencies of the component are determined and compared with a reference component, the properties of which are known. If the measured resonance frequencies deviate significantly from the reference, this indicates a defect.

In the future, the Institute's researchers would also like to specifically investigate production-related differences between planar and non-planar geometries. With these results, they hope to further optimise the simulation models and manufacturing technologies for fibre-composite ceramics and thus increase their reliability and efficiency.

Michel Winand is responsible for communication at the DLR sites in the western region.

A projectile taps the component and causes it to vibrate

A microphone records the sound of the vibrating blade model

THE DLR INSTITUTE OF MATERIALS RESEARCH

New material solutions and their respective process technologies are developed here for applications in the aerospace, energy and automotive sectors. The scientists examine metallic, hybrid and ceramic materials, develop coatings to prevent the effects of damaging environmental agents on materials, components and structures. They also research thermoelectric systems, as well as aerogels and aerogel composites. In addition, the Institute carries out mechanical material tests, and materials are analysed on a microscopic level.

"We save an enormous amount of time and materials in contrast to the tensile test we have been using up to now. We no longer have to examine a new material sample for each temperature, but can record any number of measuring points with one sample."

Jan Roßdeutscher

Ceramic combustion chambers are highly heat-resistant

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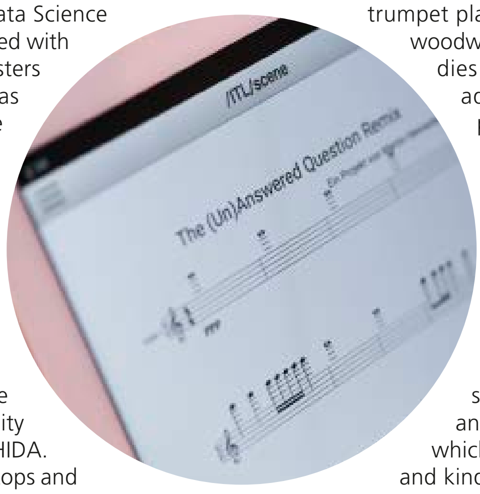
AI ADDS FEELING TO THE MUSIC

A musician and a group of DLR researchers have developed artificial intelligence that transforms an orchestral piece using live audience reactions

by Katja Lenz

No, the piece was not a smash hit – that we need to admit. However, the orchestral work 'The Unanswered Question' by Charles Ives sounded different without a doubt in this unique musical experiment – all thanks to the audience and an artificial intelligence (AI) program that evaluated the listeners' reactions to the original music and used the results to rewrite the piece.

Art in science, science in art. Saarbrücken-based musician Martin Hennecke united art and science for his project: 'The (Un)Answered Question – a musical data science experiment'. He joined the DLR Institute for Software Technology on an interdisciplinary research grant from the Helmholtz Information & Data Science Academy (HIDA). For three months, he worked with the researchers on software, developed clusters and gathered data. The key question was whether an AI program could create a live orchestral remix. It turns out that it can, as proven by a trial performance in Dortmund in May. A concert is set to follow at Saarland State Theatre in November – in front of, and with the help of, a large audience.



Lyrics, music and software come together

The event in Dortmund is on a somewhat smaller scale. There is a workshop feel at the venue – the Academy for Theatre and Digitality – which is supporting the project alongside HIDA. Three DLR employees have opened their laptops and are making final adjustments to the software. There are 10 chairs for the audience, two cameras for facial recognition, nine music stands for the musicians and another for the conductor.

The rehearsal begins with a prelude – the first part of the project. An actor recites the poem 'The Sphinx' by Ralph Waldo Emerson (1803–1882). On a screen, a large MRI image of the actor's beating heart, which was taken at the Max Delbrück Centre for Molecular Medicine in Berlin, another project partner. The theme of 'bigheartedness' is a common thread running through the project. The poem itself revolves around a story from Greek mythology, in which a sphinx is laying siege to the city of Thebes and killing anyone unable to solve its riddle. This story provided the inspiration for the piece 'The Unanswered Question' by Charles Ives (1874–1954). The US-American composer wrote long notes for a string quartet. Several times, a trumpet plays a refrain that sounds like a question. Four woodwind instruments play completely different melodies. During his lifetime, Ives was known for his adventurous compositions. True to form, this piece features certain dissonances – there are moments when it sounds a bit 'odd'.

The test audience listens to the music for six minutes. Although the music stands are set up as they would be for a real performance, the piece is not being played live; a video of a symphony orchestra is being shown. The listeners in Dortmund are wearing wristbands that record their heart rate. When the flutes start up, some pulses rise. The listeners filled out an anonymous online questionnaire beforehand, which included statements such as 'I'm empathetic and kind-hearted', 'I don't have much compassion for others', 'I'm helpful and selfless', 'I tend to be indifferent to others'. For each statement there were five possible answers, ranging from 'Totally disagree' to 'Totally agree'. This allows the AI program to make a more effective assessment of the audience. The facial recognition software distinguishes between happiness, sadness, anger, neutrality, disgust, surprise and fear. These emotions will form the basis for the AI's edits. How do people feel about the piece? The answer is apparent on the screen a little later: lots of little dots bounce back and forth between neutral, angry, sad and happy, while the heart image in the middle keeps on beating.

> *"Even if the audience is not familiar with data science, we can use the music and the visualisations to convey what is happening with the data and through the data."*
>
> **Carina Haupt**

Then the AI program gets to work. It gauges the audience's emotions and heart rate, assesses the information from the questionnaires and rewrites the piece. The form that this will take is impossible to predict. "I'm curious to hear how it will sound," says Martin Hennecke. The AI program does not work in a linear way. "If someone is feeling sad, the piece does not automatically become more cheerful." The algorithm, which the DLR researchers developed together with Hennecke, clusters the data to summarise them, evaluates them and then triggers changes to the remix.

The new piece is ready to play immediately. During the trial run in Dortmund, it is performed purely electronically. The rhythm has changed, and very long notes have become shorter. The harmonies are more pleasing to the ear and follow different sequences. During the performance in Saarbrücken, the musicians will play the remixed version directly from electronic tablets in the hall. For them, 'The Unanswered Question' will be entirely transformed once again. "The way in which the orchestra and the audience interact makes this a special artistic experience," says Hennecke. "Using digital tools and techniques from the field of data science, the experience becomes even more vivid and human, interestingly despite the fact that it is achieved using technology and computers."

© DLR

Rehearsal performance of 'The (Un)Answered Question – a musical data science experiment'. The audience's reactions are immediately recognised and displayed by the artificial intelligence.

Visualisations show the audience how researchers work

The researchers at the DLR Institute for Software Technology see the overall project as something very special. It comprises the recitation of a poem, data collection during the playing of a classical piece, and ultimately a remixed work. "Even if the audience is not familiar with data science, we can use the music and the visualisations to convey what is happening with the data and through the data," says Carina Haupt of the Institute for Software Technology. Together with Andreas Schreiber, she is responsible for the project at DLR. Among other things, the Intelligent and Distributed Systems department uses visualisations to display complex software architectures. "We are using a similar approach here. We are working with images and metaphors to combine and represent heart rate and emotions," adds Schreiber.

© DLR

Musician Martin Hennecke worked with the researchers at the DLR Institute for Software Technology. An MRI image of a beating heart can be seen on the screens.

There is no break for Martin Hennecke following the November event at the Saarland State Theatre, where he also performs as a timpanist and percussionist. His next project will focus on ballet: he is writing a score that can be changed in real time via the processing of personal data online. This data will come from the members of the Saarland State Ballet and, of course, the audience.

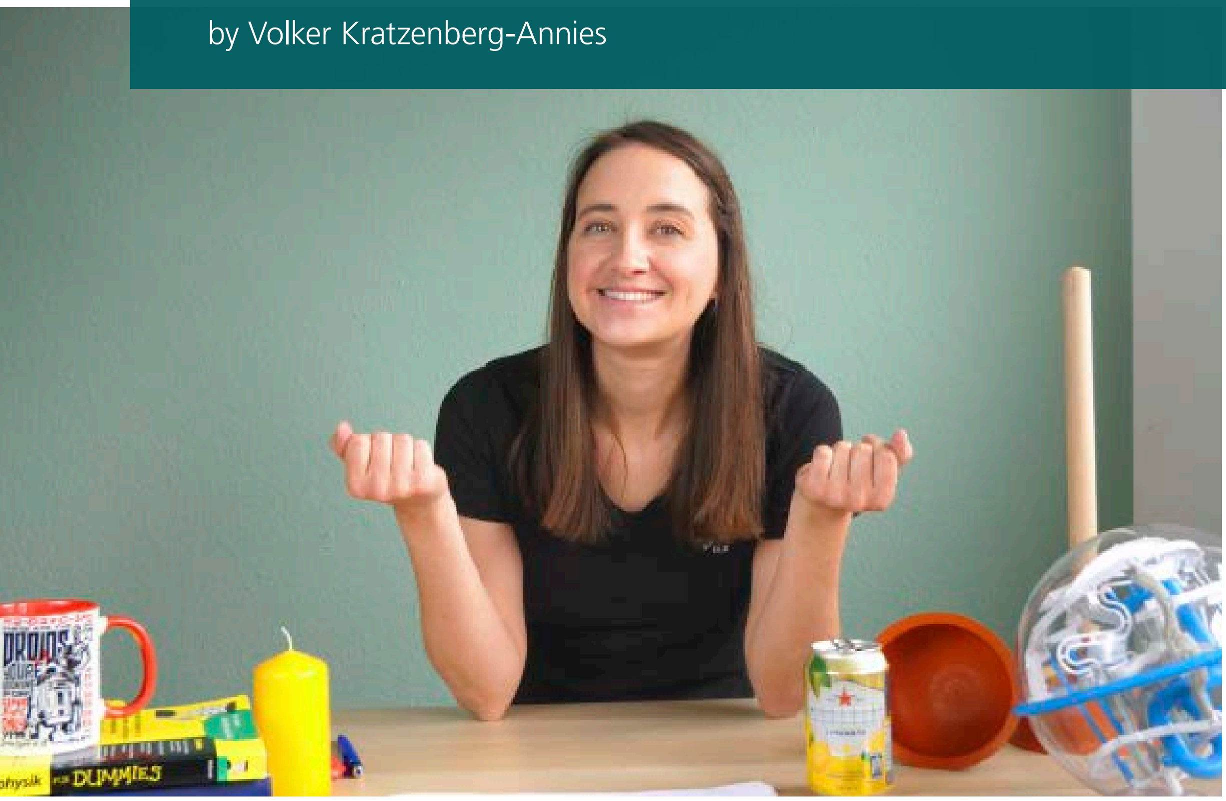
Katja Lenz is a member of DLR's Media Relations team.

Two cameras observe the audience. The recordings, along with information from a special wristband and a questionnaire, serve as the basis for the new piece of music.

THE SPACE STATION IN THE CLASSROOM

DLR_School_Labs go online

by Volker Kratzenberg-Annies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In educational videos, DLR presenter Sina Kürtz conducts experiments that children can replicate at home.

The students watch spellbound as a drop capsule falls into the depths at the DLR_School_Lab in Cologne: How will water and air mix in the small glass container when its contents become weightless in free fall? Meanwhile, the DLR_School_Lab in Jena is showing young people how a smartphone can be turned into a polarising microscope with just a few tools, allowing them to examine the surfaces of meteorites and onion peels. In Oberpfaffenhofen, a guided tour through the German Space Operations Center is a source of great enthusiasm. All of these experiences share one thing – during the activities, the students are not on site but online from their classrooms. These are 'digital lessons', developed by DLR's Education and Outreach programme during the COVID-19 pandemic, and conducted many times since then.

While this was initially the best possible substitute for in-person teaching, which was interrupted in March 2020, the online format today forms an integral part of the repertoire of the DLR's student laboratories. These programmes continue to be expanded further even though regular school attendance has resumed.

Hands-on is more fun

Each year, approximately 40,000 schoolchildren attend the 15 DLR_School_Labs, located at DLR sites and partner universities. The demand from schools is so high that waiting times are sometimes longer than a year. Almost 450,000 children and young people have visited the school laboratories since the opening of the first one. Hands-on experimentation is at the heart of the labs. Under expert supervision, the pupils carry out experiments, simplified for each age group, looking at current research topics, from electric flight using fuel cells to satellite Earth observation, from the use of solar energy to avoiding congestion on the road. Our young explorers can investigate an artificial Mars landscape with a small rover, be air traffic controllers, examine composite materials, 'bake' an artificial comet in a small space chamber, optimally align solar cells with a light source – in short, immerse themselves in the world of science, learning new things and discovering that research can be exciting and great fun.

The global response to the Coronavirus pandemic brought an abrupt halt to the programme. Instead of face-to-face set-up, online alternatives were developed on the basis of a study-of-concept, including a nationwide survey of teachers and clarification of many questions about the technology used, data protection and many other details. Approximately 10,000 schoolchildren have now taken part in DLR's 'digital lessons'. Newly developed didactic videos have been viewed more than 60,000 times and our other digital formats are also very popular.


TU Dortmund

An employee of the DLR_ School_Lab TU Dortmund at an online workshop


© DLR

Several schools connected during a live ISS call with astronaut Matthias Maurer

Interest in Germany and beyond

"I still have to give three lectures to school classes today," says Richard Bräucker in a hurry from the Monday Skype meeting. The long-time Head of the Cologne DLR_School_Lab is in his home office, while students listen to him from Dresden, Konstanz and other places, showering him with questions – and sometimes even persuading him to 'add on' another lesson. The same thing happens to all the other heads of the DLR_School_Labs, Frank Fischer from Braunschweig among them. School after school signs up for his online presentation on the International Space Station ISS. The school laboratory in Bremen oversees school projects lasting several weeks and regularly gives tips online. In Göttingen, laboratories and hangars that are otherwise inaccessible to visitors can be opened up to school classes in a virtual live tour. In this way, schools can experience the DLR school laboratories, for which the distances to travel would otherwise be much too great. National borders are no object either – online connections have been made from the DLR_School_Lab in Berlin to the German School in Shanghai and to New Delhi. Elementary schools and kindergartens also make use of DLR's online services. "These activities were a real highlight for our children during lockdown," wrote one teacher at a daycare center in Odenwald to Tobias Neff, head of the DLR_School_Lab in Lampoldshausen.


© DLR

Learning online

➋ Find all the online offers of the DLR_School_Labs as well as hands-on activities and teaching materials at **DLR.de/next.** (German only)

At the other end of the education chain, university students also benefit from this new line of activity: International summer schools on space propulsion and space weather, which otherwise take place on site in Lampoldshausen or Neustrelitz, were recently held in digital form – with participants from many countries and speakers connected from places like Kourou in South America, South Africa and Huntsville in the USA, among others. University DLR_School_Labs at Aachen, Augsburg, Darmstadt, Dortmund, Dresden and Hamburg are also active online with exciting lectures by experts, teleworkshops specially for girls, learning opportunities on social media platforms such as Instagram, and entirely new formats such as a 'digital escape room quiz!'

New formats make it possible to continually expand the offer

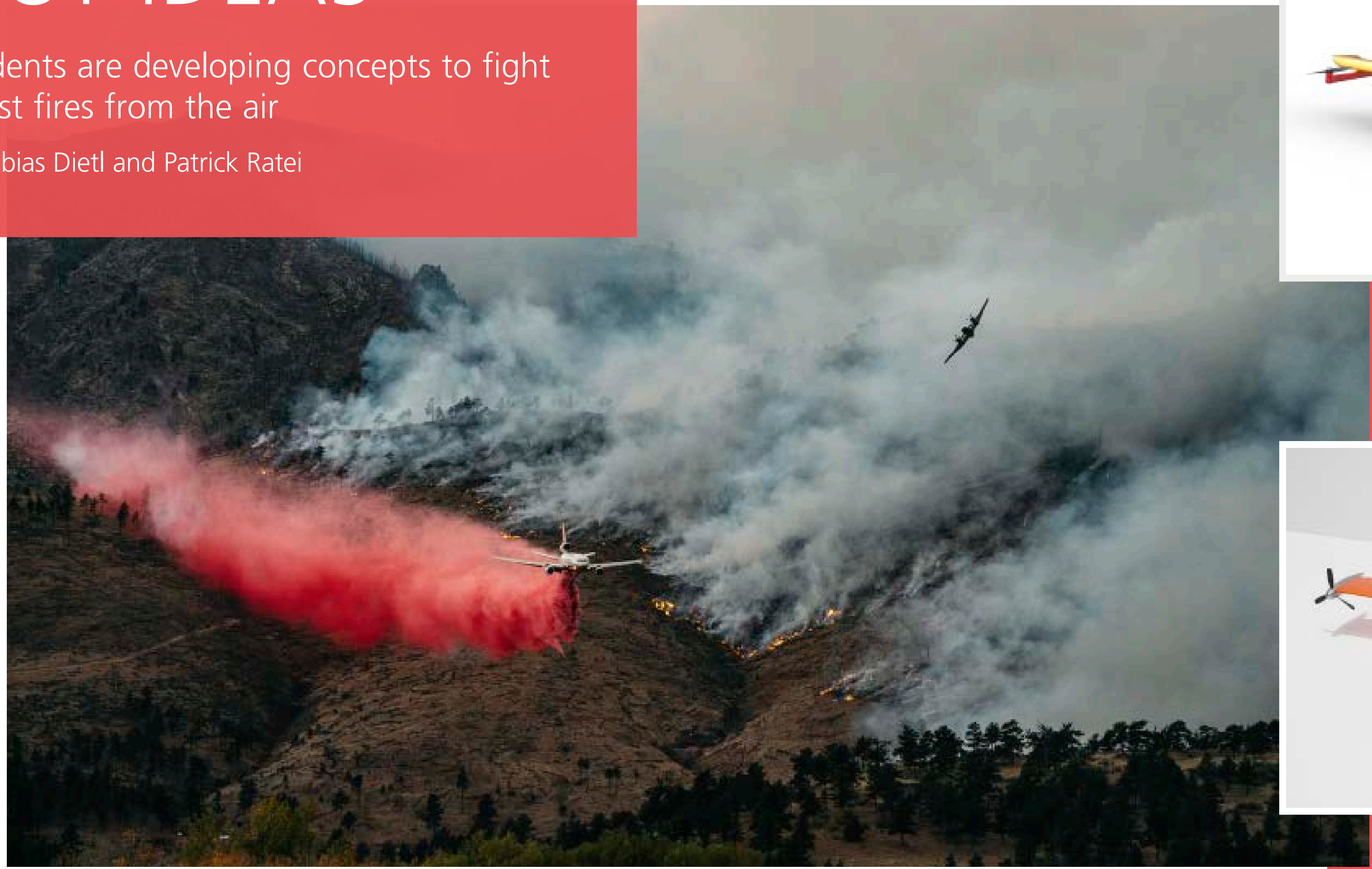
With the online formats, DLR has developed a new form of addressing young target groups, which will continue after the return to face-to-face teaching at the DLR_School_Labs. In doing so, they deliver well-grounded and fascinating content for digitalisation in education, thus supporting this important political objective. At the same time, there is potential to engage even more young people in research. Going far beyond career-oriented aspects, the aim is to promote a constructive and positive attitude towards science among the younger generation – a 'learning goal' that is perhaps more important than ever.

Volker Kratzenberg-Annies has been working at DLR since 1989 and has been involved in education and outreach at DLR since 2007.

HOT IDEAS

Students are developing concepts to fight forest fires from the air

by Tobias Dietl and Patrick Ratei



Adobe Stock/Tandem Stock

This year's hot summer will be remembered for years to come. Reports of new forest fires made the news almost daily, including in Germany, while fires in France, Italy, Spain and Portugal destroyed thousands of hectares of forest and released large amounts of carbon dioxide. With climate change, such catastrophes may become a regular phenomenon of the European summer. When areas of forest catch fire, emergency crews on the ground are often backed up by aircraft and helicopters in a bid to contain the flames. Aircraft are invaluable tools for slowing the spread of fire because they can drop large quantities of water on selected target areas. Unfortunately, this form of firefighting is very expensive and the technology used is often outdated. So, the DLR Design Challenge 2022 set students from all over Germany the task of developing new concepts for airborne firefighting.

The brief was challenging; teams had to design a fleet of aircraft that together could deliver at least 11,000 litres of water per flight to the location of the fire. Teams were free to specify any number of aircraft and a suitable delivery system. Since the aircraft had to be able to load water from nearby sources such as small lakes, rivers or the sea, they needed short or vertical take-off and landing capabilities. Each of the aircraft had to be able to be flown either by one pilot on board, from the ground or autonomously – including at night time and in poor visibility conditions. Modular design for production was also part of the mission requirement; concepts had to be structured in such a way that a single production line could produce an aircraft for firefighting, passengers or cargo transport. The hypothetical entry into service was scheduled for 2030. The six teams that applied were given four months to complete the task.

> *"The difficulty this year was having to consider the interaction of the various systems involved on top of the design of the aircraft."*
>
> **Markus Fischer**

"The difficulty this year was having to consider the interaction of the various systems involved on top of the design of the aircraft," said Markus Fischer, DLR's Divisional Board Member for Aeronautics and Chairman of the Jury, speaking at the award ceremony. He added: "All of the teams mastered these challenges and can be rightly proud of themselves."

DLR DESIGN CHALLENGE 2022 TOP THREE

Universität Stuttgart/INFERNO

The team from the University of Stuttgart, consisting of Ahmet Günay Can, Hannes Kahlo, Benjamin Knoblauch, Nicolas Mandry, Prishit Modi and Johannes Ritter, designed INFERNO. This modular, hybrid electric-powered vehicle can be operated as a firefighting aircraft or used to transport people and goods.

TU Dresden/PEL-E-FAN-T

Dominik Brunner, Hannes Jerzembek, Lennard Köhler, Paul Sanderbrand and Maximilian Wenk from Dresden Technical University designed the PEL-E-FAN-T. This unpiloted aircraft can be equipped with various modules. In fleet operations, for example, two vehicles can be equipped with a reconnaissance module in order to pass important information to the rest of the fleet, which will be equipped with firefighting modules.

RWTH Aachen/FireWasp

The FireWasp compound helicopter was developed at RWTH Aachen University. The concept, by Mucahit Fatih Evliyaoglu, Selim Karakus, Dominik Kau and Robin Mörsch, uses a conventional gas turbine. By the time it enters service in 2030, the unmanned aircraft should be able to be operated entirely with sustainable fuels.

First place – INFERNO, from Stuttgart

This full-system specification inspired the winning team, from the University of Stuttgart. "It didn't seem so at first, but the deeper we delved into the topic, the clearer it became that we would need to get pretty creative to be able to meet all the requirements," says team leader Johannes Ritter. Their INFERNO concept uses eight horizontal rotors for vertical take-off and landing and two propellers for forward flight. The drive is hybrid-electric and can be refuelled with sustainable fuels. The flying vehicle has a scoop/inlet for taking water on board, but it can also use smaller bodies of water by partially submerging. INFERNO is controlled by a single on-board pilot, so the team put a lot of thought into the flight deck design and assistance systems – after all, it has to be flown safely even in poor visibility and at night. To save time during operations, the vehicle can also be refuelled in flight.

© DLR/Universität Stuttgart/Team INFERNO

From left to right: Benjamin Knoblauch, Hannes Kahlo, Ahmet Günay Can and Prishit Modi from the University of Stuttgart team.

Second place went to the team from Dresden Technical University. Their PEL-E-FAN-T concept is an uncrewed aircraft featuring a hybrid electric power system. It can take off and land vertically and can therefore also use very small sources of water for extinguishing operations. The FireWasp compound helicopter from RWTH Aachen took third place. FireWasp combines the advantages of both helicopters and fixed-wing aircraft. The fleet consists of a reconnaissance vehicle and six firefighting aircraft – operating either autonomously or by remote control from a mobile ground station if required.

A generator of ideas and a step into the future

The DLR Design Challenge has been held since 2017. The DLR Institute of Aerodynamics and Flow Technology and the Institute of System Architectures in Aeronautics take turns organising the annual event. Topics have ranged from quiet, low-emission flying to supersonic passenger aircraft, climate-friendly light aircraft and autonomous, reliable aviation in urban areas using drone technology. "We attach great importance to the coherence of the students' concepts," says Björn Nagel, jury member and Director of the Institute of System Architectures in Aeronautics, which organised the competition this year.

For many participants, the annual competition is the start of more work: The HyBird concept of the 2019 winning team from the University of Stuttgart, for example, will be further developed by DLR's Innovation Center for Small Aircraft Technologies. RWTH Aachen University's 2020 winner, a parcel drone concept called Urban Ray, has given rise to a start-up. The students from the Technical University of Munich, who took third place in 2020 with the Mercurius hydrogen-powered drone, continue to work on the concept. DLR also benefits from the Design Challenge; since the beginning of the competition, participants have been employed on a regular basis, continuing to build their aircraft design experience.

Tobias Dietl and **Patrick Ratei** both work at the DLR Institute of System Architectures in Aeronautics. They took over coordination of the DLR Design Challenge 2022.

CLIMATE CHANGE AND THE ECONOMY

An economic and socio-scientific perspective

Interview with Stephanie Becker and Horst Steg

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The latest Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) and a current evaluation from the World Meteorological Organization underline that we are now dangerously close to global warming of 1.5 degrees Celsius. Achieving climate neutrality means facing major economic and societal challenges. Meeting the requirements for climate protection will require nothing less than restructuring our transport system, approach to mobility and entire sectors, such as the energy-intensive raw materials industry. With its 'Economics of Climate Change' funding measure, the German Federal Ministry of Education and Research (BMBF) addresses the methods and tools with which we may successfully advance climate protection and address climate change from an economic and socio-scientific perspective. The DLR Projektträger has been a partner on the activities of this initiative since the very beginning.

Why is climate economics research so important?

Becker: In order to keep global warming well below two degrees Celsius – and if possible, below 1.5 degrees Celsius – and achieve carbon neutrality by 2045, we need to know about the economic impact of climate change and which climate protection strategies are available. This is where climate economics research comes into play: it sheds light on how we might implement the economic transformation, which climate policy instruments are effective and efficient and how to address remaining climate-related risks. Such research provides reference data and other information that provide guidance and decision-making tools for the debate on of climate and energy policy, so it is a vital prerequisite for successful policy decision-making. The BMBF's Economics of Climate Change funding measure adds economic and socio-scientific perspectives to the issue, which has long been strongly geared towards the natural sciences.

How were the research findings applied?

Becker: To give one example, scientists and practitioners learned from previous environmental agreements and derived practicable recommendations for the future of the Paris Agreement, such as setting a global carbon dioxide price.

Steg: When developing funding measures it is important to consider the transfer to economy and society right from the beginning. The 'Dialogue on Climate Economics' – that overarching accompanying process in the funding measure in addition to single research projects – has also proven very important. It ensures that scientists enter into direct interaction and exchange with stakeholders from industry, administration, politics and civil society.

Horst Steg is an economist. He leads the Research Policy and Climate Protection coordination group at the DLR Projektträger. His work includes socio-economic climate research, research policy concepts and climate protection strategies.

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What are some recent examples of successful funding?

Steg: One example is the management of the phase-out of coal. Specifically, the scientists examined the development potential of the energy transition in Lusatia. The focus was on wind energy, photovoltaics, bioenergy, heat pumps and energy-efficient building renovation. A second example is the important contribution of science to the instrument of carbon pricing, which was embedded in the German government's 2030 climate protection programme for the heat and transport sectors.

How can you ensure that these changes are not just a flash in the pan, but will go on to have a long-term impact?

Steg: In the past, we were still looking to the USA for research into climate-related economics. The relevant competencies and capacities have now been consolidated in Germany, too. It is vital that such topics are not only researched under project funding for a limited period, but become areas of focus for scientific institutions, companies and society over the longer term. That is our job as a project management agency. In terms of climate economics, we have created a scientific community in Germany that can react directly to climate and energy policy issues and is able to communicate them in a way that can be understood by the general public. For instance, immediately after the Russian invasion of Ukraine, climate economists presented models and assessments of the potential effects of the war on German and international climate policy, and the economic consequences of an embargo on gas.

Becker: In the field of climate economics, Germany has an established network of scientific institutions that complement each other's expertise, exchange information and achieve reliable results. Young scientists, whose competence has been deliberately developed over recent years, are just as essential for the long-term success of such endeavours. In the future, these people will work in a wide variety of roles and functions in science, business, policymaking and administration and will bring their significant expertise and perspectives in climate economics with them.

> *"It is vital that such topics are not only researched under project funding for a limited period, but become areas of focus for scientific institutions, companies and society over the longer term."*
>
> **Horst Steg**

This interview was conducted by **Britta Paul** and **Stefanie Huland** of the DLR Projektträger.

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Stephanie Becker is a social scientist focusing on sustainable finance, climate economics and sociological issues related to climate change.

THE BMBF'S ECONOMICS OF CLIMATE CHANGE PROGRAMME

The goal is clear: Germany is to become climate neutral by 2045. This historic challenge poses a series of numerous questions to science, business, politics and wider society. Which paths should we take to achieve the transition? Which interconnections need to be taken into consideration? And which measures and instruments are effective for sustainable and efficient climate protection? More expertise is needed to achieve the ambitious goal of climate neutrality. For this reason, the Federal Ministry of Education and Research (BMBF) is financing the Economics of Climate Change funding measure, with 29 research projects tasked with expanding the necessary economic expertise and developing practical solutions by the end of 2022. The DLR Projektträger has been involved as a technical and administrative partner from the very beginning.

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FROM THE ARCHIVE

In this section, we delve into the DLR archives for stories from the past. This time, we set off on a journey to the Moon.

This pictured of Tracy's Rock is one of the most famous photos from the Apollo era. It shows Jack Schmitt examining this large rock named after Commander Gene Cernan's nine-year-old daughter.

NO STONE UNTURNED

The grand finale of one of humankind's greatest adventures

by Ulrich Köhler

"That's one small step for man, one giant leap for mankind." Many are familiar with the most famous words spoken by Neil Armstrong on the Moon on 20 July 1969. But the last words radioed from the Moon to Earth have a certain historical significance, too. They were spoken by Eugene 'Gene' Cernan, Commander of Apollo 17. Before boarding the lunar module almost 50 years ago, on 14 December 1972, he said, "and as we leave the Moon at Taurus-Littrow, we leave as we came and, God willing, as we shall return, with peace and hope for all mankind. Godspeed the crew of Apollo 17!" Some four days later, one of the greatest adventures of humankind, the Apollo project, came to an end when the Command Module America splashed down in the ocean.

The milestones and extreme feats of this daring endeavour, announced in 1961 by the US President John F Kennedy, are legendary. Between 1968 and 1972, 24 men left Earth's orbit (the only ones to do so to date). Twelve of them left their footprints in the dust of Earth's natural satellite over the course of six successful Moon landings. They all came back alive, even the crew of Apollo 13, which was saved following an oxygen tank explosion when they were two-thirds of the way to the Moon. The astronauts Virgil 'Gus' Grissom, Ed White and Roger Chaffee, who were tragically killed in a fire in the Apollo Command Module during a pre-flight test at Cape Canaveral in 1967, will also be forever remembered.

The end of 1972 marked the conclusion of Apollo, even though three more missions had originally been planned, the destinations selected and the launch vehicles built. President Nixon made the decision in 1971, deeming the programme too expensive. He also feared that there was too little political advantage to be gained from the remaining three missions. NASA did not put up much of a fight. Those in charge were extremely pleased with the results up until that point, especially as all of the astronauts had returned safely, and six crews had delivered a rich treasure trove of Moon samples and technical and scientific knowledge to Earth.

The first scientist in space

This scientific bounty was especially plentiful over the last three missions – the three 'J' missions, each lasting three days on the Moon: Apollo 15, 16 and 17 – as these lunar flights were primarily dedicated to scientific goals. The initial motivation for putting a US-American on the Moon had been a political one – to get there before the Soviets. The goal was to demonstrate the superiority of the free Western world. Nevertheless, these efforts were also accompanied by a scientific programme. To make sure that the first human on the Moon would literally have solid ground to walk on, Earth's satellite was explored beforehand using robotic probes. From the outset, the scientists involved recognised the importance of the Moon for our understanding of all four Earth-like planets. With a surface that is over three billion years old, the Moon provides an insight into the early days of the Solar System. The scientists devised numerous new experiments for Apollo 11 and the five subsequent landings, and provided scientific training for the astronauts. During this process, 11 test and Navy pilots became keen and highly trained lay scientists.

For the final mission, a 'real' scientist, geologist Harrison 'Jack' Schmitt, was selected, with the aim of even further increasing the scientific yield of the mission. Alongside the rest of the Apollo 17 crew, Schmitt thundered into the night sky over Florida on 7 December 1972. The launch of a Saturn V is said to be the loudest noise ever created by humankind. Half a million people watched the spectacle.

Almost 3000 tonnes lifted off from Kennedy Space Center in Florida for the Apollo 17 mission, the last crewed flight to the Moon.

Ron Evans recovering cylindrical film cassettes almost 400,000 kilometres from Earth

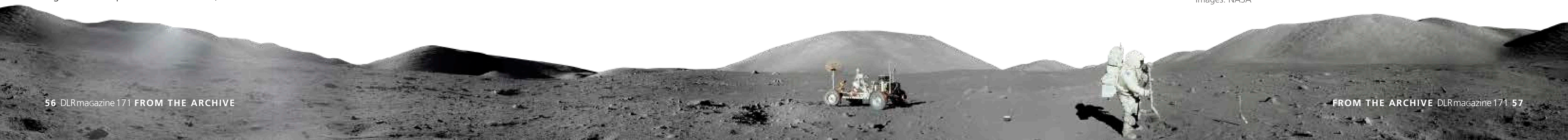
Planetary research has reaped the benefits

The lunar landing four days later ran like clockwork; even the high mountains around the Taurus-Littrow valley did not present any obstacle for Schmitt and Cernan. The two spent three days and three hours on the southeast edge of the Mare Serenitatis – the easternmost of all landing sites – which is filled with volcanic rock. This area was chosen to study a relatively old impact basin. The 3.8 billion-year-old Imbrian Basin that dominates the near side of the Moon had been studied several times on previous missions.

Over three trips with the lunar rover, each lasting more than seven hours, the two astronauts covered 34 kilometres. By the time they were done, they had stowed 110 kilograms of Moon samples in the Challenger. Ron Evans, the command and service module pilot, examined the Moon from orbit using cameras, spectrometers and – for the first time – radar. He holds the orbit record, having flown around the Moon 75 times. Upon their return, the NASA scientists did not know whether to feel sad about the premature end of the Apollo era or rejoice at the scientific and material yield from all of the experiments at the landing site, on the excursions and from orbit. Examining the samples and evaluating the data was the work of decades; indeed, it is still ongoing. The findings fill volumes. Apollo was history. Bill Anders, who circled the Moon with Apollo 8, the first 'lunar' mission in the programme, and who took the famous Earthrise photo in 1969, beautifully sums up the key insight from the whole endeavour: "We set out to explore the Moon and instead discovered the Earth."

Ulrich Köhler is a geologist at the DLR Institute of Planetary Research. As a nine-year-old, he avidly followed the steps of the last astronauts on the Moon. The first Moon landing sparked his fascination with Earth's satellite.

Images: NASA

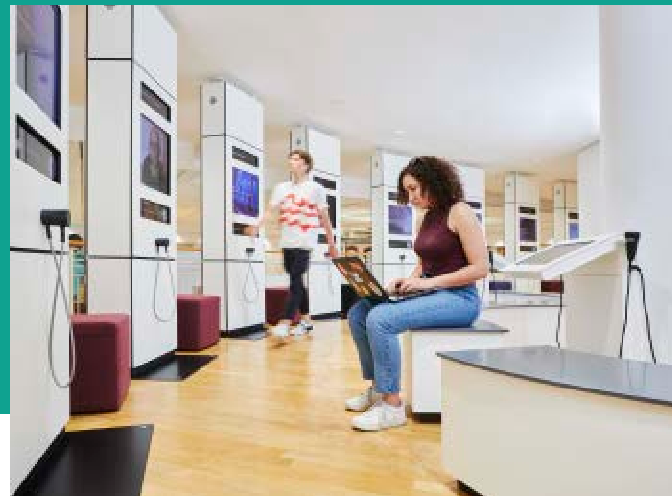


FROM BABYLON TO BROADBAND

At the Frankfurt Museum for Communication

by Joshua Tapley

Thomas Gessner/MSPT



Katharina Dubno/MSPT/Museum für Kommunikation Frankfurt

FRANKFURT MUSEUM FOR COMMUNICATION

Schaumainkai 53, 60596 Frankfurt am Main
Tel.: +49 069 6060-0

Admission:
Adults: 6 euro
Reduced admission: 4 euro
Children, youths: 1.50 euro
Children up to 5 years: free of charge

Opening Tuesday to Sunday 11:00–18:00, Wednesday 10:00-20:00

mfk-frankfurt.de

Many of us take instant and unrestricted communication for granted, but the nature of communication is always changing, across time and around the world. At the Frankfurt Museum for Communication, visitors experience the history of the place where technology and society come together, one which has been posing humankind the same challenges for millennia.

The story of communication is the story of who is allowed to speak, what they are allowed to say, and who is allowed to listen. It is the story of new technologies and new users – from Hammurabi's code to Gutenberg's printing press, Marconi's radio to the Telstar 1 telecommunications satellite. It is also the story of increasing efficiency and speed, how we have always tried to say more with less, and faster than ever before. Ideas became 1700 hieroglyphs, which became two dozen letters, which became bytes and radio waves. Each new technology requires new skills, from hard skills such as literacy and digital literacy, to poetic and persuasive soft skills that increase their effectiveness.

The exhibits at the Frankfurt Museum for Communication are not just records of how contemporaries communicated with each other. The Frankfurt 'Brieffund' – a collection of local letters from the sixteenth century – offers a window into the lives of the past, an act of communication across time to the visitor. While we may consider the way we craft an image of ourselves and present it to the outside world as a phenomenon inherent to modern social media, these letters, combined with the museum's collection of love letters written by Goethe and Kafka and telegrams from Titanic passengers, reveal that the struggle to control how the world sees us, our thoughts, feelings, fears and desires, is not as new as it seems.

Markets and monopolies

Another common fear connected to social media is that of monopoly – that a small number of entities may have too much control over the infrastructure we use to communicate. But this too, is far from a new phenomenon. In the early 1900s, the United Kingdom had an effective monopoly on undersea cables used to communicate across the Atlantic, while the Deutsche Bundespost possessed a monopoly on home telephones in (West) Germany until as late as 1990.

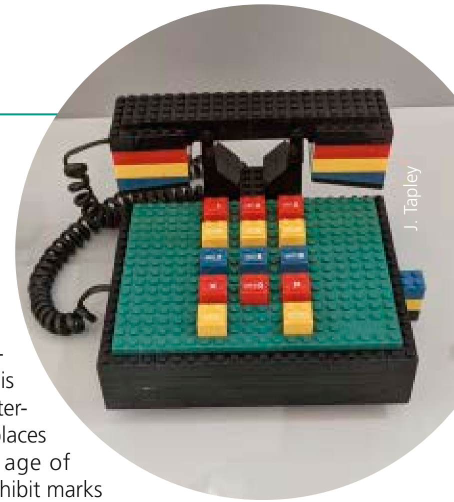
Rather than set humankind on a clear trajectory towards a better or worse society, the museum makes it clear that new communication technologies seem to amplify both the best and the worst of us. The only constant trend seems to be how increasingly important and ever-present these technologies become in our everyday lives. The more communication is censored, the more people rebel; the stronger a monopoly, the more people turn to piracy. Germans circumvented the Bundespost monopoly on telephone sets by purchasing and smuggling illegal foreign models into the country, while citizens of the Soviet Union demonstrated the freedom in their bones by carving records of forbidden folk songs and Elvis Presley hits onto used medical x-ray film. You can listen to recordings at the museum.

Trust and transactions

Like an Elvis record in an underground Soviet music club, we seem to be stuck on repeat. The internet may be the current culmination of our need to communicate more and faster, but it also brings with it some age-old challenges and concerns over trust, privacy, freedom, security, control and monopoly into the digital age. Even data privacy and fake news are not new concerns. Census data about race was collected and used by the National Socialist regime in Germany and broadcasts proclaiming the exaggerated success of recent war efforts are as old as radio itself.

The story continues

The museum is an impressive effort of communication in its own right. It brings the history of communication to life through a combination of bilingual written content, imagery, models, sounds, demonstrations, antiques, anecdotes and games. It has a lot of fun activities for children and adults and is very affordable. The staff are friendly and knowledgeable and offer a guided tour to all guests, but you are also free to make your own way around. For those choosing to go their own way, the museum would benefit from a clearer indication of the chronological order of the exhibits.



J. Tapley

The museum also contains a permanent exhibition featuring 21 video messages from experts on a range of topics: Will we have to buy our privacy in the future? How will we communicate 30 years from now? What is the future of human-machine interaction? Will virtual reality workplaces become commonplace in an age of increasing remote work? The exhibit marks a nice way to end a visit to the museum and the wonderful and worrying possibilities for the future will leave you with many things to think about on your way home.

Just like the Frankfurt 'Brieffund', maybe these video messages will find their way back into the museum centuries from now. Future visitors may learn about how we communicated in the twenty-first century, about our hopes and fears. Perhaps they will even stop to consider whether they themselves are still facing the challenges we faced from Babylon to broadband.

Joshua Tapley is an editor for the English edition of the DLRmagazine on behalf of EJR-Quartz.

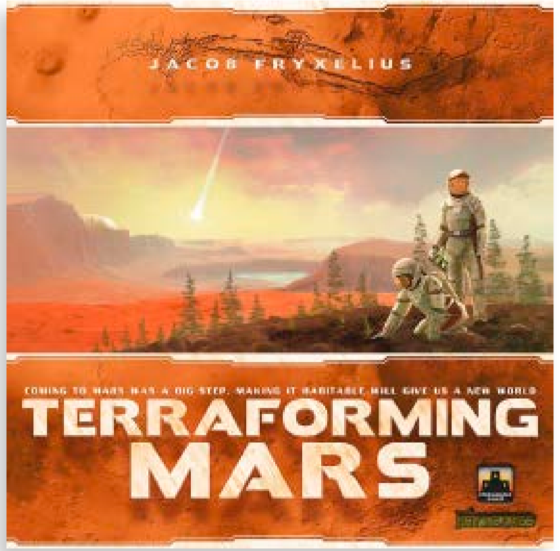
J. Tapley

The history of communication comes to life at the entrance to the museum

J. Tapley

The mass media have made their way into households. They are used for good and not so good purposes.

REVIEWS



A GENERATIONAL AFFAIR

Let's not get our hopes up: we will probably not live to see Mars colonised, let alone greened, however much as we might like to. It is a long way to our neighbouring Red Planet, and there is still a lot of scientific knowledge to be gained and technical progress to be made before it can be colonised. This is a project for more than one generation, and it is extremely complex. The board game **Terraforming Mars** gives players a taste of the hurdles and pitfalls that lurk when you set out to make a foreign planet habitable.

During the game, up to five pioneers can experience how ambitious it is to plan for a possible settlement and the 'terraforming' of our neighbouring planet. This is the term used to describe the modification of the atmosphere and the surface of the planet. It is particularly interesting that the game is based on real technologies as well as ongoing projects and approaches. In the course of the game, players have to increase three core parameters: oxygen content, water quantity and – in this, humanity has already unfortunately demonstrated an extraordinarily high level of competence – temperature.

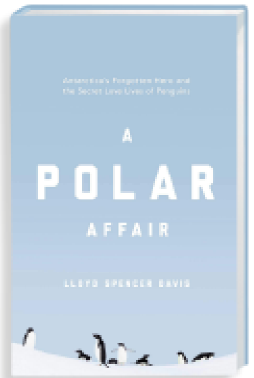
In recurring research, action and production phases, the players each represent a corporation with different entrepreneurial interests. More than 200 cards set out project and construction plans that serve terraforming in various ways: grow microbes, plant forests, flood valleys, build cities or even engineer asteroid hits. In addition, with the small change – called megacredits – you can create cities, green spaces or oceans in hexagonal tile form at any time and preferably right next to each other, because local recreation and a view of the sea are also an advantage on Mars. The more time passes, the more spectacular the feasible projects become and the more tiles on the board. Experience shows that a game lasts between 90 and 180 minutes. The actions have different effects on the three terraforming parameters or the resource balance of the corporation, which is represented by pretty, shimmering metallic dice. It quickly becomes clear that in order to make Mars habitable, you not only need ideas and patience but also building materials, energy, seedlings and, of course, enormous amounts of money. The game ends once 14 percent of the atmosphere is filled with enough oxygen to breathe, all nine ocean tiles form lakes and seas and the global 'transitional jacket' temperature of eight degrees Celsius is reached.

On the way there, generation after generation, an epic race to accumulate victory points and become the most effective terraforming corporation breaks out, always with an eye on resources and the competition. Those looking for more challenges will find them in a variety of player expansions. In Terraforming Mars, players see Mars gradually transform from a red desert planet to a colourful, liveable beacon of hope for humanity after it has gambled away the Earth, already superbly shaped by nature.

Daniel Beckmann

FryxGames/Stronghold Games

DISCOVERY AND EXPLORATION



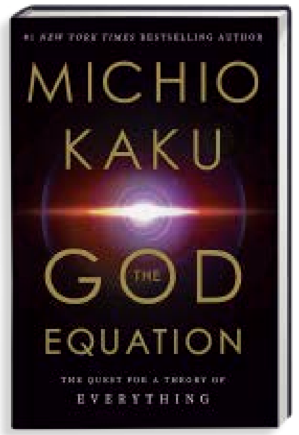
Icy cold and extremely remote, Antarctica is a deeply inhospitable place. Even after its discovery 200 years ago, it took a further 100 years for a human being to cross the continent and reach the South Pole. Today, Antarctica is an important place for climate, marine and environmental research and is continuously inhabited by researchers. It is also of interest to biologists because one species feels particularly at home on the kilometre-thick ice: the penguins.

It was the penguins that first attracted the New Zealand scientist and author Lloyd Spencer Davis to Antarctica in the seventies. In preparation for his research, Davis came across the forgotten polar explorer George Murray Levick, who had set out to reach the South Pole in 1910 together with a group led by the British adventurer, Robert Falcon Scott. Things didn't go according to plan and Levick and his five fellow explorers had to endure six months in the ice and snow. In **A Polar Affair,** Lloyd Spencer Davis tells the story of Levick and how, long before any structured research was carried out in Antarctica, he was the first to study Adelie penguins and made an interesting discovery: their love lives are remarkably similar to ours.

Davis links his own studies of Adelie penguins with those of Levick. Based on well-founded research, he paints a picture of Antarctic exploration that ranges from the adventurous beginnings with the famous pioneers Roald Amundsen, Fridtjof Nansen, Robert Falcon Scott and Ernest Shackleton to the present day. He vividly depicts pain, hardship, seal meat, whale oil and death as a constant companion. And he paints the picture of a man who discovered his interest in these gallant birds in the struggle for his own survival – a clever balancing act and an exciting read.

Timo Küsters

THE SOUND OF THE UNIVERSE



In **The God Equation: The Quest for a Theory of Everything**, Michio Kaku, professor at the City College of New York, tackles the Holy Grail of physics: the search for a formula that explains the world. From the Big Bang to the end of the Universe, this formula summarises all phenomena and the totality of physics in a single equation. As the 'theory of everything', it unites all known forces and interactions: gravitation, electromagnetism and the strong and weak nuclear forces. In Kaku's opinion, the most promising way to get to this equation is string theory. It describes the world as oscillations of tiny strings in a ten-dimensional space – a mathematics beyond the imagination of most of us – combining gravitation, special and general relativity and quantum physics quite naturally.

Kaku begins with a review of the great discoveries of physics – from Newton's laws of gravity, the electromagnetism of Maxwell and Faraday, and Einstein's theory of relativity to the quantum physics of light and matter, quantum gravity and the multiverse theory. Kaku vividly demonstrates the crucial role of symmetries in the equations, which are the key to knowledge and the unification of all laws of the Universe. In doing so, the author skilfully combines science, philosophy and even religion with the question of the existence of God.

The book fascinates and arouses more than curiosity – not least because of Kaku's ability to describe highly complex physical relationships with remarkable clarity and surgical precision. However, the book does require readers to have some background knowledge of physics and an appreciation that the 'theory of everything' encompasses a great deal that is still inexplicable to us in the Universe. The quest for the 'God equation' continues.

Jens Mende

RECOMMENDED LINKS

SPACE PODCAST FOR KIDS
reach-a-space-podcast-for-kids.simplecast.com

A weekly, family-friendly exploration of the Milky Way (and beyond!). Designed for children and based on questions from children, REACH educates with entertaining segments, fun at-home experiments and interviews with subject matter experts and thought leaders from prestigious institutions such as the Adler Planetarium, Cosmosphere, Exploration Place and more.

CAREERS AT DLR
DLR.de/jobs/en

Developing new technologies and shaping the future – at DLR, scientists carry out their research with curiosity and passion. Here, they can focus all their energy on research within a unique infrastructure and carry out pioneering work in the fields of aeronautics, space, energy, transport, security and digitalisation. Does that appeal to you? Then you're ready for your mission at DLR! Apply now!

MIGHTY ASTEROID DETECTIVE
s.dlr.de/Hera

Meet Hera, ESA's very own asteroid detective. Hera is off on an adventure to explore Didymos, a double asteroid typical of the thousands that pose an impact risk to planet Earth. This cartoon series takes you on a fun and informative journey to visit Didymos together with Hera. Along the way, you will discover all about missing planets, creating craters, terrific technologies and much more.

LIVE ATC
www.liveatc.net

Stuck in the airport terminal with endless delays? Near an airport and want to find out what's going on? Have you ever wondered what pilots talk to air traffic controllers about? Aviation fans have been sharing the transmissions they receive with others for many years. Apps like Live ATC make things much simpler, as they do away with the need to have connections.

INCELL – IN-BODY TRAVEL
luden.io/incell

Have you ever wondered what goes on inside the cells of our bodies? InCell (iOS) is an immersive VR game that allows you to race through the cells of the human body. You'll take an exciting journey inside the highly unusual micro world of human cell and stop the virus advance. This game is a perfect opportunity to test your VR device and learn more about cell microstructure, different organelles and their roles in cell vital activity.

ASTRONOMY PICTURE OF THE DAY
apod.nasa.gov/apod/astropix.html

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

Cover image

This issue's cover image shows the Test Facility for Thermal Energy Storage in Molten Salt (TESIS). The test facility of the DLR Institute of Engineering Thermodynamics in Cologne is the first to conduct molten salt storage and technology research on this scale in Germany. Here, industry can test components for molten salt storage under real operating conditions. Areas of application are energy-intensive industrial processes such as the production of steel, iron, non-ferrous metals, glass, cement or chemical products. Molten salt energy storage can increase efficiency in these processes and contribute to the heat transition.

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