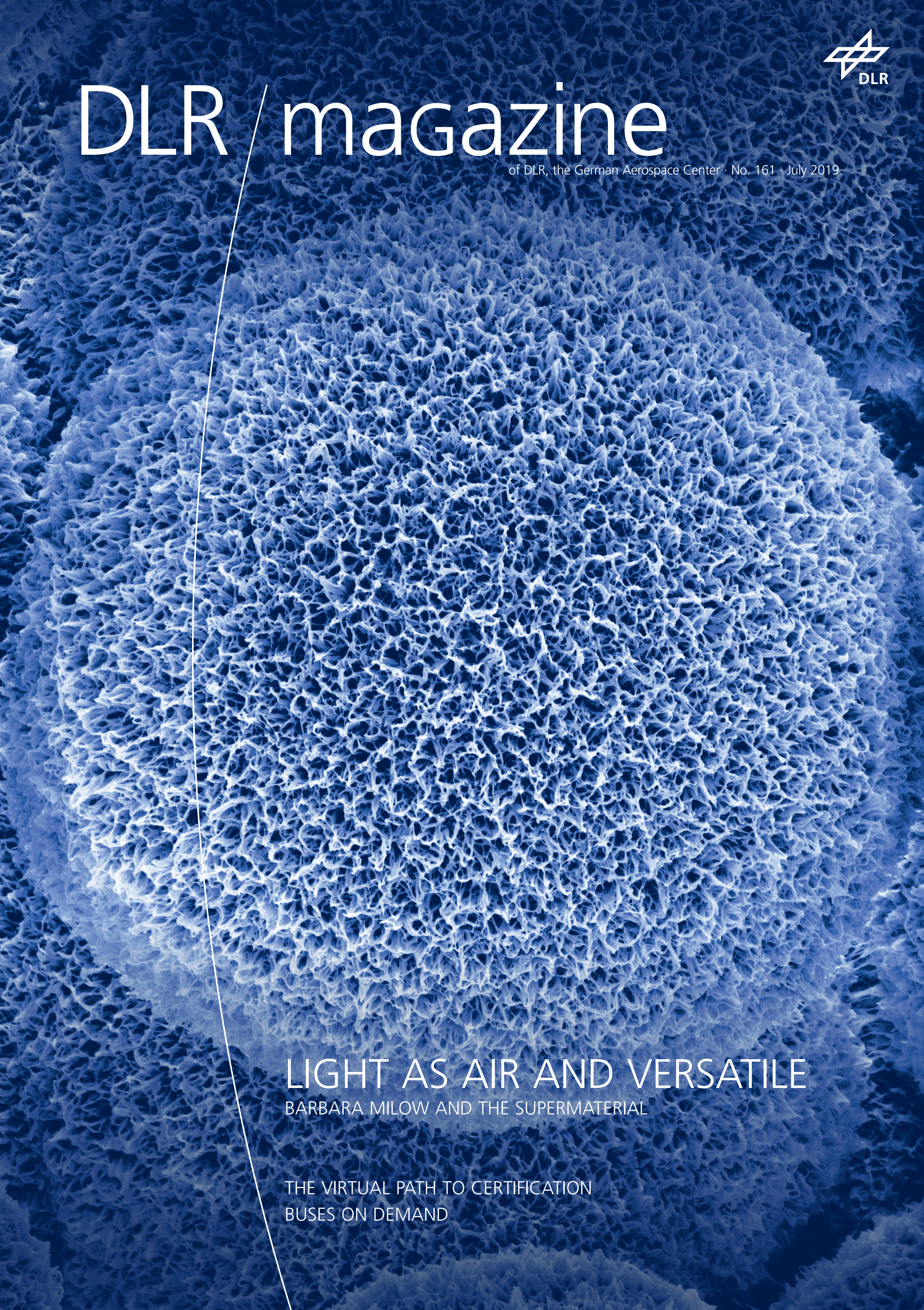


DLR magazine

of DLR, the German Aerospace Center · No. 161 · July 2019

LIGHT AS AIR AND VERSATILE

BARBARA MILOW AND THE SUPERMATERIAL

THE VIRTUAL PATH TO CERTIFICATION

BUSES ON DEMAND

DLRmagazine 161

Dear reader,

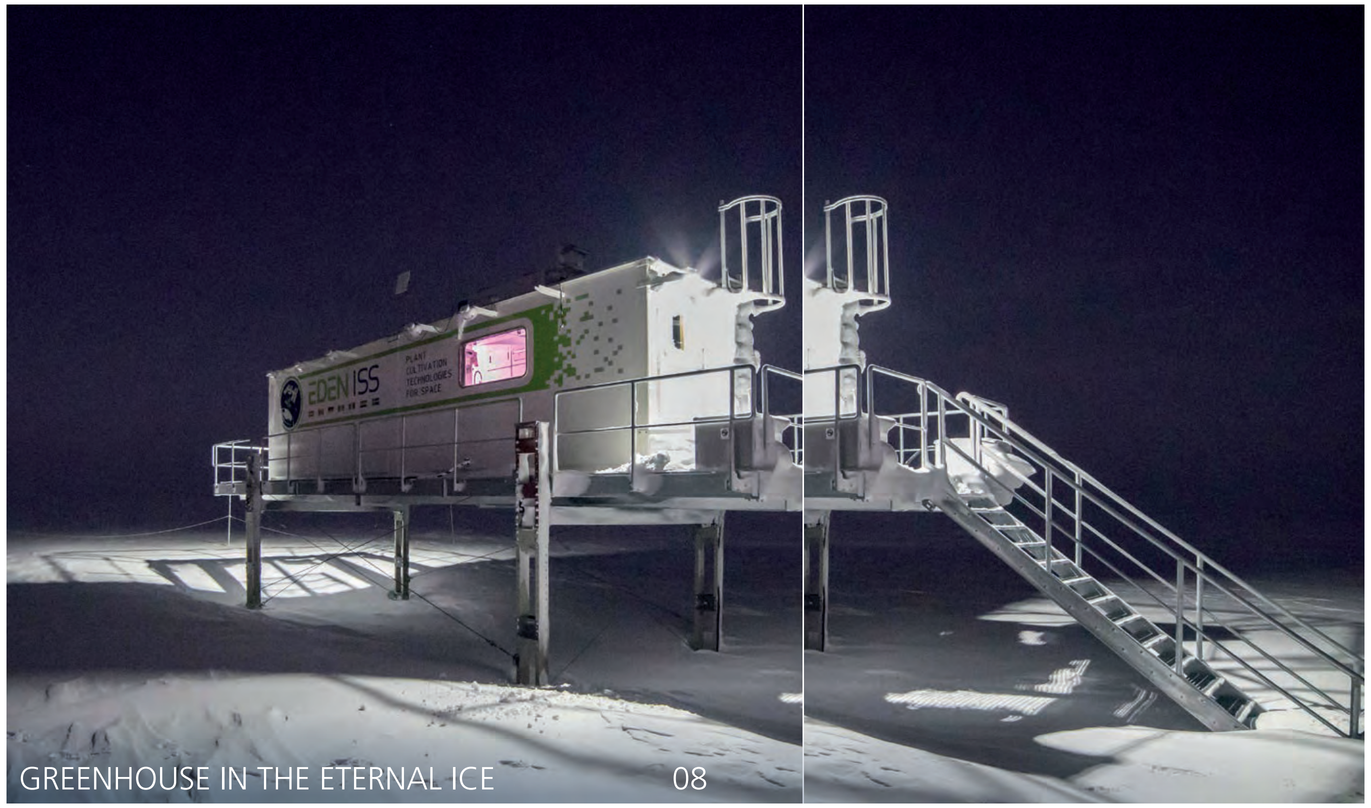
The spherical, cornflower-blue object on the cover does not – as you might suspect – come from the realm of botany (even though plants are also a topic in this issue of the DLRmagazine). Could it be a sponge? You are getting warmer. Air pockets have an important role to play here, after all, as they turn raw materials into a high-tech substance. This is an aerogel. Lightweight, electrically conductive and thermally stable – combining all of these properties in a single material fascinates Barbara Milow. They make aerogels of enormous interest, whether as stable materials in their own right or for use in filters, as insulation or even as implants. Milow and her team are constantly creating new aerogels and discovering interesting further applications that may extend their use to electric cars or aircraft.

We mentioned plants. What would you like? Tomatoes, herbs or rocket, perhaps? We have them all – in Antarctica, no less. There, DLR researcher Paul Zabel investigated whether plants can thrive without soil and sunlight in the EDEN ISS laboratory – and he succeeded. This process is suitable for inhospitable regions on Earth and for space exploration missions. That said, the Universe can now be explored virtually, as DLR researchers are demonstrating with a virtual reality system in which the Solar System is within arm's reach.

Simulations are also playing an increasingly important role elsewhere – in aircraft design, for example. In future, the certification process will be able to dispense with tedious testing and countless hours of flying. DLR is creating new techniques in this area, primarily through the use of high-performance computers that make the process faster and more straightforward. This is also opening up possibilities for completely new types of aircraft. The climate impact of air transport will no longer be a concern if DLR's vision of zero-emissions aircraft becomes a reality – a topic that we examine in this issue.

Last but not least, the July 2019 issue would not be complete without mentioning the 50th anniversary of the first Moon landing. We have put together a selection of items about the Apollo missions and hope that you find them interesting, along with all of the other articles on aeronautics, space, energy, transport and digitalisation!

Your magazine editorial team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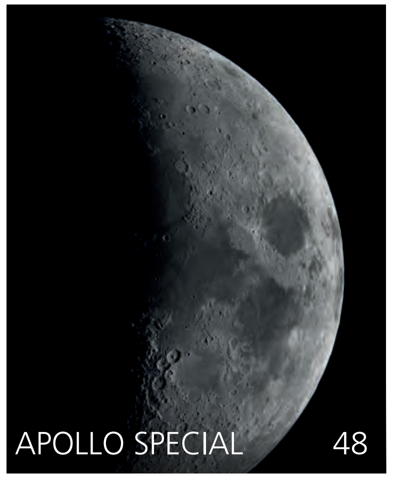
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"OUR VISION: ZERO-EMISSIONS AIRCRAFT"

Rolf Henke is the DLR Executive Board Member responsible for Aeronautics research

By Rolf Henke

Over recent months, it has become apparent that people are becoming increasingly concerned with global issues. The discussion surrounding the environmental footprint of flying is being conducted in public and is often emotionally charged, rather than founded on facts. In reality, air transport is responsible for around three percent of global carbon dioxide emissions. Soot particles and condensation trails also exacerbate the impact of aviation on the climate. Although much has improved over the last few decades, more must and will be done. To give one example, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) will come into effect in 2020. This is an emissions mitigation programme for the global airline industry developed by the International Civil Aviation Organization (ICAO). As Europe's largest aeronautics research institution, DLR will of course contribute to reducing the environmental impact of aviation. Our research activities are based on the targets set out in the European Commission's Flightpath 2050 vision paper, which DLR has actively contributed to.

This aims at reducing carbon dioxide emissions from air transport by 75 percent, nitrogen oxides by 90 percent and noise by 65 percent by 2050, relative to the figures from 2000. Our task is to improve existing aviation and rethink how it might look in future. Improving current aircraft and the way in which they operate can be achieved via aerodynamic optimisations, lightweight construction and improved engines. Noise and pollutant emissions from aviation should also be minimised alongside a flight guidance system that is oriented towards environmental sustainability. Over the last 10 years, DLR has invested over 300 million euro in the development of technologies and expertise with a view to achieving a better environmental and climate footprint for the air transport sector.

However, we are aware that previous efforts from research organisations and the aviation industry with regard to environmental sustainability have been partially cancelled out by the rapidly growing demand for air transport. For this reason, DLR is working closely with aircraft manufacturers and their suppliers, airlines, air traffic control organisations, airports and public authorities to put research findings into practice more quickly.

The German Federal Government's aeronautics research programme offers an instrument that enables industry to further improve its products and break new ground. This includes conducting research into alternative fuels and propulsion systems. Electric flight is another new area of focus. DLR can and will find answers to the pressing challenges faced by this sector. What is feasible for each size of aircraft, how and to what extent? What are the costs and benefits of manufacturing, operations, maintenance and disposal? This year, DLR will be investigating electric flight using a commuter-class aircraft with up to 19 seats.

Our vision for the future of aviation is a zero-emissions aircraft. However, this will take time and perseverance – in government, research and industry alike. And it will not be without cost …

UP, UP AND AWAY

Students are invited to contribute aircraft designs to DLR and NASA's Design Challenge

In 2018 a team of students from Munich demonstrated the boundless creative potential of young people by designing an 'eRay' aircraft concept that slashed energy consumption. This design was submitted to the DLR/NASA Design Challenge, which is back for the third time in 2019. This year, the focus is on aircraft designs and concepts for making remote regions accessible with small aircraft. The designs should be economically efficient and be applicable for both uncrewed cargo aircraft at night and crewed passenger flights. DLR and NASA have set the task for students in Germany and the United States. The launch of the competition took place on 12 April 2019 at the DLR site in Braunschweig. In autumn, the German winners will travel to NASA, where they will present their work alongside the US American competition winners.

The theme of the 2019 student competition is aircraft designs and concepts for creating transport links with remote regions

There are remote regions across the globe that are effectively only connected by air. This requires small aircraft with the lowest possible fixed and operating costs, and flexibility of use for both passenger and freight transport. This calls for new technology ideas, ranging from aircraft design to uncrewed operating scenarios. "Aviation connects the world – from isolated airfields, to airports and major hubs," said Rolf Henke, DLR Executive Board Member for Aeronautics Research and Technology, at the launch event. "It is hard to imagine life without the connection of remote regions by air, and so, together with our partners from NASA, I am looking forward to fresh inspiration from young people with designs and operational concepts that will stimulate regional air transport."

Some 40 students from five German universities (RWTH Aachen, TU Berlin, TU Dresden, TU Hamburg and the University of Stuttgart) are taking part in the DLR/NASA Design Challenge.

t1p.de/mu1h

DRONES IN THE CITY

DLR tests the City-ATM system at the Köhlbrand Bridge in Hamburg

Towards the end of April 2019, DLR and its partners in the City Air Traffic Management (City-ATM) project conducted successful flight tests around the Köhlbrand Bridge to demonstrate how drones are already able to cooperate with one another, as demonstrated by flying around a bridge, amid active shipping and road traffic. The tests were conducted at a time of day when ship and road traffic were active. This demonstrated how automated camera drones can fly safely together within the urban airspace. Safe flight was achieved with the help of flight planning, detection and identification, flight monitoring, and conflict detection and avoidance.

Two of the three drones available were in the air simultaneously during the flight tests, which were conducted as part of the City-ATM research project to test their interaction in urban airspace.

The system developed for City-ATM involved several steps. First, the pilots and drones were electronically registered and authorised for take-off clearance. Simultaneously, the flight missions were planned in detail – with any spatial flight restrictions accounted for. Once the essential waypoints had been determined they were converted into flight paths (trajectories). The system also took account of the flight performance of the devices as well as local and temporal conditions. This allowed potential conflicts to be identified prior to take-off. In future, package drones, air taxis and unmanned inspection aircraft will be able to fly around cities. As such, it is crucial that unmanned flying objects are able to detect and avoid one another reliably.

t1p.de/r05i

FUEL FOR THOUGHT

DLR transport researchers have teamed up with Aral to examine how mobility behaviour is changing and what impact this will have on fuel stations in the future. The researchers have shown that the distance travelled by passenger cars and commercial vehicles in Germany will increase by 24 percent by 2040 due to changes in mobility patterns and increasing commercial traffic. This provides fuel stations with new responsibilities but also a range of opportunities. In major cities, fuel stations can provide service-oriented mobility centres where e-bikes, autonomous car-sharing facilities and air taxis are available for use. In less congested urban spaces these could serve as interchanges with all-round facilities. In rural areas, fuel stations – with attached parcel services and shopping facilities – can take on the function of transshipment points with local supply services. Motorway stations will provide services for freight and long-distance transport, including for switches from autonomous to driver-operated lorries for urban transport.

Image: Aral

Possible scenario for a fuel station in a major city

Network and system modelling at the DLR site in Oldenburg

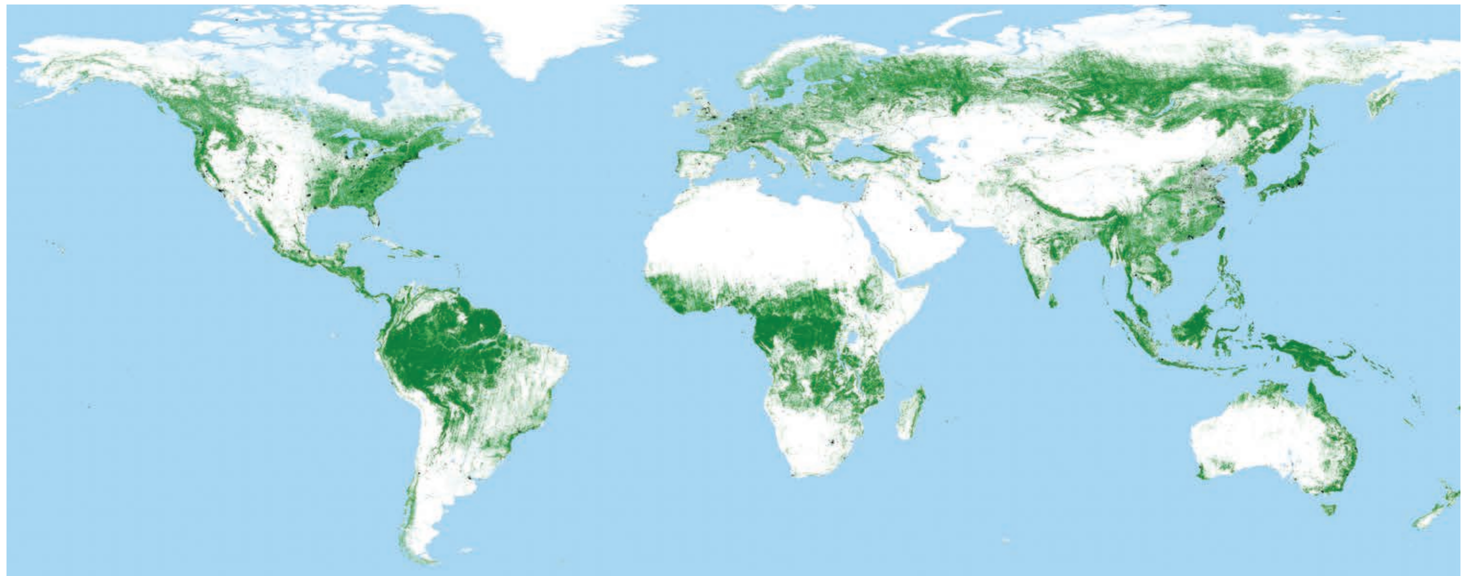
PLANNING SOFTWARE ASSISTS WITH THE REDESIGN OF ENERGY INFRASTRUCTURE

Through open_eGo (open electricity grid optimisation), the DLR Institute of Networked Energy Systems in Oldenburg has developed an open data and software pool for the optimised planning of German network and storage infrastructure. When feeding energy from offshore wind farms into the grid in future, for example, the software will be able to create forecasts for areas in which bottlenecks are to be expected and where grid reinforcements or new lines may be required in future. The platform is fully accessible to all stakeholders in the energy sector, according to the principles of open source development, and should help to model future energy systems according to economically beneficial criteria.

MONITORING GLOBAL FORESTS

Forests are considered to be the lungs of the Earth and represent vital resources for humans and animals. Yet despite their importance for the Earth's climate, they are disappearing. Satellite images show that only one third of the Earth's land surface is forested. More than half of the world's forests, which have fallen victim to deforestation since the middle of the 20th century in particular, have already been lost. DLR has created the global TanDEM-X Forest/Non-Forest Map to record and assess the condition of this 'green lung'. It has been developed using data from the elevation model created by the German TanDEM-X radar satellite mission, and has a resolution of 50 metres. The global data processing was carried out using algorithms derived from artificial intelligence. For the first time, the Forest Map provides a uniform picture of the rainforests in South America, Southeast Asia and Africa, and is available free of charge to scientific users.

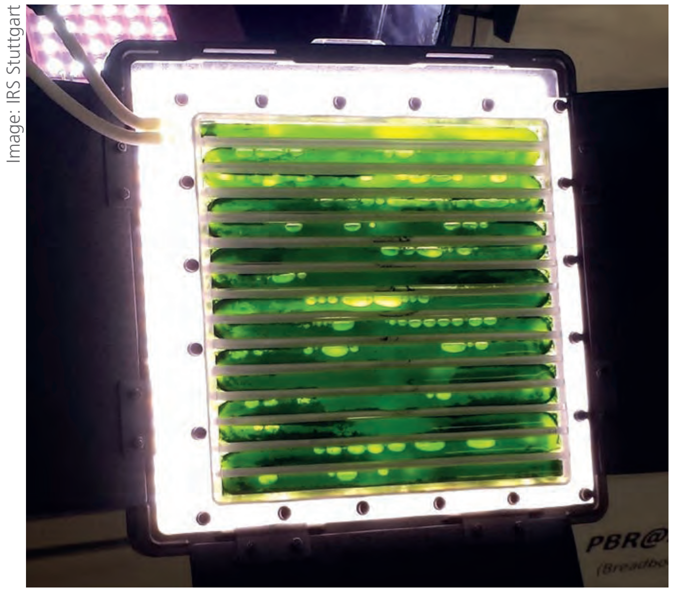
t1p.de/bljz



Global TanDEM-X forest map

Algae give astronauts on the ISS air to breathe

Image: IRS Stuttgart



The photobioreactor experiment

Whether it involves an outpost on the Moon or a long flight through space, humans are unable to survive in such conditions without technological systems that provide everything necessary for life. They require a system that is as closed and independent as possible to provide for their needs. The Photobioreactor experiment marks a big step in this direction, with algae converting the carbon dioxide exhaled by astronauts into oxygen and edible biomass by means of photosynthesis. The Photobioreactor has been devised to produce breathable air on the International Space Station for six months, and is supported by the Advanced Closed-Loop System (ACLS). Photobioreactors are of particular interest for planetary base stations or very long missions, as in addition to the breathable air that they produce, the resulting algae biomass can account for around 30 percent of the astronauts' food intake. Similar systems can be used on Earth for indoor air treatment or the removal of carbon dioxide. The experiment was initiated by the Institute of Space Systems at the University of Stuttgart and the DLR Space Administration, and was built by Airbus Defence and Space.

t1p.de/w3og

MEET DLR AT:

INTERNATIONAL AVIATION AND SPACE SALON (MAKS) 2019
27 August - 1 September 2019 • Moscow, Russia
The International Aviation and Space salon MAKS is one of the major world aviation forums. Once again in 2019, DLR will be present with a stand of its own. MAKS will be held in the town of aircraft science and technology – Zhukovsky – at the airfield of the major national testing facility – Gromov Flight Research Institute. In 2017, about 452,000 visitors from 37 countries attended MAKS, 70,000 of which were trade visitors. In total, there were 880 exhibiting companies and organisations – 700 from Russia and 180 from abroad.

IAA NEW MOBILITY WORLD
11 - 16 September 2019 • Frankfurt, Germany
Companies from a wide range of industries have been meeting at New Mobility World since 2015 to discuss the future of mobility. Part of the International Motor Show Germany (IAA), New Mobility World attracts the attention of the automotive industry, the media and policymakers. This year's event will focus on urban mobility, mobility as a service, clean and sustainable energy, connectivity and automation. DLR will showcase its concepts for the mobility of tomorrow with a stand in the NMW EXPO exhibition area.

GERMAN AEROSPACE CONGRESS 2019
30 September - 2 October 2019 • Darmstadt, Germany
The German Society for Aeronautics and Astronautics (Deutsche Gesellschaft für Luft- und Raumfahrt, DGLR) is the only association in Germany represented in all the specialist disciplines of the aerospace industry. Through symposia and conferences, it achieves a wide exchange of information and experience with regard to the achievements and problems of this sector. The German Aerospace Congress – the 68th such event – which is taking place in Darmstadt this year, is one of the most important DGLR events at the national level. DLR contributes to this event with experts and a stand in the exhibition area.

INTERNATIONAL ASTRONAUTICAL CONGRESS 2019
21 - 25 October 2019 • Washington D.C., USA
Founded in 1951 to foster the dialogue between scientists around the world and support international cooperation in all space-related activities, the IAC to this day continues to connect people involved in space from all over the world. Acting as organiser, the International Astronautical Federation is the world leading space advocacy body with 300 members, including all key space agencies, companies and institutes across over 60 countries. At this year's IAC in Washington D.C., DLR will be represented by its Chair, Pascale Ehrenfreund – at the same time incoming IAF president – as well as other members of the Executive Board, numerous experts and an exhibition stand.

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GREEN LUNG IN THE ETERNAL ICE

Image: Hanno Müller

The EDEN ISS greenhouse container in the Antarctic, here during the isolation phase.

Strong blizzards with wind speeds of up to 150 kilometres per hour, temperatures below minus 40 degrees Celsius, weeks spent in total darkness, and most importantly no escape capsule promising a quick return home, as is the case on the International Space Station. These are just some of the many challenges faced by the EDEN ISS team during its space analogue mission at the German Neumayer Station III in Antarctica, which is run by the Alfred Wegner Institute (AWI). The EU-funded research project led by DLR involves research into how plants might be cultivated in future habitats on the Moon and Mars, thus making a significant contribution towards the development of bioregenerative life support systems.

The DLR deployment team in front of Neumayer Station III of the AWI

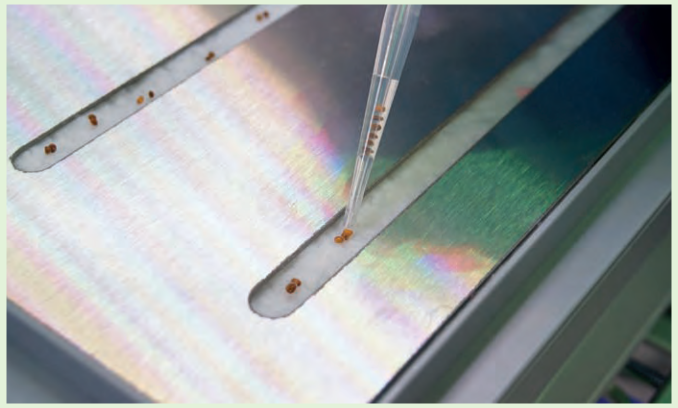
A greenhouse in Antarctica provides insights into future plant cultivation on the Moon, Mars and Earth's desert regions.

By Daniel Schubert

On 3 January 2018, the South African research vessel S. A. Agulhas II rammed into the sea ice of the Atka Bay near Antarctica's Ekström Ice Shelf. On board were the two EDEN ISS greenhouse containers. The wait was finally over for the four-man EDEN assembly team from the DLR Institute of Space Systems in Bremen, who arrived in mid-December. Poor weather conditions had delayed the arrival of the containers by two weeks. The unloading of the ship was a cause for celebration, as it marked the culmination of four years of intensive planning, hardware development, testing and enhancements. This marked the beginning of the long-awaited Antarctic mission. From the sea ice, a team of AWI engineers pulled the two greenhouse containers and a support container housing spare materials and consumable supplies over a distance of 24 kilometres to Neumayer Station III, which would serve as the base for the upcoming isolation mission. The very next day, the AWI assembly team placed the two greenhouse containers on the pre-installed platform 400 metres south of the station, which together make up the EDEN ISS Mobile Test Facility (MTF). In the weeks that followed, the DLR EDEN team installed external stairways, cable ducts, thermal, outside lighting and the carbon dioxide storage and supply system. Power was supplied by a seven-centimetre-thick electrical cable running from Neumayer Station III to the greenhouse, which had been buried in the ice the previous summer.

Storms, deep snow, frost and polar lights

The test facility went into operation on 7 February 2018, with the sowing of tomato, pepper and cucumber plants. Radishes, kohlrabi, rocket salad, lettuce, leafy Asian vegetables, and herbs like parsley, basil and chives followed over the next few days. The isolation phase began once the last summer crew left the station on 18 February 2018, leaving only the 10-strong overwintering team. From that point on, DLR researcher Paul Zabel ensured the smooth operation of the system on site.



Rocket seeds are placed on the plant mat

Image: Esther Horvath, AWI

EDEN ISS Control Centre at the DLR Institute of Space Systems in Bremen

On 20 May, the Sun set for the last time, and the polar night began for the German overwintering crew. The greenhouse continued to operate over this extreme phase. It became an endurance test. The outside temperature regularly fell below minus 30 degrees Celsius. Both the greenhouse system and the overwintering crew had to contend with storms and darkness, but the occasional aurora borealis brought some light.

Scientific experiments in a unique environment

The DLR team pursued a demanding scientific programme over the course of the mission. During the isolation phase, Zabel took over 400 plant and microbiological samples from various positions within the greenhouse. The plant tissue samples were used for food quality and food safety analyses. The collected samples were passed on to project partners in Italy and Ireland for analysis upon their return from Antarctica. The microbiological samples travelled to Cologne for examination at the DLR Institute of Aerospace Medicine. In addition, several experiments took place directly after the harvesting of the plants, including measurements of the nitrate content of the fruits. This will serve as the basis for developing rapid harvest tests for future astronauts.

The researchers used special questionnaires and several moderated group discussions to study the psychological effects that the regular supply of freshly harvested vegetables had on the isolated Neumayer crew. Tests to investigate the taste of the vegetables grown here rounded off the on-site psychological examination.

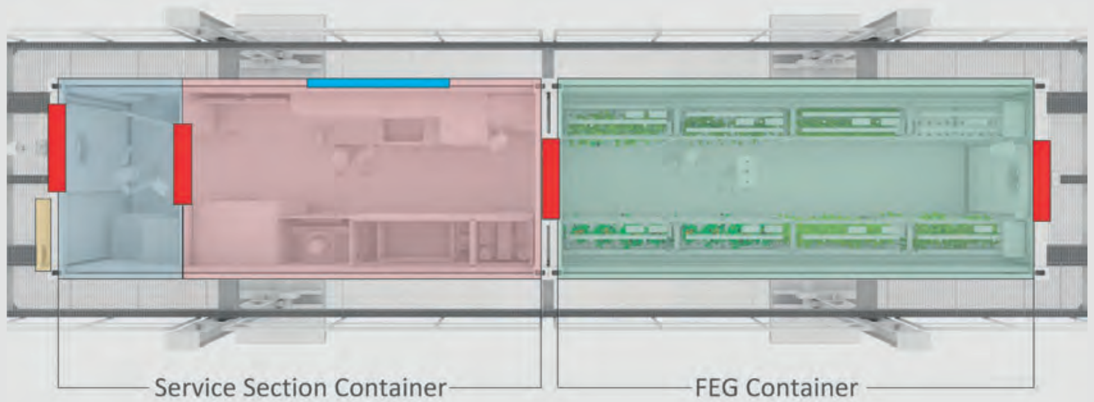
The EDEN ISS greenhouse – an international research platform on the eternal ice

The researchers regularly tested out different procedures for cultivating plants within closed systems, similar to habitats on the Moon and Mars. The working steps taking place in Antarctica were followed live from the mission control centre at the DLR Institute of Space Systems in Bremen, where the researchers were in constant contact with the greenhouse and had full remote control of its operations in the event of storms. Thirty-four cameras took pictures of the different plants every day, offering the project partners and specialists from all over the world the opportunity to observe the plants growing inside the Antarctic greenhouse and provide feedback to the mission team.

By mid-November 2018, around 270 kilograms of vegetables had been harvested despite the harsh conditions. Having over 20 types of vegetables made a welcome change to the crew's diet. With almost 260 days of isolation, 15 system- and validation tests, more than 20 scientific experiments and over 40 procedural tests, the Antarctic analogue mission marked the highlight of the EDEN ISS greenhouse project. The experience acquired will be vital for a robust and reliably functioning greenhouse on the Moon and Mars and for plant cultivation in Earth's desert regions.

Meanwhile, the EDEN ISS greenhouse will continue to be operated with support from the new AWI overwintering team. In future, it will also be open to other research groups as an international research platform, allowing their technologies, methods of cultivation and procedures to be tested under realistic isolation conditions in Antarctica.

Daniel Schubert works at the DLR Institute of Space Systems, where he is responsible for the EDEN research group. The EDEN ISS project has fulfilled his long-cherished dream of testing such a system under real conditions in Antarctica.



The EDEN ISS Service Section container houses an airlock (shown in blue) for changing Antarctic clothing. Next to it (red) is the area for the atmosphere management system, the nutrient supply system, the thermal regulation system and the data handling system. The Future Exploration Greenhouse (green) container generates fresh produce in 12.5 square metres.

THE GROWING CHAMBER OF THE GREENHOUSE

The research greenhouse is packed with modern **cultivation systems** (controlled environment agriculture; CEA). These allow independent and accelerated plant growth within the growing chamber of the Future Exploration Greenhouse (FEG).

The fully automated nutrient supply system provides two precisely calibrated nutrient options – one for vegetative plants like lettuce, basil and parsley, and the other for fruit-producing plants like tomatoes, cucumbers and peppers. A mixing computer uses various micropumps to compile the exact amount of nutrients for the plants and adjusts the pH value of the nutrient solution. Eight high-pressure pumps then spray the fine nutrient mist into each plant vessel's lightproof root compartment. The roots hang freely in the air and are able to absorb the blend of nutrients and water directly. This soil-free irrigation method is referred to as aeroponics and is highly resource-efficient.

The internal **atmosphere management system** regulates the temperature to 20 degrees Celsius, the humidity to 65 percent and actively sprays carbon dioxide (1000 ppm) into the growing chamber. The plants need carbon dioxide for photosynthesis. Air circulates around the greenhouse and is purified by various filter systems (preliminary, HEPA and activated carbon filters). The water sweated out of the plants is recovered by the system and fed back into the nutrient supply system, closing the water cycle. The only water that leaves the system is in the biomass of the harvested lettuce, herbs and fruits.

The artificial lighting system consists of specially developed LED systems. A total of 42 LED lights are installed in the greenhouse. The light spectrum of each lamp can be individually adjusted to the type of plant, with the wavelengths blue, red, far red and white. The LEDs are water-cooled, creating thermal stability within the cultivation room. An innovative thermal control system ensures sufficient heat dissipation on the roof of the greenhouse.

Welcome: fresh harvest in the station kitchen.

Image: Esther Horvath, AWI

The roots hang in the air and are sprayed at regular intervals with a mixture of water and nutrients

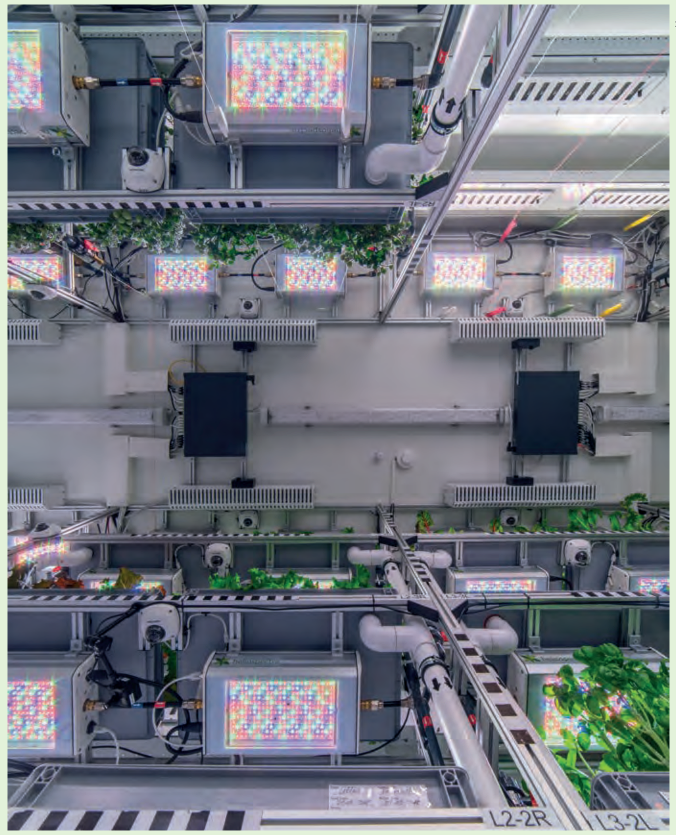


Image: Hanno Müller

View of the water-cooled LED systems from below. These shine light on the plants in a precisely coordinated day-night rhythm.

Paul Zabel is happy about his first salad harvest

SALAD THROUGH THE SNOW …

An interview with DLR Antarctic gardener Paul Zabel

Mr Zabel, you have been back in Germany for a few months now, after spending a year conducting research in Antarctica. What did you find most striking on your return home?
: At first, I was completely overwhelmed by all of the sensory impressions. The smells and sound of civilisation were mind-blowing over the first few days. Getting reacquainted with a big city and traffic is not so easy after a period of overwintering. That said, it was wonderful to see friends, family and colleagues again. Although I had a great deal of contact by telephone and the odd video call while I was there, actually seeing my family and being able to give them a hug was a completely different matter.

Why all the effort of spending a year in the Antarctic testing out plant cultivation in a greenhouse container? Could this not have been investigated in a more hospitable region on Earth?
: We wanted to test the greenhouse under operating conditions that were as realistic as possible, so it had to be just as isolated as a mission to the Moon or Mars. As far as I was concerned, Neumayer Station III was like a base on another planet. Without this kind of station, people would not survive for long in Antarctica. You are just as dependent on technology as people are during a crewed space mission. Everyone must work together and look out for one another. The station only has food supplies for the three-and-a-half months of summer. The rest of the year, the crew relies on frozen, dried and preserved provisions. A jaunt to the nearest electronics store or a quick online order are simply out of the question. This scenario is also typical of space travel. Our greenhouse provides us with lots of fresh food to see us through the remaining nine months – otherwise, we would not have any of it.

How did the extreme environment affect the greenhouse technology?
: The Antarctic climate affected the design of the greenhouse and the choice of some of its components. However, the environmental conditions had the biggest impact on the work that could be conducted on site. Knowing the weather forecast for each day and the next few to come was vital. During the winter months, the weather can turn from being fine to hurricane-like storms in just days. We always had to keep this in mind, as many tasks cannot be carried out in poor weather. As I had to pull the thermobox containing the harvested produce behind me on a small plastic sled back to the station, it could simply have been blown away by strong winds.

Growing vegetables with no soil, under artificial light and using a computer-controlled nutrient solution. It sounds very sci-fi. Did all of the plants cope well?
: The lettuce plants and other leafy vegetables really thrived. We are also more than satisfied with the growth of the tomato and cucumber plants, but we ran into some problems with the peppers and strawberries. Both types of plants did very well and grew many flowers, but the pepper plants produced almost no vegetables, and the strawberries produced no fruit whatsoever. We are currently carrying out an evaluation with our Dutch project partners to determine the cause.

Strawberry roots in a sterile agricultural medium

Image: Harald Rentsch

The researchers get a visit from two Adelie penguins

What did the crew think of the first crops 'made in Antarctica'? How do Antarctic vegetables taste?
: It was an amazing feeling! The years of work on the project and the long days on site were really paying off for the first time. The fresh vegetables went down very well with all of the overwintering team. Their favourites were the tomatoes, cucumbers and herbs. The vegetables tasted completely normal, but home-grown vegetables always taste better than the ones you get in the shops. It was nice to be able to make people happy with something as simple as a salad.

Can you describe a typical day in Antarctica, given the constant darkness and icy cold of the polar night? Did you ever oversleep when the Sun did not rise?
: I spent most mornings in the laboratory at Neumayer Station III. First of all, I would check that everything was all right with the greenhouse and the plants. I was able to gauge the situation quite well via our control system and the attached cameras. I spent the rest of the morning preparing experiments or mixing the nutrient solution. After lunch, I went to the greenhouse to check and maintain the systems, sow seeds, harvest plants and conduct experiments. I spent around four hours in the greenhouse each day, including most weekends and public holidays. Maintaining the greenhouse technology took a lot of time. The various subsystems presented numerous challenges, especially in the first few months of operation. You have to be able to respond quickly. I had to go to the greenhouse more than once on a Friday night to repair a failed system. I also had to conduct many experiments for our project partners. For instance, I had to take microbiological samples of the surfaces, plants and nutrient solution once a month.

As for the polar night, my daily routine changed somewhat. I got up much later than usual, but stayed awake longer in the evenings to make up for it. Sleeping in, in the usual sense, would be unthinkable, as you would just have to work into the night to get everything done.

You spent the year with nine other members of the overwintering team at the Neumayer Station III of the Alfred Wegener Institute. How often did you actually see one another during the day?
: As each member of the overwintering team had their own area of responsibility, we actually hardly ever saw each other during the day, but we would arrange a set time to have lunch and dinner together as a team. Of course, we also supported one another when dealing with difficult or time-consuming tasks. This gave me an insight into different areas, like station technology, meteorology, geophysics, atmospheric chemistry and sea ice physics. Weather permitting, we made joint trips to the nearby emperor penguin colony or explored the area surrounding the station on snowmobiles and snowcats.

Would you return to Antarctica, given the chance? What is happening with the EDEN ISS greenhouse now? What is next?

: Almost everything in Antarctica made a big impression on me – from the ever-changing weather conditions, storms, cold, weeks of darkness, weeks of no darkness, and snow formations created by storms to the incredible starry sky in the biting cold of minus 35 degrees Celsius. I would go back in a heartbeat!

The greenhouse is still in place and is currently being run by the present overwintering team, who are also using it to grow fresh vegetables. Next year, more members of our project team are set to travel out there to continue with the research. At the moment we are working hard on evaluating the results from last year, and have already learned a lot about how a future space greenhouse might work. We also want to use these findings to improve the greenhouse in Antarctica step by step.

The interview was conducted by Falk Dambowsky from DLR Public Affairs and Communications.

THE VIRTUAL PATH TO CERTIFICATION

Those wanting to get an aircraft in the air, a rocket into space, a car on the road or a train on the rails have a long journey ahead of them. Not only does the development of new technologies and vehicles cost researchers and manufacturers a great deal of time – the approval or certification process also often takes many years. But what if all of the test drives and flight tests were no longer necessary for approval or certification, because the majority of the required showing of compliance could simply be provided virtually, using computers?

In the cross-sectoral project Simulation-Based Certification, 15 DLR institutes and facilities are working on a tool for digitalised certification.

By Yvonne Buchwald

If the Airbus A380 had been allowed to make its maiden flight using computer simulations, the aircraft's manufacturers certainly would not have carried out 800 test flights. Much of the 2600 flying hours and large parts of the five-year test programme – with the high costs involved – would not have been necessary. Not to mention the fact that the risks for the test pilots and aircraft would have been lower. At present, every vehicle and product that is intended for market must go through a completely physical, tangible process chain for operational authorisation, in order to prove to the relevant authorities that all of the necessary safety and environmental requirements have been satisfied. "Today, we can design an aircraft or vehicle using computers, and make statements about it, even though it does not yet exist in reality. When it comes to approval or certification, however, you need a real product that can be tested," explains Sven Geisbauer of the DLR Institute of Aerodynamics and Flow Technology. According to the aerospace engineer, who leads DLR's Simulation-Based Certification (SimBaCon) cross-sectoral project: "Tests are still predominantly being conducted in real life, and the regulation authorities are still sceptical about computer-derived data." This is for a good reason – up until now, the reliability of simulation data for certification purposes has only been proven in a few selected cases. Researchers from 15 DLR institutes and facilities want to change this. They are working on interdisciplinary tasks to further develop numerical simulation methods from aeronautics, space, energy and transport in such a way that they can be accepted by the relevant authorities as a tool for verification.

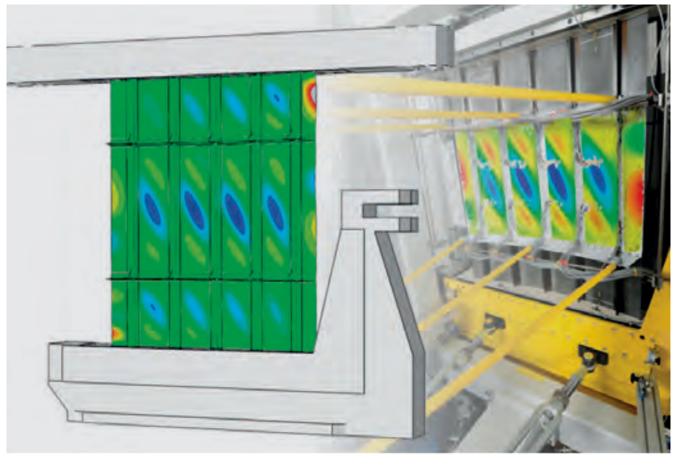
From initial analysis to virtual testing

Sven Geisbauer explains how this would work, step by step: "First of all, we need to know exactly what the authorities need – the certification requirements." In other words, an analysis. At the beginning, the researchers try to determine areas that offer potential for cost and time savings. Then, a catalogue of requirements can be drawn up and the simulation methods aligned with it. Once the requirements for certification have been exactly defined, the researchers make some initial comparisons between real-world testing and driving or flight tests and those conducted in the computer laboratory. Subsequently, the digitalised verification is tested and demonstrated on the computer, looking at components, subsystems and, if possible, entire systems like engines, aircraft, cars or trains. "Virtualisation should be applied to as many product development processes as possible – from the initial design to the development of materials and components, and through to the entire airborne or ground-based vehicle," explains Geisbauer. This means that the product design is much better attuned to the requirements for production, certification and operation from the very outset.

PARTICIPANTS IN DLR'S SIMBACON CROSS-SECTORAL PROJECT

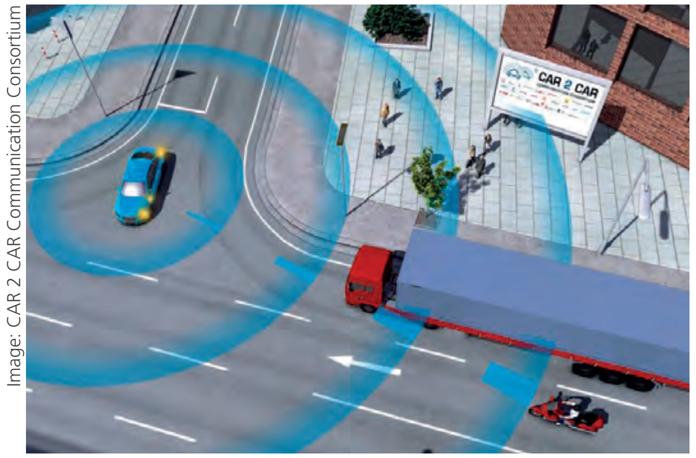
Institute of Aerodynamics and Flow Technology
Institute of Aeroelasticity
Institute of Propulsion Technology
Institute of Composite Structures and Adaptive Systems
Institute of Flight Systems
Institute of Combustion Technology
Institute of Materials Research
Institute of Structures and Design
Institute of System Dynamics and Control
Institute of Vehicle Concepts
Institute of Transportation Systems
Flight Experiments Facility
Space Operations and Astronaut Training
Simulation and Software Technology Facility
DLR Systemhaus Technik

Virtualisation needs to be applied to more and more research and development processes – right up to digitalised approval and certification.



Materials testing at the buckling point – performed here on both virtual and physical test benches.

Image: CAR 2 CAR Communication Consortium



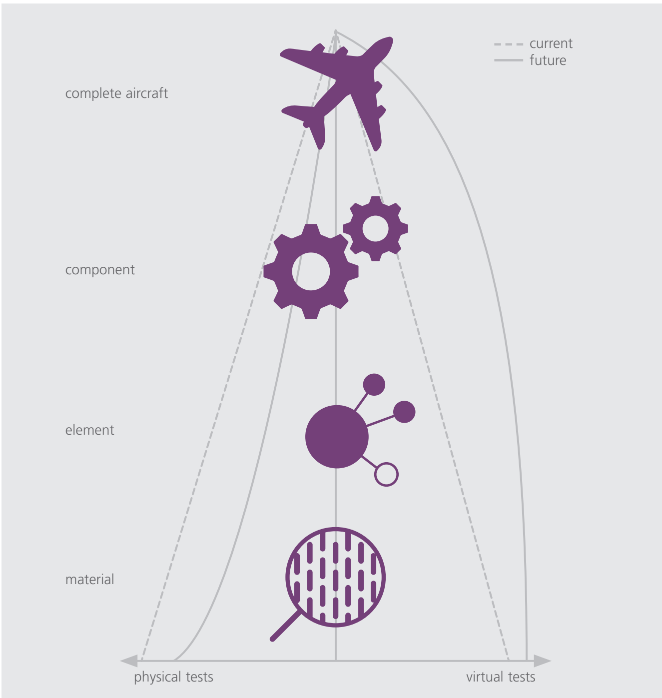
Virtual testing is also becoming increasingly important for ground-based transport, for example in the development and testing of driver assistance systems.

At the end of this demanding process, there are officially verified and technically developed and implemented digital simulation tools that can be used to show compliance for certification. The simulations should allow 'real' vehicles, components and systems to perform a virtual maiden flight or be rolled out for their first test drive and receive a simulation-based certification.

Saving costs and minimising risks

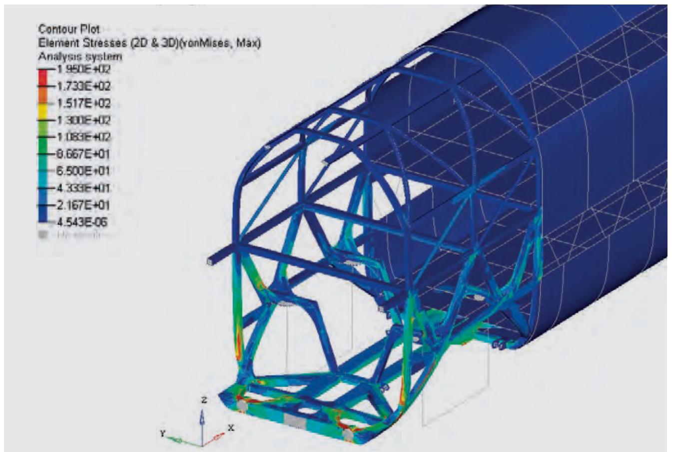
The benefits are clear: the number of real – meaning lengthy, expensive and often risky – flight and driving tests can be reduced. "The partial or even complete introduction, over the longer term, of numerical simulations into the certification processes will reduce time and cost risks, allowing us to make a real improvement to all of the processes and thus make industry more competitive," says Cord Rossow, Head of the DLR Institute of Aerodynamics and Flow Technology and coordinator of the cross-sectoral project, summing up DLR's mission and the purpose of its digitalisation initiative. Over the course of more than three decades, DLR has been developing high-precision numerical simulation methods and software, as well as the necessary high-performance computers and highly advanced measurement technology, test stands, wind tunnels and a fleet of aircraft and vehicles. "This means that we are one of very few research institutions in the world in the position to check and confirm the simulation methods that have been developed in a comprehensive way, and to identify any remaining areas of uncertainty. By bringing together all of DLR's research into numerical simulations from the areas of aeronautics, space, energy and transport, we are in a unique position to be able to meet the challenges of simulation-based certification," says Rossow.

In doing this, DLR researchers have broken new ground. Personnel from 33 departments at six different DLR sites have teamed up under the direction of the Institute of Aerodynamics and Flow Technology to create synergies. "This cross-sectoral project allows us to harness the potential for innovation across DLR and benefit from working with one another," explains Sven Geisbauer. Although certification in the areas of aeronautics, space, energy and transport may look very different at first glance, the individual areas could benefit from being combined in ways that have previously not been possible.

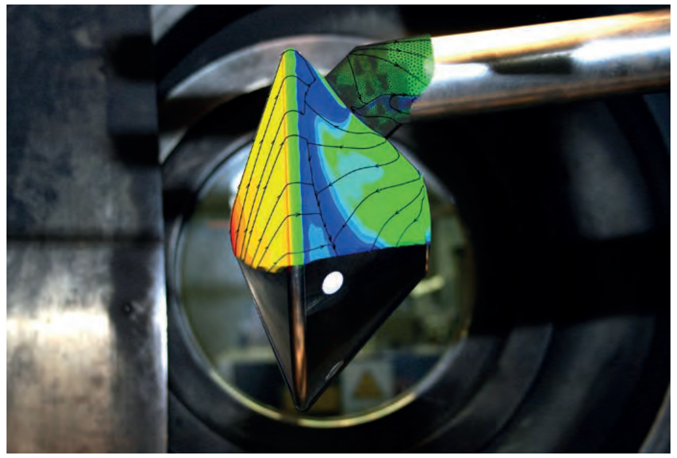


This test pyramid from the aeronautics sector shows the development steps from initial material tests to the design and testing of individual elements and components and then on to the complete aircraft system. In future, physical verification of certifications will be increasingly supplemented by virtual tests, and perhaps even replaced by them in the longer term.

For this purpose, the cross-sectoral project was initially divided into seven target areas, with the relevant professional and technical expertise pooled within each one. The target areas are self-explanatory: aircraft, helicopters, spacecraft, ground-based transport, software, construction methods and structures, as well as engines and gas turbines. All the work is focused on the further development and improvement of simulation processes, as well as addressing the challenges specific to each area. Examples include the simulation of complete flight manoeuvres by free-flying helicopters or material and structural behaviour in the case of a high-speed crash or a vehicle collision. According to Geisbauer, "Ultimately, we will identify our areas of common interest in detail, and our pooled knowledge will allow us to address important subjects more effectively than is currently the case."



Simulations can be used to test the structural loads on the body of a train. The red areas show highly stressed components.



Experimental and numerical simulations of the entry of a landing capsule into the Martian atmosphere.

The objective – realistic simulation

Sven Geisbauer always keeps the vision of the virtual product in mind – that is, the entire digital life cycle, from the initial design of an aircraft or vehicle to its development, certification, entry into service, maintenance and eventual decommissioning. However, he is also aware of the challenges that this presents: "Showing compliance to certification requirements solely based on simulation data, without other flight or ground tests, is a long way off." Yet he believes that: "We can already simulate a large number of flight and driving conditions, some of which are critical." One example is the installation of antennas on the top of aircraft fuselages in order to allow passengers to enjoy internet access during their flight. "Before such modifications are certified, it must be proven that the airflow around the aircraft will not be significantly altered by such antennas, and that all of the safety requirements are still being satisfied," explains Geisbauer. The conventional method is to conduct flight tests to demonstrate that the aircraft will not experience any impairments, such as vibrations, within its flight envelope. The certification regulations explicitly require flight tests in this case, but the authorities are already beginning to accept simulation data. The prerequisite for this is it that has been proven in advance to the authorities that the underlying simulation method really is able to correctly model the physical flow processes. For manufacturers, this means that costs and risks can be minimised.

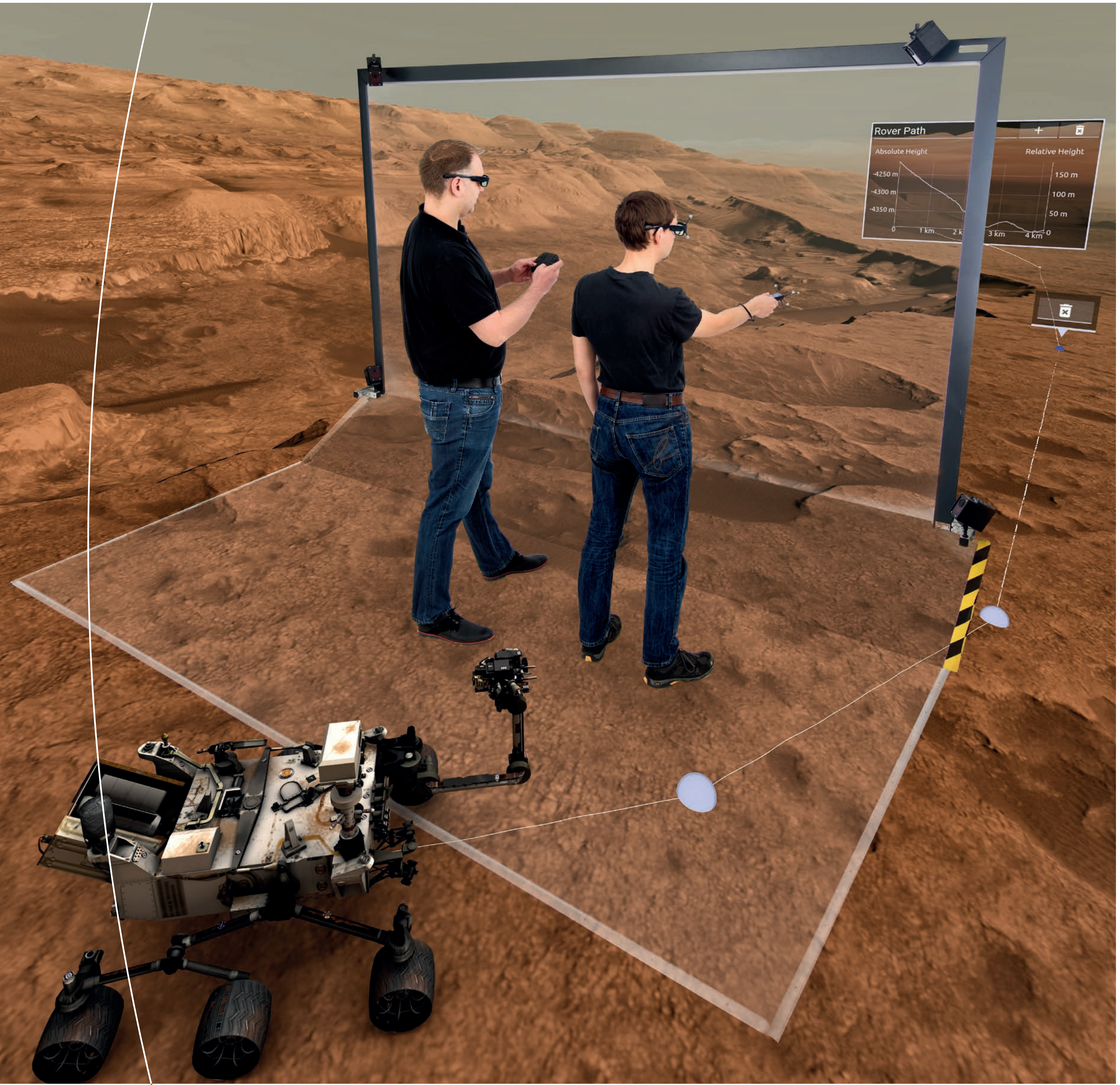
The days when test pilots had to perform risky flight manoeuvres that took the aircraft to its physical limits in order to provide the necessary proof of safety are long over. In many areas, it is now possible to provide precise predictions of whether an aircraft has the correct design and load capacity using ground tests and simulations. The test pilot then simply has to demonstrate this within a certain safety margin, up to the calculated limit values. Researchers have taken this as their starting point for improving their numerical processes in order to define these critical points more accurately, with implications for the development of aircraft and vehicles and their certification.

"It will be some time before the simulations on our screens fully match the real behaviour of vehicles and allow us to truly replicate all of the conditions," says Geisbauer. "That said, with our interdisciplinary approach and the availability of ever-increasing computing power, we are already building trust in our computer data and showing that in a few years we will be in a position to digitalise certification processes using modern numerical methods." The cross-sectoral project has a total of 26 million euro of DLR core funding. It will initially run for four years, from 2018 to 2021. The follow-up steps for the coming decades are also being designed and planned, as the researchers wish to work not only in an innovative way, but above all with foresight.

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

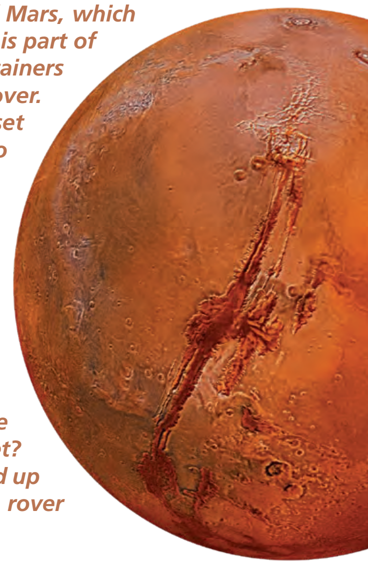
DLR CROSS-SECTORAL PROJECTS

- Global Connectivity – global broadband access
- Factory of the Future (DLR Magazine 159, November 2018)
- **Simulation-based certification**
- Big Data Platform (DLR Magazine 160, March 2019)
- Condition monitoring for safety-relevant structures
- Cybersecurity for autonomous and networked systems
- Transport 5.0
- Digital Atlas
- GigaStore
- Future Fuels (DLR Magazine 158, July 2018)



Planning future missions: With the help of virtual reality technology, scientists can travel to distant places without leaving their workplace. One possible application is the joint planning of routes for rovers on other planets.

THE SOLAR SYSTEM WITHIN ARM'S REACH



"It is 1 April 2029. We're sitting in our office at the DLR Institute of Planetary Research. Wearing virtual reality headsets, we browse through the latest images of the surface of Mars, which have just been sent to Earth by a European Space Agency (ESA) rover. The rover is part of an international sample-return mission to Mars. It is designed to collect the containers of soil and rock samples left behind in Jezero Crater by NASA's Mars 2020 Rover. We're just a few hundred metres from the location where the containers were set down eight years ago! Our task is to steer the rover to that location. In Jezero crater, we meet with ESA and NASA colleagues – well, with their avatars, as they are located at the European Space Operations Centre in Darmstadt and the Jet Propulsion Laboratory in Pasadena, respectively – to discuss the best way to get the rover to the samples. We are able to seamlessly switch from a view of Mars from the rover's perspective to images of the surroundings taken from orbit over recent years. We analyse the three-dimensional data and determine the route: are there any large rocks in the way? Is the slope too steep to be traversed? Are there any scientifically interesting rock formations along the way that might merit a special stop and careful examination? We can survey the virtual terrain in just a few movements. One engineer raises concerns about the duration of the journey – will we make it to our planned destination before sunset? To find the optimal route, we conduct a simulation using a virtual rover. We speed up the visualisation and eagerly follow the position of the Sun in the sky. Yes, the rover will indeed have reached its destination shortly before sundown."

Ernst Hauber, DLR planetary researcher

Using virtual reality to plan future space missions

By Simon Schneegans and Markus Flatken

The notion of researchers planning a future mission to Mars while being there – without leaving their workplace – will soon no longer be a futuristic fancy. Virtual reality (VR) will make it possible to wander around the surface of distant planets, carefully prepare rover missions, measure distances and identify landing sites. To achieve this, planetary researchers and software engineers at DLR are developing CosmoScout VR, a software that makes virtual travel through the Solar System and to individual planets possible.

Combining large amounts of data

CosmoScout VR can display huge datasets for entire moons and planets in detail. But this capability is also one of the greatest challenges facing engineers during the development stage. The difficulty lies in that the volumes of data acquired by today's satellites are so vast that they can only be analysed in batches when using conventional methods.

The European Space Agency (ESA) Mars Express spacecraft, which has been orbiting our planetary neighbour since 2003, is a prime example of this precise issue. One of its seven measuring instruments is the High Resolution Stereo Camera (HRSC) developed by DLR, which images the Martian surface in high resolution. The datasets acquired by the HRSC to date amount to approximately five terabytes. As researchers need a virtual copy of reality that is as detailed as possible for scientific analysis, the software must combine different datasets, including multispectral data, simulated atmospheric data and subsurface radar data. The data used are often from various missions. The total amount of data for analysis can range from a few hundred gigabytes to several terabytes. But state-of-the-art high-end graphics cards offer only 48

CosmoScout VR is a virtual 3D Solar System developed by researchers at the DLR Simulation and Software Technology Facility in Braunschweig.

Its development began under the name Terrain Renderer, as part of the EU CROSS-DRIVE project (Collaborative Rover Operations and Satellites Science in Distributed Remote and Virtual Environments). The software has undergone further development since, and now simulates not only Mars, but the entire Solar System.

CosmoScout VR uses OpenGL to represent the Solar System, and runs on Windows and Linux. The source code is freely available under the MIT licence.

https://github.com/cosmoscout

gigabytes of memory, and a smooth VR display requires at least 60 frames per second. To optimally utilise the limited resources of such graphics cards and enable the visualisation of the vast amounts of raw data, the researchers use special algorithms that automatically adjust the level of detail. As the raw data are not generally stored on the user's computer, the data are loaded over the network as required. Therefore, standardised interfaces such as a Web-Map-Service (WMS) can be used to integrate the user's own datasets into the CosmoScout.

The Solar System is big – very big

An additional challenge faced by the developers is the hard-to-imagine size of the Solar System. CosmoScout VR uses NASA's SPICE Toolkit to calculate the motion of celestial bodies. DLR researchers have developed algorithms that make it possible to represent planetary surfaces with millimetre precision. Given the colossal size of our cosmic neighbourhood, this requires a high degree of accuracy not needed for other VR applications. To travel through space at speed, CosmoScout VR always adjusts the maximum speed of movement by using the distance to the nearest celestial body or satellite. If the users are located outside the Solar System, they will travel at many light years per second, but as they approach a planet or satellite, their maximum speed is progressively reduced to a few kilometres per hour. Additionally, the users automatically follow the position and rotation of the corresponding celestial body. This makes it possible for researchers to see Mars rotate around its axis once a day from orbit, and the Sun rise and set from the Martian surface. This motion technology allows researchers to both survey the surface of a planet centimetre by centimetre and get an overview of the planet from orbit within seconds.

In order for the scientists to be able to interact with their environment, the next virtual celestial body must never be more than an arm's length away. If the Solar System were always represented on a 1:1 scale, the virtual planetary surface would be too far away to work effectively with the simulation. Instead of actually covering a virtual distance of hundreds of kilometres to enter planetary orbit, the software shrinks the planet. Researchers travelling through the Solar System see the football-sized planet from the perspective of an interplanetary giant and can touch it by stretching out their arm.

Virtual reality offers benefits for collaboration

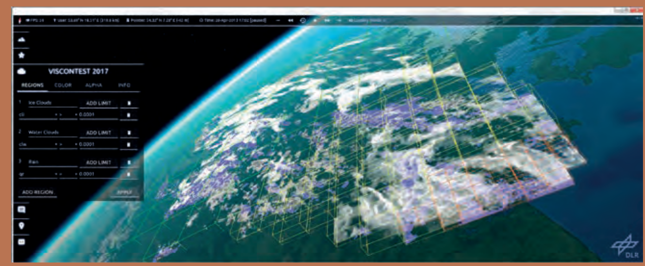
A key advantage of using VR to plan future missions is that the gestures and facial expressions of the researchers – who are all working from different locations – are also transmitted as they interact. This makes collaboration much more efficient. In addition, the VR application offers scientists a tool that allows them to conduct field tests on other planets in the same way as they would on Earth. The application is not restricted to merely depicting reality but can extend it to cover a range of options that are impossible in real life. For example, information such as height values or angle of inclination can also be displayed. In addition, the scientists have more efficient navigation options at their disposal – making travelling at the speed of light possible.

Through the VR headset Mars looks close enough to touch

FROM MARS' MOONS TO CLIMATE RESEARCH ON EARTH

As a universally applicable virtual Solar System, CosmoScout VR is not restricted to specific planets. In addition to future missions to our planetary neighbour – such as Mars 2020 – the software also lends itself to expeditions to other celestial bodies. Examples are ESA's JUICE mission to Jupiter in 2020, the Martian Moons Exploration (MMX) mission led by the Japan Aerospace Exploration Agency (JAXA), which will bring samples from the Martian moon Phobos back to Earth, and the Mission to the Moon by PTScientists GmbH. But CosmoScout VR can also be used for Earth-orbiting missions, such as the repair of defective satellites (on-orbit servicing).

Of course, it offers many applications beyond mission planning. Researchers from the DLR Simulation and Software Technology Facility and the DLR Institute of Atmospheric Physics are currently working on an extension to the ESCiMO (Earth System Chemistry Integrated Modelling) data for the visualisation and analysis of climate simulations. CosmoScout VR should make it possible to display, interactively research and analyse two petabytes of climate data.



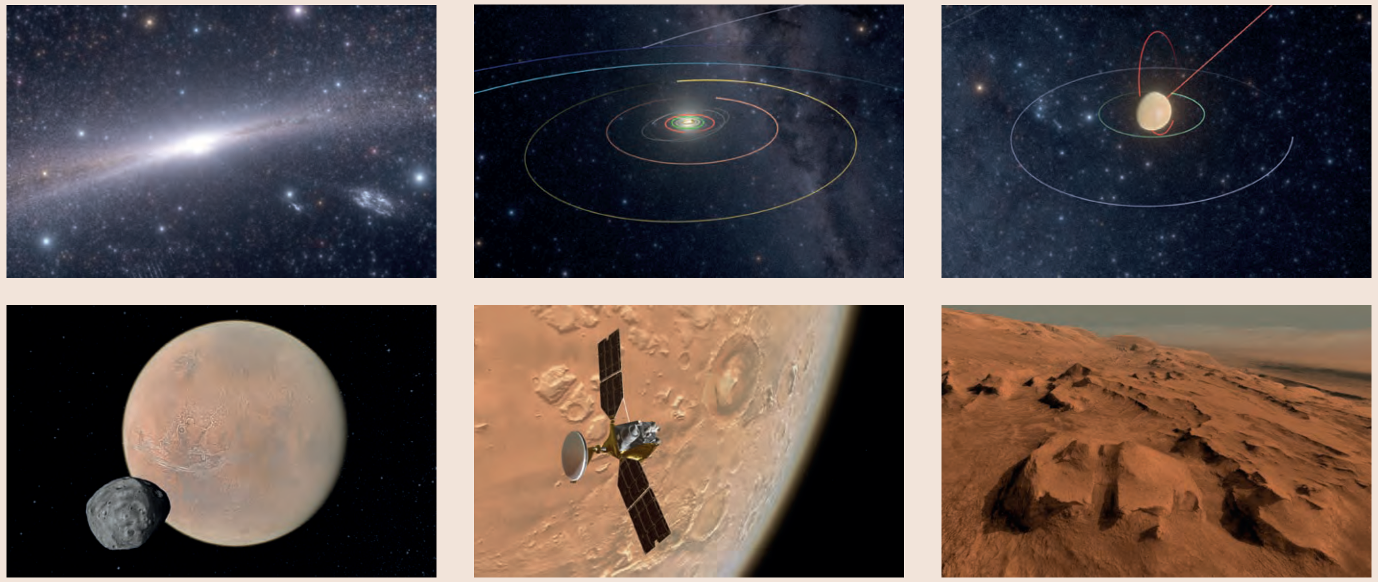
Results of a weather simulation from the High definition clouds and precipitation for advancing climate prediction project – HD(CP)² – in CosmoScout VR.

The software also makes it possible to simulate a camera on a spacecraft. It can display virtual camera images of an autonomous landing flight in real time, which the developers can then use to verify their algorithms. Lastly, the software offers non-scientists insights into research and the possibility of experiencing past, current and future space missions up close.

All of this can be in- tegrated into the workplace and brings variety to every day tasks. The downsides to the technology are the expensive hardware, complex installation procedures, indirect interaction with the virtual scene, almost no haptic feedback, and the feeling of dizziness that many users experience when travelling through virtual space. With CosmoScout VR, DLR researchers are investigating the advantages and disadvantages of VR technology and working on solutions to ensure that these negative side effects of the working tool of the future are soon a thing of the past.

Simon Schneegans is a member of the Interactive Visualisation working group at the DLR Simulation and Software Technology Facility. He conducts research into methods for the photorealistic representation of objects in virtual reality (VR).

Markus Flatken develops and researches scientific visualisation methods in the same group. He focuses on the analysis of large datasets using high-performance computing resources.



These images are snapshots of a seamless virtual journey through space. The flight begins in the outer reaches of our galaxy, many tens of thousands of light years from the Sun (Figure 1). In our Solar System, the orbits of the planets are represented by coloured ellipses (Figure 2). The following image shows Mars. The orbits of its moons, Phobos and Deimos, can also be seen, along with the elongated elliptical orbit of Mars Express in red (Figure 3). Figure 4 shows Mars with Phobos. After a fly-by with the Mars Reconnaissance Orbiter (Figure 5), the journey ends in Gale Crater (Figure 6). The high-resolution satellite data from the HiRISE camera allow the area to be examined with centimetre precision.

DIGITAL – FROM TOWER TO FLIGHT DECK

27 March 2019, 10:11 – the DLR Falcon research aircraft takes off from Oberpfaffenhofen Airport; its flight is a world first. On board is a demonstration version of the new L-band Digital Aeronautical Communications System (LDACS). In future, it should enable cryptographically secured, efficient data exchange between air-traffic control and the flight deck. In addition, the researchers are testing an alternative navigation system that will guide aircraft safely to their destination – even in the event that their satellite navigation systems fail. By the time the Falcon completed its approximately 90-minute journey, the team had taken a major step towards LDACS standardisation.

LDACS digital aeronautical communications – secure data and voice transmission.

An article from the DLR Institute of Communications and Navigation

The technology underlying the rather cryptic LDACS acronym can be compared to a terrestrial mobile radio network specifically adapted for aviation. The ground station is analogous to the mobile network base station, and the radio equipment in the aircraft corresponds to a smartphone. The new system will allow a better exchange of instructions and information between air-traffic controllers and pilots, as data and voice can be transmitted simultaneously. A team of DLR researchers has been working on LDACS with external partners since 2007. Alongside Frequentis AG and the University of Salzburg, the European Organisation for the Safety of Air Navigation (EUROCONTROL) and Deutsche Flugsicherung GmbH, the German air-traffic control organisation, have also been involved in developing the technology from the beginning. German industry partners Rohde & Schwarz GmbH & Co. KG, BPS GmbH and iAd GmbH became partners approximately six years ago and have been playing an important role since then.

New air-traffic management requires a modern aeronautical radio communications system

The new development is driven by the need to modernise the current air-traffic management system. Advanced, efficient communications are an important prerequisite for ensuring the safe and effective management of steadily growing traffic volumes. "Analogue technology from the 1930s is still being used for aeronautical radio communications today. This is seen as highly inefficient and cumbersome in the modern age. It needs to be upgraded urgently," says Michael Schnell, Project Manager at the DLR Institute of Communications and Navigation. An example of one such unwieldy process is the method of changing flight sector. At present, pilots must verbally register and deregister with the air-traffic controllers and manually enter the new radio frequency when changing flight sectors. The air-traffic controller then communicates route changes to the pilot verbally, using voice radio, which the pilot reads back to rule out possible misunderstandings. The pilot then manually enters the changes into the flight management system on board the aircraft. In future, such data will be transmitted automatically and activated upon confirmation by the pilot.

In addition, the existing analogue voice radio makes very inefficient use of the frequency spectrum. "Only a limited number of frequencies are available for aeronautical radio communications, yet the number of flights is growing year on year," notes Schnell, adding: "It is high time for us to enter the digital age!" LDACS will not only make the communication between pilots and air-traffic controllers more efficient, but it will also enable the exchange of complex information that cannot be transmitted using the current analogue voice radio. For example, the transmission of routes will include time information. When combined, the flight path and time data create a 4D flight trajectory. This indicates

The DLR Falcon research aircraft takes off for its first flight with LDACS

THE WORLD'S FIRST CRYPTOGRAPHICALLY SECURED TRANSMISSION OF PRECISION LANDING DATA

During the flight tests, Michael Schnell's team managed to carry out another special demonstration, this time of the world's first cryptographically secured data transmission to an aircraft for the Ground-Based Augmentation System (GBAS) precision landing system. GBAS provides correction data for satellite navigation, enabling new, quieter and more fuel-efficient approach procedures, which also allow reduced separation between aircraft.

At present, correction data for GPS are sent via VHF Data Broadcast (VDB) when landing with GBAS. Due to the limited bandwidth of this service, other satellite navigation systems such as Galileo, GLONASS and Beidou have not been catered for. The new digital aeronautical radio standard LDACS is able to send GBAS correction data for several satellite navigation systems simultaneously, thus enabling higher system availability. The GBAS correction data are also transmitted in a cryptographically secured manner by LDACS. This means that the exchange of information is protected against possible cyber-attacks and an automated landing approach cannot be manipulated.

both the route the aircraft will fly, as well as additional information on when the aircraft will arrive at specific points on that route. Situations in which two aircraft could come close together can thus be identified and avoided before the aircraft take off.

Cryptographically secured flight and communications

Thanks to its high capacity, LDACS digital aeronautical radio can support all current and foreseeable communications services necessary for modern air-traffic control. The structure of the system also allows the integration of new applications, including sectorless air transport. This would allow air-traffic controllers to consider the airspace as a whole and contrasts with current methods that divide the airspace into distinct areas, each the responsibility of a different controller. LDACS also provides communication services for airlines, enabling them to manage their fleet more effectively. One key advantage of LDACS over conventional systems is that data is exchanged over a cryptographically secured connection. "In view of the increasing automation of air-traffic management, cyber-security is absolutely indispensable, as the human is increasingly being taken out of the loop," explains Schnell.

Christoph Günther, Director of the DLR Institute of Communications and Navigation, explains the main challenge encountered during the development of LDACS: "No new frequencies could be made available for this digital service. The new system thus had to allow its service to be operated in parallel with other services in the same frequency band." This meant that the researchers were not able to use commercially available technology. Using specially developed technologies, they positioned LDACS in the frequency spectrum between existing aeronautical navigation systems.

One system – plenty of functionality

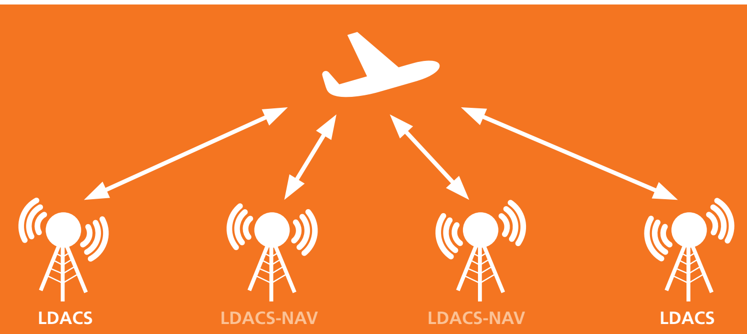
Although LDACS was primarily developed as a communications system, it can also be used to reliably and accurately determine the position of an aircraft. To do this, the researchers used LDACS signals from different ground stations, supported by inertial and barometric altimeter measurements. LDACS can therefore also be used as a back-up for satellite navigation, allowing the existing and costly ground-based navigation infrastructure to be dismantled.

The team has been working on another innovation since early 2019. LDACS will also be able to connect aircraft with one another. This would allow the exchange of real-time flight data on the position, destination and speed, as well as about air currents and the local weather situation.

From theory to practice

"Theory is fine," says Schnell, "but you have to show the world that your idea really works. This is particularly important in aeronautics, where safety is of the utmost importance." As part of the Integrated Communications and Navigation (ICONAV) project, the team addressed the navigational functionality of LDACS while including a first laboratory demonstration. In the Migration towards Integrated

During the first test, the Falcon flew over four ground stations. Two of them are navigation stations (LDACS-NAV), which send LDACS signals to the aircraft for the purpose of position determination. Two are LDACS stations, which send and receive digital aeronautical radio data.



HOW DOES THE CRYPTOGRAPHIC PROTECTION OF GBAS DATA WORK?

LDACS uses the Timed Efficient Stream Loss-tolerant Authentication (TESLA) broadcast authentication protocol to secure the GBAS data transmission. With TESLA, time is divided into intervals of equal length, with each interval assigned a key with which the message is cryptographically secured. Post-quantum cryptographic methods can be used to generate these keys. After a predefined number of time intervals, the sender releases the keys to all of the recipients. The keys then make it possible for the recipients to verify the authenticity and origin of the message. This ensures that GBAS messages are not falsified and that data from unauthorised persons or systems does not enter the system.

The first test of a cryptographically secured GBAS transmission is in progress and the aircraft is receiving GBAS correction data completely digitally for the first time

The experimental setup installed in the research aircraft

COM/NAV Avionics (MICONAV) project, a fully functional and airworthy demonstration model was built and trialled in the laboratory and during flight tests.

In addition, the team set up four ground stations in the southwest of Munich. Two of these stations are fully operational LDACS ground stations, while the other two are navigation stations. The latter only transmit LDACS signals, which are needed by aircraft to determine their position. Communications take place with the two LDACS ground stations that can transmit and receive. The researchers carried out six measurement flights with the LDACS demonstration system fitted in the DLR Falcon research aircraft. "Our measurement campaign was a complete success," concludes Schnell. "We were able to test and validate all of the essential communications and navigation functionalities in flight." Registering and deregistering with the LDACS ground station was quick and free of errors, as was the hand-over from one ground station to another. During the flight, the aircraft and LDACS ground stations communicated reliably with one another in different situations including high-altitude overflights and take-off, landing and taxiing at the airport. The researchers used typical aeronautical applications such as Controller-Pilot Data Link Communications (CPDLC) and Automatic Dependent Surveillance – Contract (ADS-C) for data exchange. To ensure secure communication the researchers also implemented a 'post-quantum' cryptography algorithm that will enable LDACS communications to withstand future cyber-attacks of the most modern kind.

What now?

Fully implementing the technology into flight guidance systems worldwide will likely take a few years. A DLR-led working group at the International Civil Aviation Organization (ICAO) has been working on standardisation since 2016. "Once the standard is finalised, manufacturers and airlines will be called upon to adopt it," says Schnell. In his opinion, this could happen by 2022.

POST-QUANTUM CRYPTOGRAPHY

Post-quantum cryptography refers to encryption techniques that – unlike current methods – cannot be cracked by quantum computers. Quantum computers are the subject of ongoing research and allow multiple hypotheses to be tested in parallel. This makes quantum computers particularly fast and efficient.

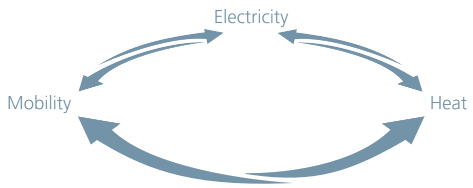
THE MICONAV AND ICONAV PROJECTS

DLR implemented the Integrated Communications and Navigation (ICONAV) and Migration towards Integrated COM/NAV Avionics (MICONAV) projects together with partners Rohde & Schwarz GmbH & Co. KG, BPS GmbH and iAd GmbH. Both projects were part of the Federal Aviation Research Programme (LuFo), funded by the German Federal Ministry for Economic Affairs and Energy (BMWi).

Carsten Agert

is Director of the DLR Institute of Networked Energy Systems. A physicist, he has been a professor of energy technology at the University of Oldenburg since 2008. At the same time, he took over the running of the newly founded EWE Research Centre NEXT ENERGY, which was transferred to DLR in 2017 and became the Institute of Networked Energy Systems. Among other roles, Agert was vice president of the Association of European Renewable Energy Research Centres (EUREC) from 2009 to 2011, a member of the Energy Transition Round Table of Lower Saxony's state government from 2015 to 2016, and has been spokesman for the Executive Board of the Lower Saxony Energy Research Centre since 2017.

SYSTEM SWITCH DURING OPERATION



The energy transition has two clear winners so far among renewable energy sources – photovoltaics and wind. In total, renewables now generate approximately 40 percent of Germany's electricity supply. But how can they be developed nationwide to provide heating and facilitate mobility for both people and goods? How can they replace fossil fuels, which are soon to be abandoned? Carsten Agert, Director of the DLR Institute of Networked Energy Systems, believes the answer lies in sector integration, also known as sector coupling.

An interview with Carsten Agert on sector integration in the field of energy supply

The average share of renewable forms of energy within our power supply system exceeded 40 percent this year. This demonstrates the success of the energy transition, right?

: It is a gratifying snapshot – but we have to look at things in their overall context. Industrialised countries have set themselves the target of reducing emissions of carbon dioxide equivalents by 80 to 95 percent by 2050 compared with the base year of 1990. If we look at what has to be achieved by 2050, we can see a fundamental, far-reaching change ahead – which can probably only be compared to 19th-century industrialisation in terms of its sheer scale.

So, have we been addressing the energy transition too slowly?

: As I see it, we have been too one-sided. For about the last 20 years, since the Renewable Energy Sources Act came into force in 1998, we have done the obvious – installing wind turbines and solar power plants. So we have harvested the 'low-hanging fruit'. By contrast, the transport sector has largely been overlooked, which is why we are seeing stagnation in this sector, with the share of renewable energy in fuel at about six percent. The heating sector is looking very similar. So our interim conclusion is this – yes, the energy transition is under way, but we are still at the beginning. Now is when it actually starts to become difficult.

… but are you confident that DLR's energy research will be able to develop robust concepts for a stable, safe and economically attractive energy supply system?

: Absolutely. It is true that the expansion of solar and wind power within the electricity sector has reached a level that makes further expansion structurally and technically more difficult. However, if we include the heating and mobility sectors, which are also structurally complex, we will be able to develop attractive cross-sectoral solutions. As researchers, our task is to look for areas of flexibility within the energy system that may help us to cope better with the reality that patterns of production and consumption do not always match. The massive storage and flexibility potential that we need to match supply and demand can only be achieved through sector integration. Although it is a term usually associated with e-mobility, we understand sector integration to mean 'combining power, heat and transport in such a way that these three sectors can grow together to form a large, integrated energy system.

At DLR's Grid Lab in Oldenburg, it is possible to depict residential areas realistically, with all of their energy flows. For example, the researchers are investigating new network structures and the integration of electromobility into the energy system using a real-time simulation system.

Why are the interfaces between the different energy sectors so important to the success of the energy transition?

: Sector integration represents the point of entry from a mere electricity transformation to the true energy transition. At present, for example, the heating sector is still primarily based on natural gas, and, in some cases, also on oil. But if we look at the 2050 climate goals, one thing is abundantly clear: we cannot continue to produce heat simply by using fossil-derived methane or oil. Mobility is facing a similarly profound change. Cutting around 80 to 95 percent of Germany's carbon dioxide emissions by 2050 means that cars can no longer be allowed to emit fossil-derived carbon dioxide molecules. The average lifespan of a car is 15 years, so the last new car that still burns fossil fuel should be produced no later than 2035 for the German market. The European Union recently held discussions about whether we can call for a 30, 35 or 40 percent reduction in emissions for new cars by 2030. We would actually have to demand 100 percent five years later. In other words, if we are to have a chance of achieving our climate goals, we must very quickly switch the heating and transport sectors completely to renewable energy. Making such changes will give us the opportunity to harness the immense potential for greater flexibility offered by sector integration. We need that flexibility if we want to design a stable energy system around the fluctuating supply of renewable energy. What is more, sector integration gives us access to major storage potential.

How exactly does sector integration work? From a technical point of view, why is it important to make the energy system more flexible? How can we offset fluctuations in the power grid with heating and mobility?

: If too much energy from renewable sources is fed into the grid – perhaps because there are strong winds – we can reduce the output of the generating plants, or we could use or store the excess energy. In this case, we have to bear in mind that it is much cheaper to store heat than electricity. So if I have an electrically powered heating system that is coupled with a thermal storage system, it makes sense to generate heat when there is a surplus of electricity, not just whenever I need heat. Thermal storage systems therefore give our energy systems greater flexibility.

But sector integration also works in the other direction. Take mobility, for example – we can make hydrogen during the periods when there

The DLR Institute of Networked Energy Systems in Oldenburg, Lower Saxony, currently has approximately 150 employees. It develops technologies and concepts for future energy supply systems based on renewable energy sources.

is more than enough electricity. In this case, the energy is stored as a chemical source. This hydrogen can be converted back into electricity at any point if the demand exceeds the available renewable energy in the grid. Our goal is to couple the transport sector with the electricity sector at both ends – we turn electricity into hydrogen but leave ourselves the option of using transport infrastructure to turn the hydrogen back into electricity. DLR's energy and transport institutes are already working closely together in this area.

Your examples are based on hydrogen. Do you believe that this chemical source will shape the future energy system alongside electricity?

: We would do well to agree on a common chemical energy source for the future, within the context of sector integration. I do not imagine, for instance, that we will be using hydrogen for transport, synthetic gas for heating, and perhaps another molecule for a third application, as we would need specialised logistics and infrastructure for each one. However, the question of which energy source that will be remains to be answered. Personally, I believe it will be hydrogen.

Let us imagine a future in which one chemical energy source has been selected, and there are sufficient facilities supplying renewable energy. Does that mean that energy researchers will have done their job?

: The work really begins once the individual technologies are running and established. The way in which these future networked energy systems operate will be fundamentally different from how they work today. Decentralisation, fluctuating generation and digitalisation are the key areas that will provide us with challenges at the system level of the energy transition for many decades to come. In order to address these challenges, we at the DLR Institute of Networked Energy Systems are developing technologies that can transport energy across sector boundaries. We want to be sure that such technologies do the right thing at the right time, work reliably and are user-friendly. In addition, we incorporate them into the systems analysis as part of our overarching strategy, which takes into consideration technical, sociological, environmental and economic aspects. When designing future energy systems, we also need individual technologies such as solar power plants, storage systems and gas turbines, which are being researched at other DLR institutes. But the further course of the energy transition will largely depend on whether we manage to fundamentally reshape our energy system using very good individual technologies, including the system level.

Your researchers are looking at the desired transformation of the energy system from many different perspectives – from energy management to system services, through to highly specific recommendations for action by industry and government. Why does converting the existing system to renewable energy present such big problems?

: The technical requirements of the future power system are very complex. Let us take one example – even on days when there should not be any storage problems, as the amount of energy available from the solar and wind generators approximately matches demand, we still need an array of new solutions in order to ensure a stable energy system based on renewable sources. Among other things, this is due to the fact that we are still deriving a lot of benefits from the inertia of large, traditional generators. These help us manage the stabilisation of our electricity system. Turning to solar and wind, we are essentially dealing with power electronics that do not have this inherent inertia. This has a number of implications, especially for the short-term regulation of energy systems. In addition, the energy system will be highly decentralised. It will no longer be a matter of controlling a handful of large power plants, but rather countless small power plants.

Let us look at a current hot topic – the expansion of the major power lines from windy northern Germany to the south of the country. To what extent can the energy system be stabilised by interregional or even European networking?

: Better interregional networking is a fundamental prerequisite for ensuring the security of supply that we are used to today while using renewable energies in the future. In the decentralised, regional parts of the energy system, we will never find the degree of affordable flexibility that would allow us to manage energy autonomously on a small-scale, at the local level. That is why we need large-scale, high-performance networking for security of supply. Otherwise, we will not be able to create an energy system that is reliable, stable and affordable.

Given all these enormous challenges, do you sometimes wish that you had someone like Greta Thunberg at the Cabinet Table? In future, should the government create stricter framework conditions for the success of climate protection and the energy transition?

: The spirit of the 'Fridays For Future' movement would be good for climate policy, there is no question about it. In the electricity sector, the energy transition is faltering, and the expansion of renewable energy sources has not yet delivered the desired degree of effectiveness in terms of reducing emissions. But the bottom line is that it is still making progress. In the transport, aviation and heating sectors, however, the energy transition has hardly begun. I would argue that the decisions on phasing out fossil fuels should be seen as an opportunity to finally install a nationwide – and cross-sectoral – system for minimum pricing or taxation of carbon dioxide. This would stimulate resourcefulness within our national economy much more effectively than fragmented, hotly contested attempts at regulation. The younger generation is reminding us on a weekly basis that we need to act now.

The interview was conducted by Heinke Meinen of Communications at the DLR Institute of Networked Energy Systems.

"Storing heat is much cheaper than storing electricity," stresses Carsten Agert. Against this backdrop, DLR is conducting research into electricity-based heating systems combined with thermal storage at its Combined Heat and Power (CHP) Laboratory. If the heat is generated at a time when there is a surplus of electricity, this makes the energy system more flexible.

The DLR researchers in Oldenburg are also investigating how electromobility can be integrated into future power systems. For example, this could make it possible to use the batteries of electric cars to compensate for power grid fluctuations.

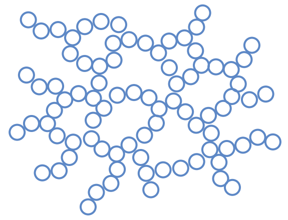
The 'eye2sky' monitoring network, which is currently being set up by DLR in northwestern Germany, measures the formation and movement of clouds in the sky across the entire country. This allows the yield of solar power plants to be predicted minute by minute. Such exact predictions are not possible using satellite imagery, because the shadows of clouds – rather than their position – are the decisive factor for the yield of solar power plants.

Barbara Milow and the supermaterial: Aerogels are extremely versatile and therefore interesting for many different applications, for example as insulating materials, filter materials, as well as implants. This is what makes these light and airy materials so fascinating for the DLR researcher, who holds a professorship at the University of Cologne.

HOW DO AEROGELS DRY?

Drying aerogels without damaging their inner structure is essential but difficult. The solution lies in what is known as supercritical drying. In this process, the pressure and temperature are increased until the density of the liquid and gaseous phase – two of the three classic phases of aggregation – is balanced. This homogeneous phase turns the fluid into a supercritical fluid. The compression of the molecules creates a fluid without capillary stresses, so that there are no forces acting upon the pore structure. The gel does not shrink during drying, but rather retains the shape and structure of the wet gel, while becoming an aerogel.

LIGHT AS AIR AND VERSATILE



Whether for the electric car or the next-generation train – according to Barbara Milow, aerogels will soon be indispensable in many areas. The DLR scientist and her working group are developing this highly porous and lightweight material for a vast array of applications.

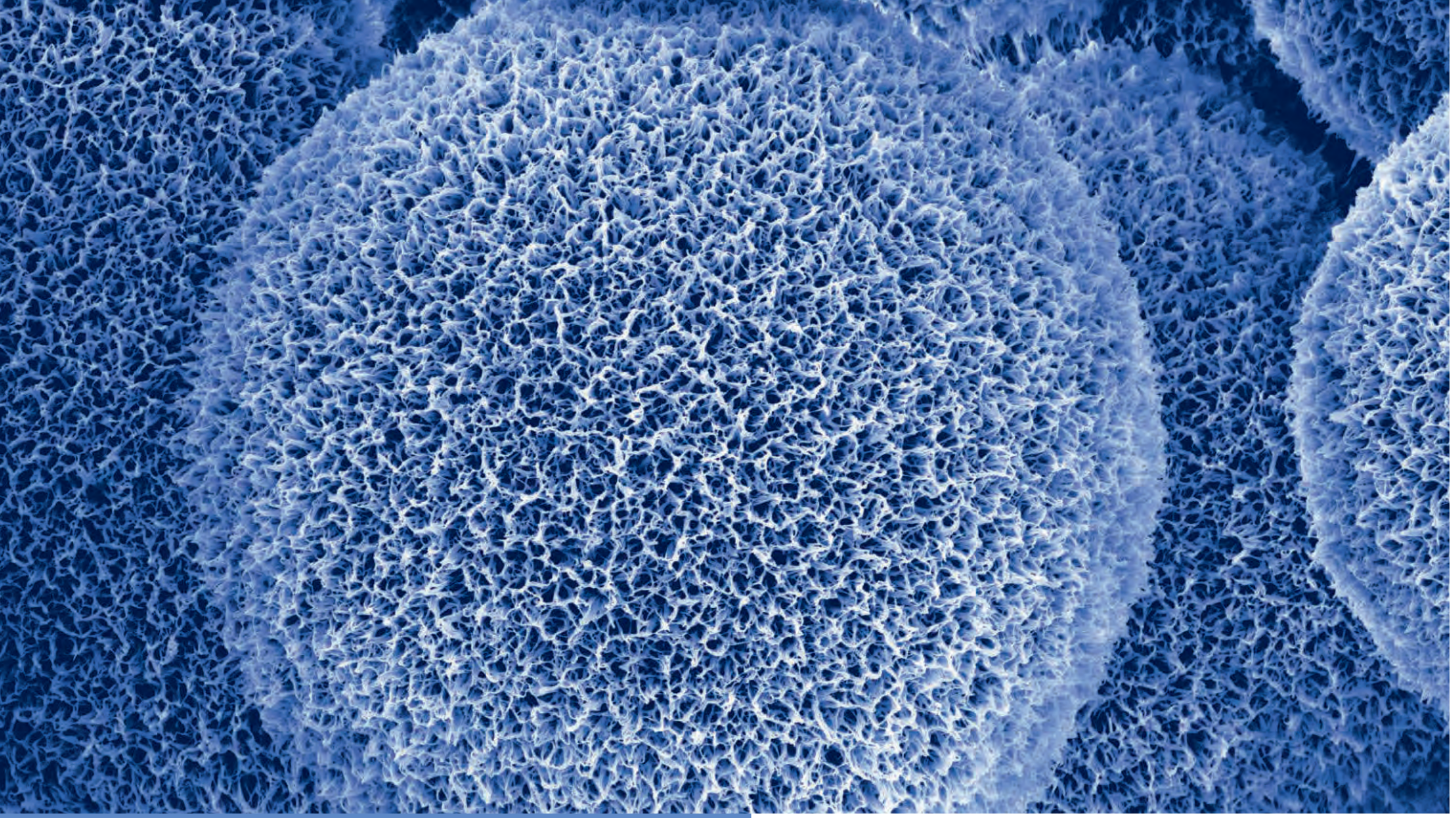
When researchers cook up new recipes for aerogels, it all sounds quite simple. But is it?

By Frank Seidler

Barbara Milow looks intently at a glass beaker, taking in every detail. She likes the excitement of waiting to find out whether the experiment has worked, or whether something has gone askew. Only afterwards will she know whether a test has been a success or an ostensible failure from which she might nevertheless be able to learn something that proves crucial for later research. “This always fascinates me,” says Milow. “I’m enthralled by chemical synthesis, how materials and their properties are related, and the development of entirely new materials.” The scientist, who holds the Chair of Nanostructured Cellular Materials at the University of Cologne, and her colleagues at the DLR Institute of Materials Research have cause for excitement today. The experiment has gone according to plan: the gelation of the silica solution is clearly discernible. And Milow does not want to leave anything to chance. Nevertheless, things do not always go as expected when she and her team of technicians, engineers and scientists literally cook up new recipes for aerogels in their laboratory.

Aerogels are state-of-the-art materials. They essentially consist of air surrounded by a fine yet solid structure, not unlike a sponge. Materials such as silicates, (bio-)polymers and metal oxides are used for the solid structure, accounting for between one and 20 percent of the finished aerogel. Aerogels have a very low density, which makes them extremely light. This is one of many reasons why Milow is so enthusiastic about this material. “In principle, the manufacturing process is very simple,” she says. “You combine the components, they gel, you dry the gel, and the result is a material with an incredible number of applications. It can have the electric conductivity of carbon while also offering good thermal insulation due to its nanoporous structure. It is almost unprecedented for one material to have such a range of properties.”

The scientist has led the Aerogels and Aerogel Composites Department at the DLR Institute of Materials Research since late 2018. With 32 employees, it is the largest research group dedicated to this subject area in Germany. The scientists are working together to gain a better understanding of the materials’ gelling process and to open up possible areas of application. Silica aerogels are very stable at extreme temperatures and are being developed for sound and thermal insulation in aircraft cabins or fuel tanks. Thermoset aerogels, meanwhile, make outstanding insulating materials, as they are neither toxic nor flammable. Biopolymer aerogels have an inner structure that is similar to felt, and are used for the adsorption of air pollutants, humidity or materials that are susceptible to oxidation. Due to their definable nanostructures, carbon aerogels can contribute to new battery concepts or be used to optimise casting processes. When combined with other



A new biopolymer aerogel developed by DLR scientists in a laboratory experiment. The spherical and filamentary structures are created when chitosan is combined with a thermoset.

AEROGELS AND AEROGEL COMPOSITES

Biopolymer aerogels consist of naturally occurring macromolecules such as cellulose, chitin or carrageenan. Chemically bound nanometre-thin fibres give the material its stability. This felt-like structure makes them particularly suitable as filters, for example, for regulating humidity in aircraft cabins, as well as for the adsorption of carbon dioxide.

Thermoset aerogels are lightweight materials that insulate heat and sound. Accordingly, they are of particular interest for the construction of vehicles, trains and aircraft, or as an alternative to polystyrene. They can range from brittle to super flexible, depending on the composition and drying process. They are based on an aqueous resorcinol-formaldehyde solution. When combined with other aerogels, such as silica-aerogel granulates, they form composites with better thermal and mechanical properties.

Carbon- and silicon-oxycarbide aerogels are formed during the thermal treatment of thermoset, biopolymer-based or hybrid aerogels. They are very stable in high temperatures and are used in the sand casting process in foundries. Their large internal surfaces allow them to absorb the gases that occur during the casting process, thus preventing casting defects such as gas bubbles, non-metallic inclusions or sand adhesion. DLR is working to transfer its manufacturing process from the laboratory to a pilot-plant scale.

Silica-based aerogels, also known as frozen smoke, are the most studied type of aerogels. Due to their low thermal conductivity, they are used as an insulating material, but other applications include aerogel particles in cosmetics. In recent years, researchers have developed a new variant: soft, flexible aerogels that remain stable at temperatures of up to 500 degrees Celsius. DLR scientists are working on new formulations to further improve the material.

materials, their positive properties can be harnessed to form innovative aerogel composites. In conjunction with the University of Duisburg-Essen, the DLR researchers have also developed an aerogel concrete that is not only very light, but also provides excellent heat insulation. "The possibilities that we are now seeing are almost limitless, and new areas of application are emerging all the time. It is amazing, considering that research into aerogels began nearly 90 years ago," Milow says.

Good things take time

In the 1930s, scientists worked on removing fluids from wet gels – also known as hydrogels. Aerogels were considered to be any materials that were produced from wet gels and that – after drying – bore the network- and pore-like structure of a hydrogel within the material. These early researchers found it extremely difficult to control the forces that acted upon the pore walls inside the material during the drying process without destroying the structure of the gel and causing the pores to collapse. In the beginning, the drying process would take around a week, so industrial use was out of the question. It was not until the 1960s that scientists succeeded in greatly simplifying and thus accelerating the aerogel production process. They realised that the pore fluid in wet gels might predominantly consist of methanol. Researchers also discovered that material properties, such as the network-like structure of the aerogels, could be controlled via the pH value. Milow was just a child at the time.

During the period when companies like BASF, Hoechst and Henkel were deploying various solutions for wet gels in the 1980s, with a view to developing aerogels with a range of properties, she opted to study chemistry at the University of Cologne, followed by an internship at the Chemical Investigations Office in Trier. "For my doctorate, I went to the DLR Institute of Space Simulation, where I conducted experiments with liquid-liquid systems in microgravity conditions. I was even lucky enough to be able to support the ground-based research for the D2 space mission as a doctoral candidate, which was something that many of my predecessors wanted to do," Milow says. "At that time, I had very little to do with aerogels."

A few scientists at the same institute were working with this interesting material, but it would be another 10 years before Milow became intensively involved in aerogel research. That is how long she worked at what is now the DLR Institute of Solar Research, focusing on the decontamination of waste water using solar energy. "When my contract ended, I needed a reference from my old institute and contacted one of my former colleagues," she recalls. "He was the one working on aerogels with his team back when I was doing my doctorate. I wrote to him, saying, 'Lorenz, I need a reference or a job,' and he replied, 'I can give you both.' That was in 2005. Aerogels have been my focus ever since."

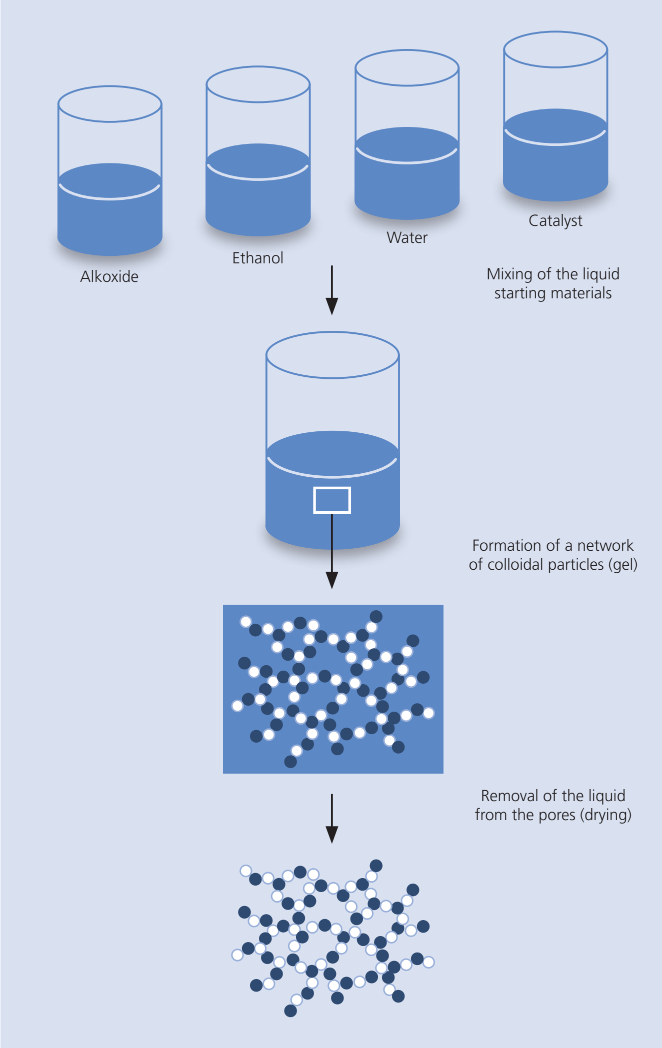
Research into the unknown

At that point, the group was facing an existential dilemma: although funding opportunities were opening up for their projects, the researchers learned that the working group was to be disbanded after a change in the institute's management. "We could not just bury our heads in the sand, so we began to actively raise the profile of this area." The team visited countless foundries across Germany in order to research and develop their production process. In doing so, they gradually opened up a wide range of applications for their materials. For instance, the group developed aerogel structures as model systems for bone implants. Today, their working group at the University of Cologne is making implants out of 'foam-like' biopolymer structures and have reached a stage where these aerogel structures are not rejected after being inserted into the tissue.

Milow and her team consider it important to replace syntheses that include toxic substances and to use other processes instead. "Apart from formaldehyde, the chemicals that we use are all environmentally friendly. We are always looking for materials that we can work with in a sustainable way." The group has found some unorthodox ways of achieving this feat: "On one occasion, we used cinnamaldehyde to make aerogels. It made the whole laboratory smell like Christmas. Unfortunately, it proved to be more detrimental in the required concentrations."

An ambitious vision

"At first, I was sceptical as to whether the team would stick together, everything would work out and the funding would come through. I wrote numerous proposals. But it turned out even better than I could have hoped, and today we are bursting at the seams." Since then, Milow's attention has turned to the next generation. Today, she and her department are working on components for all areas of research at DLR. They are currently developing a material to prevent aircraft fuselages from icing up on long flights. Hydrophobic – meaning water-repellent – aerogels should stop water from accumulating and forming heavy layers of ice.



"My dream is to have a separate centre of excellence for aerogels here at DLR, where we can produce prototypes and very small series of new raw materials and components," the researcher says. The staff at the University of Cologne, where Milow recently became a professor, would also be able to work there. She is proud of that, and her delight at working in this field is apparent when she talks about future projects and new areas of application. Of course, it all takes a lot of work, and perhaps she could have restricted herself to one or two specific areas. But Milow shakes her head: "Keeping things small just isn't my kind of thing."

Frank Seidler is responsible for marketing and communications at the DLR Institute of Materials Research.

Flexible rubber-like aerogel from the family of silica-based aerogels. This aerogel type is suitable for thermal insulation or shielding and can be used at temperatures up to 500 degrees Celsius – for example for cabin insulation of aircraft.

Anko Börner
is Head of the Real-time Data Processing Department at the DLR Institute of Optical Sensor Systems in Berlin-Adlershof. He is responsible for the IPS project. He and his team began working in the field of satellite-independent navigation 15 years ago.

THE NEXT GENERATION OF NAVIGATION

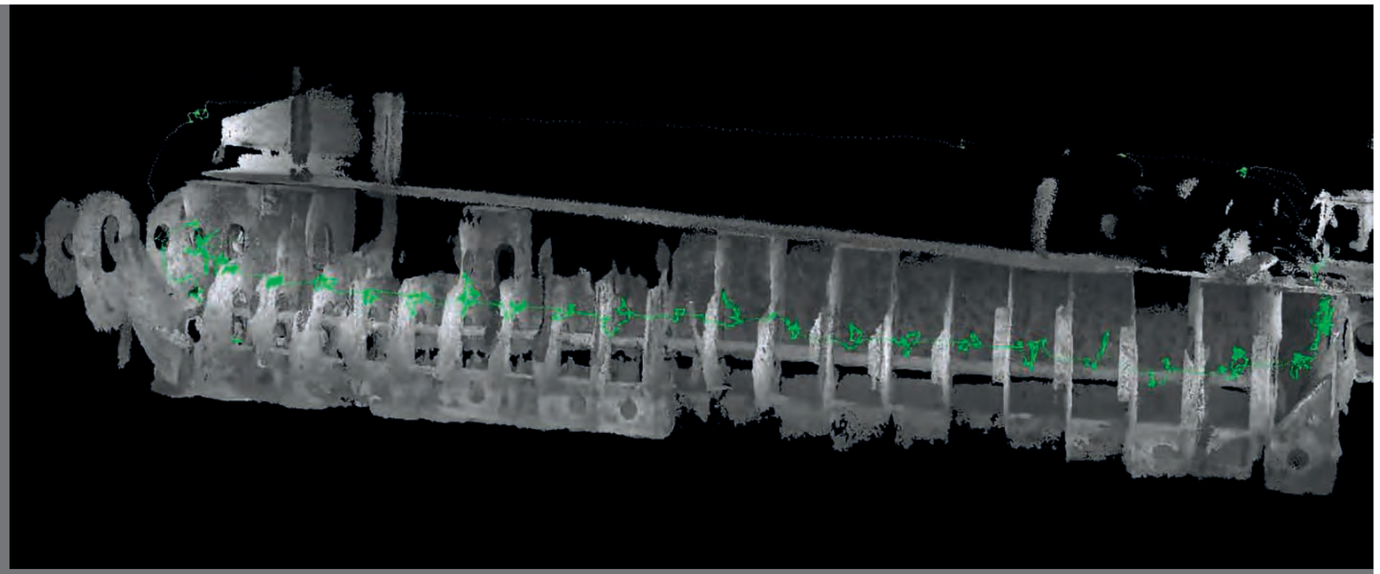
Anko Börner and his team at the Institute of Optical Sensor Systems have developed the Integrated Positioning System (IPS), which allows reliable orientation in space. In an interview with DLR Editor Julia Heil, he explains how his idea became a market-ready product, and why going up and down in a lift more often proved crucial to the project.

The Integrated Positioning System – IPS – enables position determination without satellite navigation systems.

Navigation is now an almost indispensable part of our everyday lives. Knowing our position in space is vital to understand how to get somewhere, generate measurement data or create accurate models of our surroundings. What are the problems with currently available systems, and what was your idea for addressing them?
: If we want to get from A to B, we enter our destination into a navigation system. This then determines where we are, before guiding us to our chosen location. This works well provided that systems like the Global Positioning System (GPS), which analyse satellite signals, are available. However, situations invariably arise in which we do not have a signal, such as indoors, underground, in industrial complexes, or indeed on the Moon or Mars. Yet we also need to be able to determine our position in such instances. Of course, we know that humans are capable of navigating without GPS. Our ancestors were always able to find their way back home. To do so, we use two sensors – our eyes and our sense of balance. So, we said to ourselves, if people can manage with these sensors, then technology should be able to mimic them. A commercially available stereo camera takes on the role of the eyes, while an inertial measurement system takes the place of the sense of balance. We can link these data and use them to determine our position.

The result is the Integrated Positioning System, known as IPS, which can orient itself in a similar way to humans.
: Yes, that is the basic principle behind IPS. The system includes a stereo camera system, comprising two parallel cameras spaced a defined distance apart. These record image data every 100 milliseconds. The images are transmitted to a computer in real time. There, an algorithm searches for landmarks – conspicuous points. These could take the form of a door handle indoors, or a tree outdoors, to give a couple of examples. The stereo camera system provides three-dimensional information relating to the landmarks it observes. If I continue moving with the system, tracking the object points and thus picking them up from different positions, I can estimate the distance travelled between image acquisitions. Over time, a movement path emerges, and IPS gradually explores the space.

As IPS can only determine relative movements, it cannot determine whether it is in Dresden or Berlin, so it is important to integrate the information into the real world. We use systems such as GPS, WLAN or visual landmarks for this purpose. This is not necessary for every application, but the system provides for such solutions. IPS is also suitable for 3D modelling of its surrounding environment.



Three-dimensional model of a ship's hull based on a point cloud generated by IPS

Depending on how you move around a space with the system and what is recorded, you can create a complete 3D model of the environment, or even examine specific areas in detail. In which sectors is this of particular interest?
: At present, our system is designed for inspection tasks. For instance, when insuring ships, it is important that particular areas, such as the ballast tanks, are inspected at regular intervals. For this, a person has to descend into each tank and document its condition for the inspection. Nowadays, this is done with a notebook and a camera. In the process, the person must maintain the sense of direction. Our system makes it much easier and more reliable. The inspector can take a picture of damaged areas using IPS, ensuring that the damage is documented, along with the exact position. This inspection application works remarkably well. In addition, other areas of application can really benefit from navigating with such technology. One example is automated driving. In this case, a highly accurate and absolutely reliable navigation system is a fundamental prerequisite. Any mobile robot or autonomous system needs to know where it is and what its surroundings look like. Just think of an autonomous vehicle in a multi-storey car park or in a street canyon! That is why we need technology like IPS, which is not dependent on satellite data. The system is also a perfect testing platform for artificial intelligence. We can create training data sets, let the system learn certain tasks, and understand how machine learning works.

The new DLR system also helps to orient the user in industrial plants in which satellite data cannot be received

The project began in 2004. How did it develop from the initial idea to the finished product?

: At the beginning of our research, it was a question of whether a system could reliably navigate independently of satellite navigation systems. Our first 'test device' was an aluminium extrusion, to which we attached two cameras and an inertial measurement system. We connected a laptop to this structure and investigated whether this kind of assembly would actually work. Back then, commercialisation had not even crossed our minds. The idea only came to fruition when we met up with Det Norske Veritas – Germanischer Lloyd (DNV-GL), a major ship insurer, at a DLR workshop. The DNV-GL representatives said that they needed just this kind of system for ship inspections, thus constituting a potential user. That was about five years ago. Up until then, we had financed the project from a variety of basic funding sources, with the help of DLR Technology Marketing, and third-party funding.

So, you found your user with the ship insurer?

: Exactly. This meant that we took a giant leap forward. They were able to specify exactly what they needed from this kind of system – how heavy the device could be, what it would need to withstand, and which data were required by the inspectors. Knowing this allowed us to design the device as it is today and address the quality assurance of this type of product. A commercial system has to be absolutely reliable. For instance, it has to work even if one of the cameras does not have a clear view or if people walk across its field of view. One of our favourite experiments was travelling in a lift with IPS. This forced it to recognise that it could not trust its eyes but had to rely on its sense of balance – meaning the inertial measurement data.

Financing the project nevertheless remained a challenge. We applied for funding designated for transferring technological developments from large research institutions to industry. We were very confident that such funding would be awarded, as we had a great idea, an excellent consortium and many applications. But our applications were turned down several times – sometimes because we could not prove the required market maturity, sometimes because we were too application-oriented. Members of staff who had worked in this area had to be transferred to other projects, and IPS appeared to be on the verge of failure. Fortunately, DLR Technology Marketing stepped in and took over financing of the decisive phase. We are very grateful that they did! The entire technology transfer process also gave us an insight into where we can make future improvements in order to be successful. In particular, we need to be much faster with administrative matters.

The navigation system was awarded the Berlin Brandenburg Innovation Prize in November 2018. In retrospect, what were the decisive factors for its success?

: At the beginning, we really did not know whether the basic idea was actually feasible. After all, we are talking about technology that did not yet exist, rather than the umpteenth replica of a product that has undergone minor evolutionary changes. Once we had established that it worked, we wanted to make the project a commercial success, too. An experienced team that can work on this specific topic over long periods – and we are talking about five to 10 years – was essential. It was also important to get members of staff with different areas of expertise involved. Our core team consisted of engineers, mathematicians and geographers, with ongoing support from the wider institute, in the form of the secretariat, technicians, scientists and the management team, as well as the overarching infrastructure. Together, this has paid off 100 percent. It was a constant learning process. Usually, our research affords us a lot of freedom. In a technology transfer process, there are strict rules that have to be adhered to around the clock, whether you like them or not. Alongside the development work, professional management and quality assurance are also crucial, despite being tasks that researchers are less inclined to take on. If just one of these areas is not given sufficient attention, the whole thing will fail. Our goal was to succeed, and success meant industry adopting our system. We have achieved this, and we are very proud to have done so.

"WE ARE TALKING ABOUT TECHNOLOGY THAT DID NOT YET EXIST."

Image: DMT

The Integrated Positioning System (IPS) developed by DLR consists of a stereo camera system (far left and right) and an integrated inertial measurement system. An additional camera (second opening from the right) acquires the inspection images. The LEDs at the centre are used for illumination.

Image: DMT

Use of IPS during the inspection of a mine

IPS is also used for research in the areas of autonomous driving and surveying of road infrastructure, as shown here with a research vehicle from the DLR Institute of Communications and Navigation.

OTHER POTENTIAL APPLICATIONS OF IPS

In addition to the inspection of ships, the system can be used in the mining sector, as the condition of the facilities has to be checked and recorded on a regular basis. Researchers have already used IPS in conjunction with the spin-off company VINS for forest inventory. At present, only random samples are used to determine the number of trees within a given area of forest. IPS can provide precise information on exactly how many trees there are, together with their height and diameter, within the area in question. The researchers have also developed a functional demonstrator that can be integrated into different vehicles. One of these systems was used on the road in New Zealand in 2018 to survey the traffic infrastructure at accident black spots.

Three-dimensional model of a bridge, also based on a point cloud generated by IPS.

BUILT TO LAST

There is one thing that has not changed at the DLR site in Cologne between the year of its establishment, 1959, and the present, 2019: construction. Back then, it was the start of something new, and today it represents DLR's on-going growth. Here, at the headquarters of the Executive Board and the Head Office, the different fields of research – aeronautics, space, energy, transport, security and digitalisation – converge.

The DLR site in Cologne turns 60

By Julia Heil and Michel Winand

The DLR site in Cologne … then … and now

Aerial photos from 1965 and 2017

INSTITUTES AND FACILITIES AT THE DLR SITE IN COLOGNE

Institute of Propulsion Technology

Institute of Air Transport and Airport Research

Institute of Aerospace Medicine

Institute of Materials Physics in Space

Institute of Solar Research

Institute of Materials Research

Institute of Engineering Thermodynamics

Microgravity User Support Centre (MUSC)

Quality and Product Assurance

Simulation and Software Technology

Systemhaus Technik

Technology Marketing

Supersonic and Hypersonic Technology

DLR_School_Lab

PARTNER FACILITIES AT THE SITE

European Astronaut Centre (EAC)

European Transonic Windtunnel (ETW)

Cryogenic Wind Tunnel Cologne (DNW)

In 1959, Franz Josef Strauß, German Minister of Defence, laid the foundation stone for one of Europe's most modern research and development facilities on the site of the former Wahn dynamite factory. In 1953, the ban that had been imposed on aviation research after World War II was lifted. Interest in science, economics and politics grew to establish a modern research institution for aviation in post-war Germany. The interim site of the German Institute of Aviation (DVL), the forerunner of DLR, in Aachen was soon bursting at the seams. A temporary location at Essen-Mühlheim Airport proved unsuitable in the long term. A new solution was necessary: a site with a connection to an airport for research flight operations and enough space to accommodate new institutes and facilities. What was then a 35-hectare plot of land on the edge of the Wahner Heide, close to Cologne Airport, met all of the requirements.

The finest research on 55 hectares

In the years that followed, the DLR site in Cologne became well and truly established not only as a renowned location for German aeronautics research – with the institutes of Air Jet Propulsion, Applied Gas Dynamics, Space Research, Materials Research and Resistance – but also for space research, which was picking up speed. In Cologne, for example, German astronauts prepared for the Spacelab-1, D1, D2, MIR'92 and MIR'97 missions. Today, the researchers at what is now a 55-hectare site work on exploration missions such as Rosetta, MASCOT and InSight, as well as scientific experiments on the International Space Station (ISS). Materials physicists conduct research into the effects of microgravity on materials or test how buildings might be constructed on the Moon using lunar dust. The ESA European Astronaut Centre is involved in the selection and training of astronauts. When German ESA astronaut Alexander Gerst returned to Earth from his first space flight in 2014, he flew directly to the DLR site in Cologne, instead of heading off to Houston or Moscow for follow-up examinations, like his predecessors. In Cologne, he was looked after at the :envihab aerospace medicine research facility. Today, most European astronauts come straight to the DLR site in Cologne upon their return to Earth.

The aeronautics researchers in Cologne are also carrying on the tradition. One example is the HBK-5 high-pressure combustion chamber test facility of the Institute of Propulsion Technology. It was built in conjunction with industry partners Alstom and Rolls Royce and opened in 2014. Gas turbines for applications in energy technology and aviation have been tested there ever since.

> We are well prepared for the future! Whether it involves the transformation of the energy system, turbine research, new materials or flights to the Moon or Mars – the DLR site in Cologne will be able to contribute.
>
> Rolf-Dieter Fischer, Site Manager

The site gained prominence at a European and international level due to its work with German-Dutch Wind Tunnels (DNW) and the European Transonic Wind Tunnel (ETW). Many institutes work closely with industry to ensure that scientific innovation is quickly transformed into marketable products. Even at the site, the short distances and synergies are conducive to working together: for instance, new turbine blade concepts are being developed at the Institute of Propulsion Technology and built as prototypes for test operation at Systemhaus Technik in Cologne.

Investing in the future

Together, the research institutes and facilities on the site work across all of the disciplines covered at DLR. Application-oriented institutes such as the institutes of Engineering Thermodynamics, Materials Research and Solar Research continue to evolve and therefore use the necessary research facilities together with their internal and external partners. As such, the Cologne location is likely to remain a building site for some time to come. Since 2013, the aforementioned institutes have been working together on technology for sustainable energy supply at the CeraStore centre of competence. One of DLR's most recently established large-scale facilities is the Test Facility for Thermal Energy Storage in Molten Salt (TESIS), which went into operation in 2017, and is being used to further develop energy storage technologies on an industrial scale. A research building for the German Air Force Centre for Aerospace Medicine and a new building for the Executive Board are also being built.

These will see the Cologne site continue to grow as DLR's headquarters. And visitors to DLR are likely to walk past one building site or another for some years to come.

1959 Founding of the Cologne site by the German Research Institute for Aviation – (Deutsche Versuchsanstalt für Luftfahrt; DVL)

1962 onwards The institutes of Air Jet Propulsion, Applied Gas Dynamics, Space Research, Materials Research and Resistance move in

1981 Relocation of the Institute of Aerospace Medicine to the DLR site in Cologne

1990 Founding of the ESA European Astronaut Centre (EAC)

1992 The Microgravity User Support Centre (MUSC) starts operations

1994 The solar furnace is completed

2003 Founding of the DLR_School_Labs Cologne

2011 Founding of the Institute of Solar Research

2013 Opening of CeraStore, a centre of excellence for energy storage

2014 Opening of the HBK-5 high-pressure combustion chamber test facility

2017 The TESIS thermal energy storage test facility goes into operation

1950 1960 1970 1980 1990 2000 2010 2020

BUSES ON DEMAND

Imagine a bus that arrives exactly when you need it and drops off its passengers right where they want to go – quickly, flexibly and reliably. It is the stuff of dreams for public transport users. Transport researchers from three DLR institutes have conducted tests with a digitally supported 'on-demand bus' to find out how it might work. Here are the findings of a real-world laboratory experiment.

Schorndorf Real-World Laboratory – DLR transport researchers develop and test an innovative digital concept for on-demand bus services.

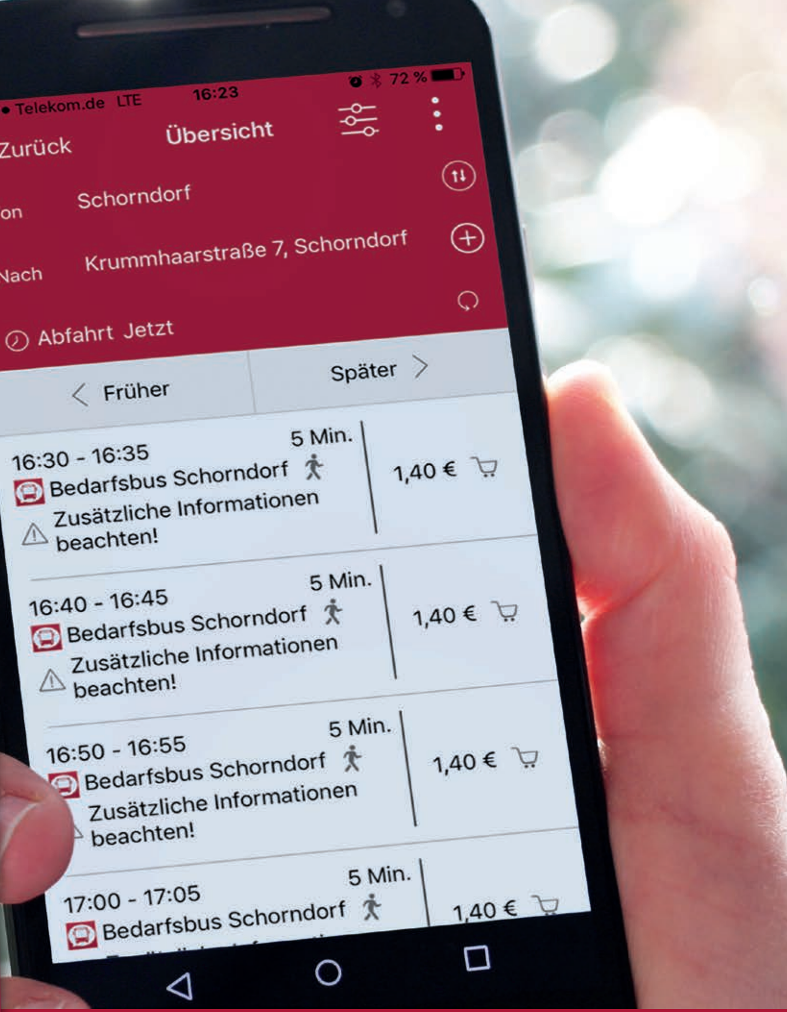
By Denise Nüssle

Curiosity, excitement, joy, albeit disappointment and annoyance from time to time. Locals experienced the whole range of emotions on seeing the two little buses from the Schorndorf Real-World Laboratory turning the corners of the sometimes narrow streets of Schorndorf's Südstadt district. The mission was to pick up passengers on time and at the right place and take them to their respective destination, in accordance with their individual travel specifications. In other words, this was a bus service without fixed routes or bus stops. For about three years, this mid-sized town east of Stuttgart – with a population of around 40,000 – was the scene of a research project that is unique in Europe. Based in the hometown of Gottlieb Daimler (whose name was also given to one of the buses), transport researchers from DLR worked together with their project partners and local citizens to develop and test a forward-looking mobility solution. The bus ran on demand, rather than according to a timetable – not as a new or additional service as is the case with other projects – but as a substitute for two existing bus routes. The aim was to design a more flexible and sustainable public transport network, aligning it more closely with users' needs. At the same time, it sought to minimise empty runs, thus reducing the amount of traffic and using resources in a more targeted way.

Public transport on demand – flexible even during off-peak times

"Many innovative mobility initiatives concentrate on specific target groups or inner-city areas of large cities. By contrast, Schorndorf's structure makes it representative of many towns in Germany, which have seldom been considered for this development due to their size and location. Yet many people feel that local transport is insufficient and lacks flexibility in precisely such areas," says Mascha Brost, a DLR scientist and project manager at the Real-World Laboratory, describing the starting point for the project. One example of this is the dilemma over whether to run local public transport at times of low demand, such as late in the evening or on weekends. If buses operate a tight network, with frequent services, they often carry few passengers or are completely empty. Although running buses less frequently and on fewer routes keeps the costs and environmental impact down, passengers see this as inflexible, making it less appealing. On-demand bus systems are a possible solution. "With the Schorndorf Real-World Laboratory, we wanted to find out how providing buses on demand might work for all sections of the population, and what opportunities and challenges are involved in the introduction of such a system," Brost says. There were three key focus areas: the operating concept for the on-demand bus, the participation of local people, and the development of innovative vehicle concepts for future on-demand bus systems.

The launch in February 2016 marked the start of an exciting, busy time that was both personally and professionally demanding for the project team. In addition to their scientific analysis, they had to set up a functioning system of on-demand buses that would prove its worth over the pilot period of nine months while ensuring the provision of a proper public service. It was therefore important to take a close look at the status quo on the ground as early as possible, organise vehicles and consider the framework conditions and regulatory requirements for local public transport. This specifically meant finding out where the minibuses from the Real-World Laboratory were generally able and allowed to drive and stop, for example. On their forays around the applicable area in Schorndorf's Südstadt district, the team recorded traffic signs, pedestrian paths, kerbs and inclines in order to identify more than 200 potential places for getting on and off the bus, in addition to the existing bus stops. These virtual stopping points and flexible routes allowed for new, bespoke direct connections and shorter walking distances to the stops.



App for ordering the flexible on-demand bus at the Schorndorf Real-World Laboratory

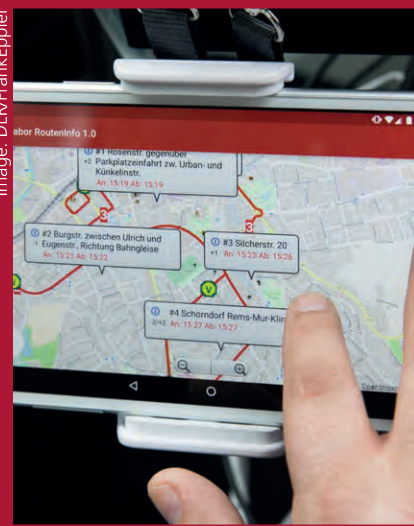
Image: Schorndorf Real-World Laboratory

A wealth of information, aimed at getting as many local people as possible involved

The two minibuses of the Schorndorf Real-World Laboratory

Image: Stadt Schorndorf

Image: DLR/FrankEppler



Bus drivers' Schorndorf Real-World Laboratory user interface

Image: Reallabor Schorndorf

Katharina Karnahl (left) of the DLR Institute of Transportation Systems, Braunschweig, has a background in transportation and management and has been at DLR since 2002. She has concentrated on business development for research topics with a focus on local public transport and intermodality.

Mascha Brost (centre) of the DLR Institute of Vehicle Concepts, Stuttgart, has a background in mechanical engineering and integral design. She joined DLR in 2015. Her focus is on conducting studies and technology assessment for sustainable vehicle concepts.

Laura Gebhardt (right) of the DLR Institute of Transport Research, Berlin, has a background in geography, sociology and urban research. She joined DLR in 2014. Her research priorities are people's mobility within urban contexts and forward-looking mobility concepts.

Participation as a success factor – Schorndorf citizens provide local expertise

From the very beginning, the Real-World Laboratory team ran an extensive communication and participation campaign – a vital part of the project – in order to inform Schorndorf citizens and community bodies, and to actively involve them. This included public information events, surveys, interviews and the test users, not to mention mobility workshops and several sessions with representatives of different user groups. In the process, discussions were held regarding what the local people needed and wanted from the on-demand bus. "For us, the local citizens acted as experts in their day-to-day lives," says Laura Gebhardt, the DLR team member responsible for participation. "The local people were participants and co-developers. Their knowledge, desires and requirements all went into the design of the on-demand bus. Our goal was not only to create a functioning, user-friendly system, but also to promote its acceptance and transparency at the same time." This was all the more important because the (new) on-demand bus system also asked something new of its users: in order to take the bus, they needed to find out about it themselves and play an active role, specifically by ordering the bus.

The operating concept – the digital heart of the on-demand bus system

The Real-World Laboratory group set about developing the digital ordering system on the basis of these insights. As a central component, it connected all those involved with the on-demand bus system. Users could transmit their travel request via the smartphone app, online, by telephone or in participating shops, restaurants and cafés, specifying where and when they wanted to be picked up, and where they wanted to go. A special, continuously optimised algorithm then calculated a route based on all of the requests and informed the users of the actual pickup and drop-off times and places. The drivers of the two minibuses received a current route via a user interface specially programmed for this application. "The expertise of all project partners has gone into the development of this operating concept. As we did not have a long test phase before going live, we were faced with the challenge of making ongoing improvements to the system while it was actually running, meaning fixing bugs quickly and incorporating feedback from users to ensure and improve the system's performance," Brost says.

The acid test – premiere of the on-demand bus

After two years of preparation and development, live operation of the on-demand buses began in March 2018. The two minibuses from the Schorndorf Real-World Laboratory were specially fitted out for local public transport and used from Friday afternoon until the end of operations on Sunday night. The normal timetable applied outside these times. Numerous challenges cropped up over the first weekends of live operation, in particular, and emotions were running high. Some members of the project team travelled on the buses around the clock, explaining the concept and helping with any issues. "Expectations were extremely high, and especially in the initial phase, when the booking system did not always run smoothly, we were on the receiving end of both constructive criticism and a lot of anger, which we first needed to come to terms with." The bus drivers were very supportive of the project team, Gebhardt recalls: "We were utterly thrilled. The bus drivers thought on their feet, came up with solutions on the spot, patiently explained the concept over and over again to the users, and quickly adapted to a very different way of operating."

The live operation phase for the on-demand bus came to an end in early December, after 39 weeks, and the team was able to look back on a very exciting and eventful time. From a scientific perspective, they had collected a wealth of data and experience, the evaluation of which would provide new insights into designing and implementing forward-looking mobility concepts for local public transport. The two minibuses carried more than 10,000 passengers and covered more than 20,000 kilometres over that time. An average of 250 people used the service every weekend. Two-thirds ordered the bus via the app, while the remaining third used the telephone ordering service. The other ordering options – the website and participating outlets – were rarely used.

"The practical operation of this solution clearly demonstrated the opportunities and challenges presented by this kind of mobility system," Brost concludes. Compared with the set-route system, around 10 percent of the vehicle kilometres and some 20 percent of potential round-trips were saved due to a lack of bookings. As the team used smaller buses, the fuel consumption was more than halved, and the avoidance of empty runs went down very well with many citizens. A positive trend also emerged from the user surveys: while around 35 percent of people were either satisfied or very satisfied with the Real-World Laboratory bus concept in May, this figure had risen to 50 percent by the end of October. The scientists attribute this mainly to the continual improvement of the system and to the effect of familiarisation. There was also a clear generational split: younger users tended to take to the system more easily, and expressed greater satisfaction than older users.

In retrospect, the DLR researchers agree that the project team achieved the best possible solution thanks to the huge dedication of all participants. "But informing and involving all of the potential users with the limited resources of a research project was harder than we thought, particularly with regard to the topic of barrier-free access," says Katharina Karnahl, who researches operating concepts for local public transport at DLR and oversaw the implementation of the operating concept at the Schorndorf Real-World Laboratory.

It also became clear that it will take changes to the local public-transport system a lot of time to be accepted: "We underestimated how much people rely on their routines," Karnahl adds. At the same time, the project team was often delighted at the level of engagement from local people as well as their constructive and sometimes very detailed suggestions on how to improve the project by working together. "Over time, a genuine Real-World Laboratory community emerged, made up of local citizens, bus drivers and the project team," Gebhardt says in summary.

Already during the project, the Schorndorf Real-World Laboratory team received numerous requests to present their work in talks and publications for local communities, associations, companies and academia. Although the project has officially come to an end, the researchers' work continues: the collected data needs to be finally evaluated and publications need to be written. But the thirst for knowledge is still there: "We all want to continue conducting our research in this area and finding out about innovative mobility concepts. For instance, it would be exciting to develop other scenarios for the use of on-demand bus services," say the scientists, looking ahead to the future and other possible joint projects.

Research in everyday conditions means constantly checking the actual experience

SCHORNDORF REAL-WORLD LABORATORY

Definition: A real-world laboratory is a research format whereby scientists cooperate with partners from the real world (companies, municipalities) and civil society (local people). Together, they initiate changes and support, observe and analyse the transformation process. The focus is on mutual learning in an experimental environment.

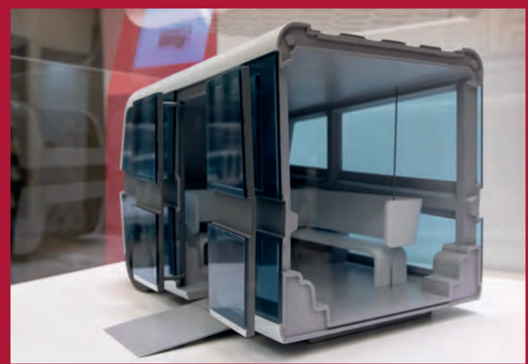
Funding: The Schorndorf Real-World Laboratory was one of seven research projects funded by Baden-Württemberg's Ministry of Science, Research and the Arts to test future-oriented solutions to challenges in metropolitan areas.

The partners: The partners of the DLR transport researchers included Schorndorf Town Council, the Transit and Tariff Association Stuttgart (VVS), Knauss public buses, Esslingen University of Applied Sciences and the Center for Interdisciplinary Risk and Innovation Studies (ZIRIUS) at the University of Stuttgart.

INNOVATIVE VEHICLE CONCEPTS FOR FUTURE ON-DEMAND BUS SERVICES

The Schorndorf Real-World Lab also focused on the development of innovative vehicle concepts. The team devised virtual design concepts and created some of them as 1:10 scale models for that purpose. The concepts were designed in the most optimal way possible for the requirements of an on-demand bus system. The size, number of seats, barrier-free accessibility and interior design of the buses were given equal consideration, as were matters relating to drive technology, energy consumption and emissions.

Images (2): DLR/FrankEppler



Accessibility was an important aspect in the development of the vehicle concept

Images (3): DLR

Design models of forward-looking vehicle concepts for on-demand bus systems

Visible from afar in the morning fog: Weilheim's 30-metre antenna.

A 'NERVOUS SYSTEM' FOR SATELLITE COMMUNICATIONS

Ensuring reliable communications with satellites or the International Space Station requires a global network of ground stations and data links. The challenge is to make sure that this communications system keeps working even if it fails. This article is part of the 'Glorious Giants' series, which gives an insight into DLR's large-scale facilities.

A network of ground stations ensures the exchange of information with Earth-orbiting satellites and more distant spacecraft

By Florian Kammermeier

Large amounts of data must be transferred between Earth and space. More than 1700 satellites are operated by Earth's many countries. Commands have to be sent to space and data has to be received from spacecraft 24/7. However, reliably communications with satellites from the ground can prove to be a challenge. More than 1000 of the satellites circling Earth do so at high speeds and low orbits between 200 and 2000 kilometres. These are primarily research satellites, observing our planet's surface, its atmosphere and clouds. In the same way as the International Space Station (ISS), many of them circle the Earth in only 90 minutes, completing 16 orbits each day. They move across the sky so quickly that they appear only briefly over ground stations before descending below the horizon after five to 15 minutes of contact time.

Many of these satellites are in what are referred to as polar orbits; this means that every one of their orbits passes over both of Earth's poles. The plane of each orbit is rotated slightly with respect to the previous one, so that the satellite can eventually pass over every part of Earth's surface. These satellites often need to receive commands, if they have experiments on board, for instance, or are required to observe a forest fire. They also return large amounts of data – satellites such as Sentinel-5P, which measures the composition of the atmosphere – transmit several terabytes of data to Earth every day. The Launch and Early Orbit Phase (LEOP) of a mission requires a great deal of contact time with the spacecraft as they make their way to their final orbit, and during their commissioning phase.

No time to stand alone

All this creates a need for as many contact opportunities as possible, each maintained for the maximum time. A single receiving station is seldom sufficient. Satellites in polar orbit come within the range of the DLR ground station in Weilheim, south of Munich, about four times a day, for 10 minutes each time. Antennas located closer to Earth's poles are able to establish more frequent and longer contacts. In the Arctic, contact can be made during up to 12 of the 16 daily orbits. However, even in the best-case scenario, a single polar antenna is out of contact with any given satellite for over an hour between overflights.

In order to transmit large amounts of data, to enable contact or to send commands at any time – particularly in the event of an emergency – global networks of receiving stations and data links have been created to act as the 'nervous system' for satellite operations. DLR has one such network, which is operated, managed and even designed by the German Space Operations Center (GSOC) and the German Remote Sensing Data Center (DFD), both of which are part of DLR. However, DLR owns only some components of the network – two large ground stations in Germany, a smaller facility in northern Canada and another in Antarctica, together with a few kilometres of fibre-optic cable. Most of this 'nervous system' belongs to other organisations. Some ground stations are owned by other space organisations or private companies, while the data links are generally provided by network operators such as Deutsche Telekom. This international collection of systems requires the establishment and maintenance of cooperative relationships. For example, data from the Japanese Hayabusa2 spacecraft, which travelled more than 300 million kilometres to visit the small asteroid Ryugu, were received by DLR in Weilheim. For its part, DLR sometimes contacts its spacecraft using NASA antennas or private ground stations, such as the one on the island of Spitsbergen, off the coast of northern Norway. The site from which contact is made also depends on the type of mission. Where is the target object, and what is its orbit? How sensitive does the receiver need to be in order to receive the signal?

Amplifying, translating and relaying

The ground stations are responsible for everything that happens between the reception of the data transmissions from the spacecraft and their delivery to the outbound data link. Their personnel service the antennas, activate the correct transceivers for each operation, point the dishes at the satellites and ensure that they are tracked. When the transmissions reach the ground, the signals are amplified, undergo frequency conversion and are then demodulated and decoded. This translates them into a language that computers and data transmission systems can understand. Analogue signals with noise, errors and encoded data come in, and clean digital data goes out. This procedure used to be prone to failures, says Martin Häusler, Head of the Weilheim Ground Station. "But we are now very reliable and experienced at receiving satellite data," he says. "These days, a lot of it is standardised. If you adhere to the standards, everything works."

These processes are implemented at all the stations that receive data on behalf of DLR around the world. The data – whether from Weilheim, 30 kilometres away, or from Inuvik in northern Canada, at a distance of 6700 kilometres – are relayed to DFD and GSOC at DLR's site in Oberpfaffenhofen, which might be seen as the centre of the 'nervous system'.

In some cases, the data have a long way to travel – the journey from Inuvik to Oberpfaffenhofen, in particular. Indeed, the data stream from a satellite often covers more kilometres on the ground than it does on its journey to Earth. The Communications and Ground Stations Department is specifically tasked with looking after these systems. The data links are required for many things – they have to ensure a stable flow of signals, so bandwidth must always be available for a satellite transmission. Damage must also be repaired as quickly as possible, and the link must be protected against electronic 'eavesdropping'. "The conventional Internet is too unreliable for our purposes, and the maintenance of Internet data links in the event of damage would take too long. We cannot wait several weeks for a link to be repaired," says Osvaldo Peinado from the Communications and Ground Stations Department. "For this reason, DLR uses 'private' links whenever possible, such as the connection implemented by Deutsche Telekom between Munich and Stockholm," he explains. For several thousand euro a month, commercial and institutional users are able to reserve bandwidth in this way and send data directly.

Reserving connection capacity and negotiating with network providers

Similar data links extend to many regions of the world and also connect Europe and America. It is rare, however, for a link to run from the region around Oberpfaffenhofen directly to its destination. In practice, this means booking different links from a receiving station over the shortest possible route, and negotiating with various network providers to make this happen. "If a receiving station is only needed for a special mission, a connection might only be rented for a few weeks," Peinado says. A number of commercial organisations have also entered this market and are now offering satellite contacts as an overall package. They have ground stations around the world and fixed connections with their facilities. As a satellite operator, DLR only needs to reserve one cable to these hubs, such as those provided by Kongsberg Satellite Services (KSAT) in Tromsø, Norway, or the Swedish Space Corporation (SSC) in Stockholm.

Peinado recounts a story that demonstrates how difficult things can become, even when using private data links. When the fibre-optic connection between Europe and Houston had recently been established, the performance of DLR transmissions was repeatedly degraded. This phenomenon was observed over a period of weeks, with the performance degradations primarily occurring at approximately 10:00 on the East Coast of the United States. At first, no one understood why this was happening. "The technology was working perfectly," Peinado explains. "But then one of our colleagues identified the cause – Wall Street opens at 09:30 New York time. Stock trading was overloading the connection."

Data transmission from satellites can be jeopardised by more than stock trading – this can occur when connections simply fail altogether. In one instance, a fishing vessel damaged a transatlantic cable off the coast of Florida. As a result, the direct connection between Oberpfaffenhofen and Houston was interrupted for one week. However, this did not present a problem. "We switched to an alternative connection to Houston, via New York, until the primary link was repaired," Peinado recalls. The redundancy principle applies to all the connections. Even if they are just a few kilometres long, there are always two separate routes to the same destination.

At DLR, this means that all links lead to Oberpfaffenhofen.

TWO IS BETTER THAN ONE

It was the worst possible moment to lose contact – in 2008, the European Columbus module was being docked with the ISS, supervised from the control centre at DLR in Oberpfaffenhofen. The DLR site was crowded with journalists and politicians, who had all come to witness this historic moment. Five minutes before the docking manoeuvre, the warning lights for the control centre data connection started blinking. The main connection had failed. An excavator had damaged the connection during construction work near the site. However, the docking team and the journalists only learned about this once the mission had been successfully completed. The back-up connection took over automatically. For the remainder of the docking manoeuvre, the data left the building through the replacement link, rather than through the now disconnected primary link. It is always a good idea to have two of everything.

The international Inuvik Satellite Station Facility (ISSF) in Canada

NEUSTRELITZ

Neustrelitz has been an active ground station since 1913, when the Imperial Telegraph Test Office used its antennas to send signals over distances of up to 100 kilometres. Today, Neustrelitz is an established node in the global network of ground stations and focuses on receiving payload data for remote sensing missions, small scientific satellite missions, as well as real-time data processing.

WEILHEIM

DLR's largest ground station is located 50 kilometres southwest of Munich. It is renowned for its striking 30-metre dish antenna. Signals from the depths of space are received here, as was the case in the autumn of 2018, when signals were received from the Japanese Hayabusa2 spacecraft, which was approaching an asteroid 300 million kilometres from Earth. The German Armed Forces also receive signals from their geostationary satellites via the DLR site in Weilheim.

INUVIK

With temperatures as high as 30 degrees Celsius in summer and as low as minus 40 degrees Celsius in winter, this ground station in northern Canada demands a lot of its team. Its position is particularly useful within DLR's receiving system – it is so close to the North Pole that polar-orbiting satellites can make up to 12 contacts with it every day. The inauguration of the station marked an increase in collaboration between the German and Canadian space organisations, and received the blessing of the local Inuit people, whose elders consecrated the station.

GARS O'HIGGINS

If there is one place even more inhospitable than Inuvik, it is the GARS O'Higgins ground station. Winds of up to 300 kilometres per hour sweep across the Antarctic Peninsula. The station can only be supplied by ship or by aircraft, and in winter the four-member team can only be reached by air. However, the station's location makes it ideal for satellite communications, which are conducted from there all year round. Ironically, the satellite data are relayed back to the other continents via satellite, or as a magnetic tape sent by ship or aircraft.

Background image – the nine-metre antenna at GARS O'Higgins.

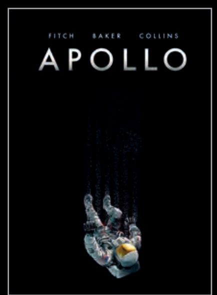
TRIBUTE TO APOLLO

2019 marks the 50th anniversary of humankind's Moon landing, so it does not come as a surprise that the Apollo programme has become of public interest. As varied as the honours are, they all have one thing in common: respect for technological and human achievement at a time when modern navigation and communications technology was in its infancy. This section features some selected information on this topic.

In addition to the Apollo programme, the Moon itself continues to arouse great interest – from both the scientific community (DLR Magazine 160, April 2019) and from photographers. One of these photographers is DLR researcher Rolf Hempel, who acquired the impressive photograph of the waxing Moon featured here. It shows the Apollo 11 landing site (marked with a cross). To see the image up close visit dlr.de/vollmondbild.

THE MOON MISSION AT MUSEUMS

The Technik-Museum **Speyer** is home to what it claims is Europe's largest space exhibition, 'Apollo and Beyond'. In the anniversary year of the Moon landing, exhibitions on this theme can also be seen elsewhere: 'Fly me to the Moon. The Lunar Landing: 50 years later from 20 July until 3 November 2019 at the **Museum der Moderne in Salzburg** ● 'Spaceship living room: the Moon landing as a media event' until 22 September 2019 at the **Museum for Communication Nuremberg** ● 'Apollo – 50 years since the Moon landing' until 10 March 2020 at the **Ries Crater Museum** ● 'Hello Universe! The experience of space travel' until 5 January 2020 at the **Heinz Nixdorf MuseumsForum in Paderborn** ● The special exhibition 'Race to the Moon: much ado over a small step?' until 8 September 2019 at the **Peenemünde Historical Technical Museum**.



THE MOON MISSION IN BOOKS

What would the history of the Moon landing be without the impressive photographs taken by those involved? How would we imagine the Universe were it not for the fascinating images acquired by the Hubble Space Telescope? NASA has opened its archive 50 years after the Moon landing. The result is a stunning picture book covering 60 years of the history of space travel – from the very beginnings of rocket development to the latest missions to Mars. The synopsis of **The NASA Archives (Taschen)** sums it up as "a profound meditation on why we choose to explore space and how we will carry on this grandest of all adventures in the years to come." 'Meditation' hardly seems sufficient given the sheer fascination of this captivating book, featuring over 400 historical photographs, some of them spread across two pages, along with technical sketches and illustrations. This is a book of superlatives, and not just in terms of its size!

This isn't the place to find the iconic images of Moon walkers or the barren surface of Earth's satellite. Instead, **Apollo: the extraordinary visual history of the iconic space programme** explains the Moon landings with detailed diagrams and visuals. This debut work by graphic designer Zack Scott is remarkable for its lovingly detailed drawings, and manages to make Apollo, a colossal feat of technology, entertaining even for readers who are not already well versed in the field of space travel.

Apollo to the Moon uses 50 key artefacts from the Smithsonian archives to tell the story of the Apollo programme. The bold photographs, fascinating graphics and engaging stories in the book by **National Geographic** celebrate one of humankind's greatest endeavours. Each historical feat is symbolised by a different object, such as a Russian stamp honouring Yuri Gagarin. A real treat for space fans.

A different take on the historical journey to the Moon: **Apollo 11 (SelfMadeHero)** tells the story of the eponymous mission in the form of a graphic novel, with the focus on Neil Armstrong, Buzz Aldrin and Michael Collins. The fantastic drawings by Mike Collins (no relation to the astronaut himself) bring a unique sense of drama to the adventure and show the more sombre moments alongside the huge successes, in keeping with the tradition of graphic novels, which tend to take a dark tone.

FROM THE APOLLO ARCHIVE

● The record for speed on the Moon is held by Apollo 17 commander Eugene A. Cernan, who drove through the Taurus Littrov valley at a staggering 18 kilometres per hour. Due to the low gravity, the rover's wheels lost their grip several times.

● Cernan also boasts a record – in distance. He travelled a total of 35.74 kilometres with the lunar rover. The Soviet Lunokhod 2, part of the Luna 21 mission, travelled a total of 39 kilometres in the surroundings of Apollo 17 in 1973.

● 400,171 kilometres: Humans were never further away from Earth than on 14 April 1970 – and this occured during the aborted Apollo 13 mission, which had to be steered around the Moon in order to use its gravity for a 'free return path': Oxygen, electricity and water were running out. Luckily, James A. Lovell, Jack Swigert and Fred Haise survived.

OUR MOON AS AN OPPORTUNITY

An astronaut's perspective

Image: ESA/Philippe Sebirot

The Moon has fascinated humankind since time immemorial. As a constantly recurring guardian in the night sky, many see it as a sign of constancy. For space explorers, it is like a history book, providing us with an insight into the origins of the Solar System. What's more, it is the ideal platform for testing new technologies that allow people to make use of its resources.

Germany and Europe as a whole have a great and unique opportunity to shape the next decade of space exploration and make a vision come true: With modern technologies such as virtual reality, people will be enthusiastically exploring Earth's satellite together with astronauts in the future.

We should set a course for the Moon in 2019 and seize the opportunities that it offers.

Matthias Maurer

THE FIRST HUMAN ON THE MOON

Exhibition – 50th anniversary of the Moon landing

The face of a man who had just made history – Neil Armstrong. Joy, triumph, relief, but also concentration. In this moment, the Apollo 11 astronauts were not yet back on Earth. Armstrong and Aldrin were still in the Lunar Module, 400,000 kilometres from home. As is the case with mountaineering, the toughest part lay ahead of them – the descent, the return to Earth. However, they had accomplished the decisive feat – they were the first humans to walk on the Moon.

This image reflects the highly challenging mission – the difficulty, the danger and finally the sensational success. One does not see a moonwalker in a white protective suit, but rather the face belonging to one of the 400,000 people who helped Apollo achieve success. The programme was without doubt the most impressive technological project of its time. The fact that the first landing was controlled manually does not detract from this; the decision to ignore an error message from the on-board computer rather emphasises the experimental nature of the undertaking. Above all, the mission revealed the professionalism of its participants as well as the important role that people play in exploring the unknown.

This photograph, taken by Buzz Aldrin immediately after the completion of the walk on the lunar surface – along with 19 other colour images – is part of the exhibition about the Apollo programme that the DLR Institute of Planetary Research created this year. It shows images from Apollo 8 through to Apollo 17, missions that explored and redefined the limits of what was humanly possible at the time. Visitors can see famous images such as Earthrise over the lunar horizon, but also lesser-known photographs such as the 'mailbox', an improvised device with which the Apollo 13 astronauts saved themselves from carbon dioxide poisoning after an explosion caused oxygen to leak from their Command Module. The Apollo 8 to 10 missions, which were preparations for the Moon landing, also have their place in this historical journey. Short texts below the photographs chronicle hair-raising moments, extraordinary scientific achievements and the personalities who shaped the programme. In December 1972, the project of the century came to an end with the completion of the Apollo 17 mission.

Neil Armstrong died on 25 August 2012. But this image continues to tell his descendants about his bravery and his emotional state following a pioneering accomplishment. It is as if the photograph wants to tell the viewer something – there is more beyond the horizon.

Image: NASA/DLR

Panel from the exhibition '50th anniversary of the Moon landing'. Neil Amstrongs words "That's one small step for [a] man, one giant leap for mankind" went down in history.

EVENTS 2019

21 July
Open day at the DLR site in Oberpfaffenhofen

10 August
Long Night of Astronomy in Berlin

6 September
Night of science at DLR Neustrelitz

29 September
Open day at the DLR site in Lampoldshausen

The exhibition can also be loaned to interested institutions and schools, free of charge. Only the transport costs have to be paid.

Contact: planetenforschung@dlr.de

TECHNOLOGICAL TREASURE TROVE

Image: Deutsches Museum/Lichtenscheidt

The special exhibition 'A history of Playmobil technology – the Oliver Schaffer Collection' will run until 25 August 2019. A total of 5000 figures show how this classical toy developed. The themes range from archaeology to polar research and expeditions to Mars.

The Fischer plastic dowel, the ion trap and the Transrapid 06 have something in common: The three inventions are part of the permanent exhibition at the Deutsches Museum in Bonn. Around 100 exhibits here tell the story of contemporary research and technology since the end of World War II and show great examples of German developments over the past 70 years. The 'little sister' of the Deutsches Museum in Munich definitely has a charm of its own.

A tour of the Deutsches Museum in Bonn

By Doris Pfaff

At the southernmost end of Bonn's Museum Mile, the Deutsches Museum boasts an exquisite selection of exhibits. For those who do not intend to cover everything and do not have too much time, the city's Wissenschaftszentrum, where the exhibition is showcased, is just the thing. Physics, chemistry, biology, medical technology, aerospace and environmental science: developments in these fields since 1945 are outlined in a condensed overview at this museum, which opened in 1995. Five areas with exhibits covering the whole spectrum of the aforementioned disciplines stretch across a 1400-square-metre space, featuring everything from elementary particle physics and brain research to developments in space flight. The museum also casts a spotlight on German research findings.

The Transrapid on display on approach to the lower museum entrance presents the technology collection visible from afar: The motor unit of the magnetic levitation train takes the visitor back in time to the demonstration journey taken along the

31.5-kilometre test track in Emsland, Germany in the 1980s. One could say that the groundbreaking maglev technology was the forerunner of modern high-speed trains. Even though maglev trains were not successful in Germany, they proved to be a hit in China.

Walking around the museum is like stepping into a time-lapse video and travelling through seven decades of milestones – from the 1950s to the present day. Touching and trying things out is allowed and strongly encouraged at selected stations. Numerous interactive exhibitions make the museum a particularly exciting experience for children, as do the experiment tables on phenomena relating to optics, magnetism and acoustics. Anyone who fancies a go on the theremin can try it out here: this harp-like, electrically operated musical instrument can be played simply by making movements in the air. It was used to play music for the soundtrack of Alfred Hitchcock's thriller 'Spellbound'.

TV as a new mass medium

Between the two floors, visitors will learn all about the German economic revival. The first flush of prosperity mainly affected the West German population and sparked a growing demand for consumption and entertainment. This was the point at which transistor radios made an appearance in living rooms. And while the Berlin Wall was being built, TV became the new mass medium – first in black and white, and from 1967 in colour. Things were running at a different pace now, quite literally, as an atomic clock had now been invented, losing only one second every million years. The specimen that told Germany the time until 1991 is now part of the exhibition in Bonn. The Paul ion trap that makes it tick, as it were, is explained in detail here.

Just a few metres farther is the rotor system of a very large rescue helicopter, which attests to advances in flight technology. The keen wanderlust of the West Germans spurred on the aviation industry, as reflected in Reinhard Mey's perennial 1974 hit song 'Über den Wolken'. The construction of the BO 105 helicopter was followed by the founding of the German Federal Air Rescue Service. The peace movement reached its peak in the late 1980s, the Cold War came to an end, and the Berlin Wall fell. The exhibit addresses it all.

In 1983, Ulf Merbold became the second German to travel to space and the first non-US citizen to fly aboard NASA's Space Shuttle. Also on board was the Spacelab – which had been developed in Europe. Part of it, the materials laboratory, is at the museum. It was created by what was then the German Test and Research Institute for Aviation and Space Flight (DFVLR), the predecessor of the German Aerospace Center.

During the same decade, the automotive industry placed an increasing emphasis on safety, with the vast improvement and development of seatbelts and airbags. In simulated accidents, dummies were used to show which forces were exerted where. The kind of damage caused by such crash tests is apparent from the displayed Dummy Hybrid III – strapped to the car seat and badly battered with numerous scratches, patchy paint and missing limbs.

Microelectronics and optical storage possibilities

The latter half of the previous century was marked by German reunification and the breakthrough in microelectronics. The first mobile phone prototype became available in 1973, and the Gameboy in 1989. Advances in optical storage capabilities led to CD and DVD technology, displacing vinyl records and video tapes. The twentieth century also saw considerable progress in the field of medicine: insulin was manufactured synthetically for the first time in 1960; the discovery of plastic helped with the development of implants; and ultrasound examinations allowed doctors to see inside the body. Modern diagnostic procedures such as amniocentesis started to find their way into hospitals. Here, all of this is clearly explained using display cases, models, information boards and instruments.

Research possibilities in and on the water as well as in space seemed almost limitless at the end of the last century. From the early 1980s, the Polarstern research vessel enabled the first extensive expeditions to Antarctica and the Arctic. The icebreaker, which is still in use today, can accommodate around 70 researchers and be operated at temperatures as low as minus 50 degrees Celsius. The 1:50 scale model of the ship gives an idea of its features and shows how large and remarkable it was in relation to other ships at that time. Further on, the model of the drop tower is just as exciting, including the drop capsule of the Center of Applied Space Technology and Microgravity (ZARM) in Bremen. ZARM has been conducting research into microgravity, spaceflight technology and hypersonic technology since 1985. Since 2004, a catapult at the foot of the tower has allowed the drop capsule to be launched from below. Using this mode, the microgravity experiment time can be extended to almost 10 seconds.

A new millennium, the euro and Angela Merkel

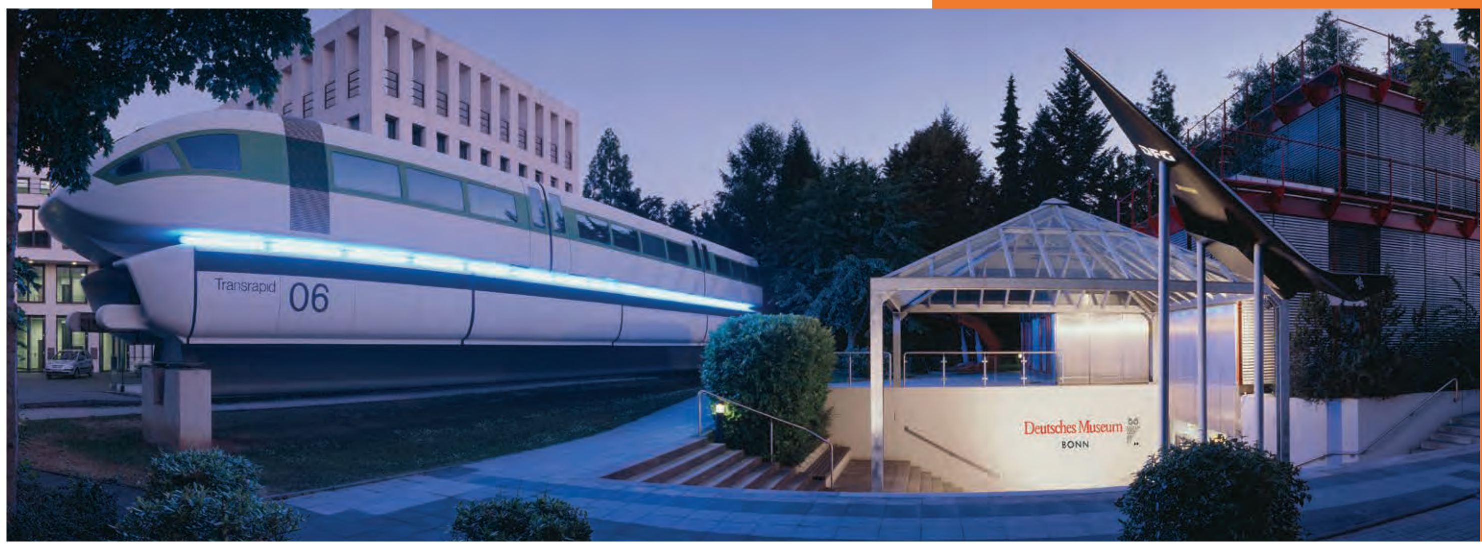
The advent of the digital age and the new millennium marked a time of huge change. The euro replaced the Deutsche Mark, Angela Merkel became the first female German chancellor and the iPhone conquered the market. The Internet could now be accessed via mobile phones, and digital media began to seep into all areas of life. The exhibition delves into the exciting complexities of this time, looking at the physical context and offering original exhibits from these periods. And since interaction with the exhibits is expressly encouraged, it is hardly surprising that families and school pupils gather at the Deutsches Museum in Bonn. The museum concept is toned down a little for certain exhibits, especially if they are intended to appeal to young visitors. Not all of the exhibits are understandable without an explanation, requiring not only a fascination with technology and science, but also a basic knowledge of these topics. Anyone who has both is bound to enjoy this treasure trove, right at the end of the Bonn Museum Mile.

Images: Deutsches Museum Bonn

Fascinated by the model of the Polarstern ice-breaking research vessel. Since 1982 it has regularly undertaken expeditions and is considered a landmark of German polar research. The icebreaker will be frozen in sea ice at the North Pole for a year. That will enable polar researchers to investigate the polar winter while the Polarstern makes an unknown voyage on the sea currents. This will offer them a unique opportunity to work on a floating field laboratory.

Astronauts carried out scientific experiments relating to metals research, fluid physics and crystals under microgravity conditions in the Materials Laboratory of the Spacelab module.

Visitors can see the Transrapid 06, built in 1982, at the entrance to the German Museum in Bonn



DEUTSCHES MUSEUM BONN

Address
Deutsches Museum Bonn
Ahrstraße 45
53175 Bonn

Opening times

Tue – Fri and Sun	10 - 17h
Sat	12 - 17h

Admission

Adults	9 euro
Concessions & groups of 10 or more people	5 euro
Family card	20 euro

Contact
Telephone + 49 (0)228 302-255

info@deutsches-museum-bonn.de
www.deutsches-museum-bonn.de/en

SHOCK AND AWE

The shimmering, blueish-green form looks a bit like a paramecium, but it is in fact a coral reef. Or not quite: it was once a coral reef. Until 2014. A recent satellite image shows a military outpost with an airfield. In addition to China, five other countries are claiming ownership of this archipelago in the South China Sea due to its abundance of raw materials and rich fishing areas. Hence such strongholds.

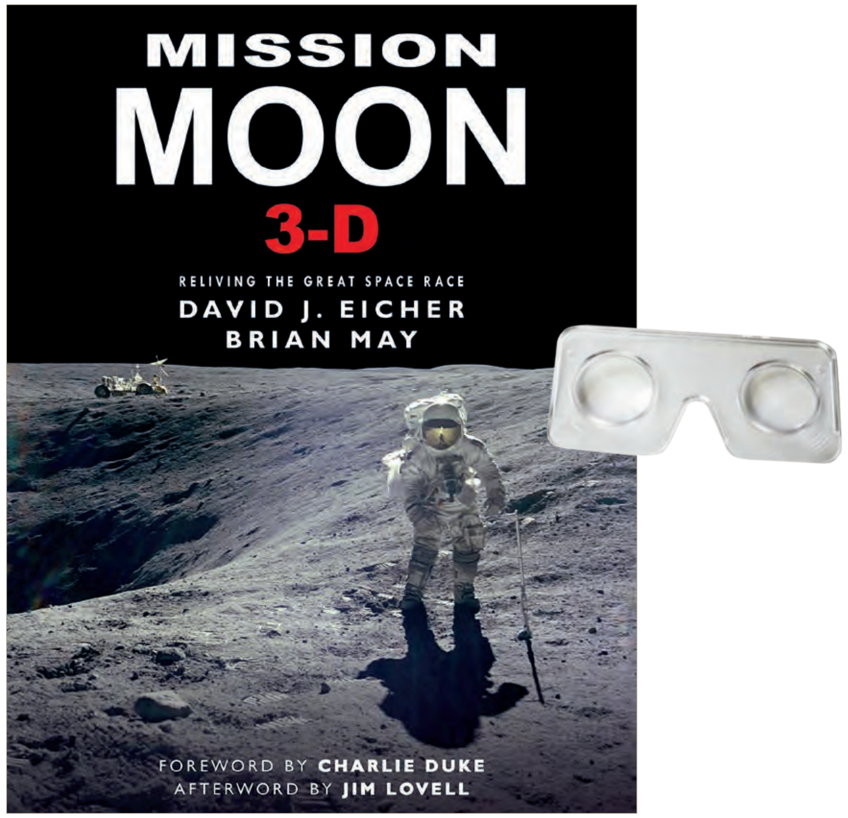
The two half-page images are almost lost amid the lush, mostly double-page picture spreads in the book **New Human Footprint.** Yet they are a striking testament to the brutal interference of humans with nature. Readers will likely rub their eyes and ask themselves, is that actually true? The satellite images provide the answer: man reshapes his environment anew, in extremely varied, often spectacular and frequently frightening ways. 'Our World in Transition', the subtitle of chosen by the publisher, **eoVision media,** could hardly be more apt.

Many of the pictures will be familiar from previous titles in the Footprint range, such as the shot of the pyramids in Egypt, with the city of Cairo rushing menacingly towards them. Others have never been published before. One example is the image of the Iranian oasis town of Keshit, which looks like a tree with a trunk and leafy crown when seen from space, as though sketched out by an artist, but was actually shaped by a traversing underground river. The ploughed-up landscape of brownish-black stripes in the brown coal mining area near Hambach and a sulphur-framed crater lake in Indonesia, are both astonishing and shuddering. A spine-like network of oil wells and pipelines in Kazakhstan, patchwork of evaporation basins for lithium production in Chile, transport routes on salty Bolivian soil that bundle like brush hairs, hundreds of strictly linear arranged rows of parabolic troughs of a solar power plant in Morocco and mosaic-like aquaculture areas in China all illustrate both human resourcefulness and its impact on the environment.

The 'footprint' that people leave on Earth is rapidly changing our planet. The back-cover of this impressive 255-page photobook reads: "These fascinating and often surprising views reveal just how big our impact is." Our Earth: is it still a garden, or has it become one massive dumping ground?

Cordula Tegen

MISSION MOON 3D – RELIVING THE GREAT SPACE RACE



In honour of the 50th anniversary of the Apollo 11 Moon landing, David Eicher (Editor-in-chief of Astronomy magazine) and Brian May (Astrophysicist and lead guitarist of Queen) present **Mission Moon 3-D, Reliving the Great Space Race.** Former astronaut Charlie Duke wrote the foreword, and the afterword is by Jim Lovell.

The story starts on 25 May 1961, when President John F. Kennedy announces his ambitious goal to land a human on the Moon and bring him safely back to Earth. Eicher paints a clear picture of the social and political context that initiated the space race, and follows it from Sputnik and Gagarin via the Luna programme and the Apollo missions all the way to the ISS. He concludes with some of the more recent developments in space exploration. There is also a chapter remembering those who lost their lives while developing the technology that would enable space travel and Moon landings.

The credentials of the authors alone merit a closer look at yet another account of the Moon landings. But what really makes this volume stand out are the wonderful stereoscopic pictures featured throughout the book. Apparently, experienced viewers of stereo photos can see the 3D images without help, but for the rest of us an Owl Viewer and viewing instructions are included at the back. With a bit of practice, the stereographic photographs come to life before your eyes. Some of these photos were actually taken by astronauts while they were on the Moon, with a special camera to record detailed pictures of the Moon's surface. The stereographic pictures of the astronauts and lunar landers were assembled from photos made with their regular cameras (left on the Moon to reduce the weight of the Lunar Module). Additionally, contemporary video material was sourced for stills and images from the ViewMaster reels devoted to the US space missions were used. (Re)constructing the stereoscopic photos by Brian May and his team has taken a great deal of skill, and the result is well worth the effort.

Merel Groentjes

RECOMMENDED LINKS

AVIATION IN ONE PLACE
skybrary.aero
Looking for information on flight operations, air traffic management (ATM) and aviation safety in general? Then look no further. Skybrary is a universal portal that enables users to access the safety data made available on the websites of various aviation organisations - regulators, service providers and industry alike.

SEISMIC MONITOR
earthquake.usgs.gov/earthquakes/map/
We live on a dynamic Earth, and this implies that it shakes and moves from below. Our planet experiences seismic activity on a continuous basis. Are you curious about where earthquakes are occurring at any given time? The United States Geological Survey Earthquake Hazards Program offers a platform where you can see all the latest seismic activity at play on Earth. It includes the magnitude of the earthquake, the exact coordinates and its depth.

CURIOSITY MACHINE
curiositymachine.org
Iridescent has launched the first-ever global artificial intelligence education programme for children and their parents. Families create AI solutions to real problems in their communities. Their mission is to empower children and their families to become leaders and innovators of the future. From speech recognition to helping patients with diabetes. This programme, which features activities, videos and more, will open your eyes to the numerous possibilities offered by artificial intelligence.

MORE THAN JUST A MUSEUM
www.exploratorium.edu
The Exploratorium is more than just a museum. "It is an ongoing exploration of science, art and human perception – a vast collection of online experiences that feed your curiosity." What gives meat its flavour? How do crystals grow? What is the science behind growing plants? Fancy a journey to Antarctica? For this and more, visit exploratorium and start your exploration journey.

LIFE AROUND ASTEROID RYUGU
twitter.com/haya2e_jaxa
On 3 October 2018, the MASCOT lander successfully landed on asteroid Ryugu, took numerous pictures and carried out numerous experiments. And, although MASCOT's mission is complete, its mothercraft Hayabusa2 is still hard at work. What is happening on asteroid Ryugu? What is Hayabusa2 doing at the moment? Stay up to date on all of the mission operations and highlights via the Hayabusa2 twitter account – directly from asteroid Ryugu.

About DLR

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

DLR has approximately 8200 employees at 26 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Bremerhaven, Cochstedt, Cottbus, Dresden, Göttingen, Hamburg, Hannover, Jena, Jülich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Oldenburg, Rhein-Sieg-Kreis, Stade, Stuttgart, Trauen, Ulm, Weilheim and Zittau. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

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Cover image
Shown here is the spherical structure of a novel biopolymer aerogel developed by DLR researchers in a laboratory experiment. It is produced by combining chitosan with a thermoset. You can read more about the versatile aerogels and about Barbara Milow who, together with her team, is 'cooking up' new recipes, on page 30.

DLR
Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

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