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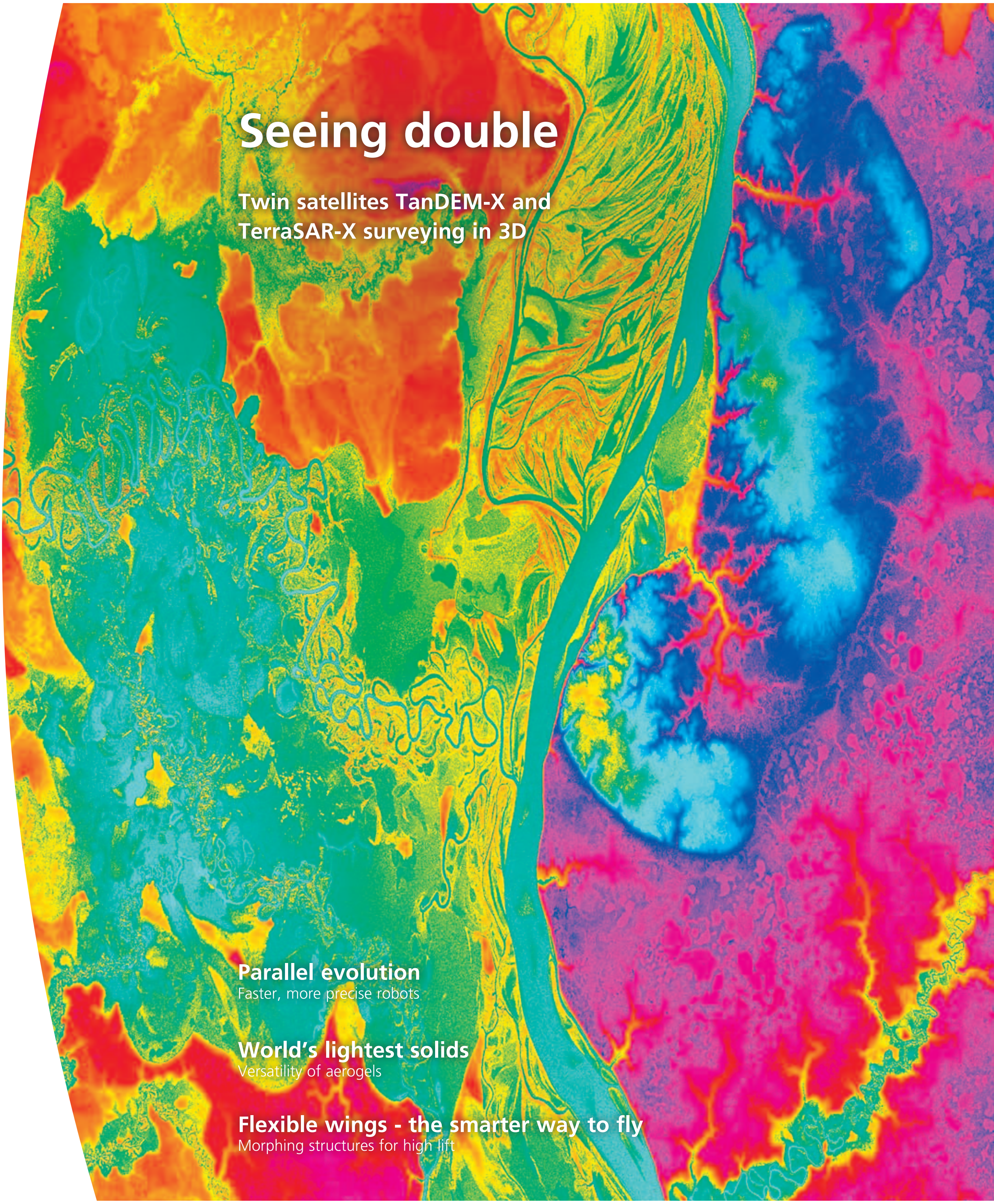
DLR magazine 129·130



Seeing double

Twin satellites TanDEM-X and TerraSAR-X surveying in 3D

Parallel evolution
Faster, more precise robots

World's lightest solids
Versatility of aerogels

Flexible wings - the smarter way to fly
Morphing structures for high lift

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A car that drives sideways

A design that works on the Moon and has been planned for Mars; the drivetrain is integrated into the wheels. What works in space should work on Earth as well; designed by robotics specialists at DLR, the Robomobil includes technologies used for space missions and robotic arms on the International Space Station. The result: a two-seater capable of driving sideways that, in the future, could become a mode of urban transport and even be completely autonomous.

Front page image: The surface of the Earth in a different perspective – a radar image of TerraSAR-X and TanDEM-X shows the landscape around the Siberian river Taz

Dear readers,

The public communication of science represents an important link between the scientific community and wider society. While the main role of scientific and research institutions is to further our knowledge of science and technology, the main task of their respective communications departments is to disseminate this new knowledge to a broader audience than the scientific community alone. This might sound straightforward, but what does it entail in practice?

Science communication has a number of goals, ranging from the establishment of broad, social acceptance of new technologies and the encouragement of interdisciplinary synergies through to fostering dialogue – and the targeted transfer of knowledge – between researchers and industry. For us at DLR, it is about conveying our scientific excellence, our social, economic and international relevance, our interdisciplinary approach to research and our innovative capabilities. Likewise, because scientific research is supported by taxpayers' funds, we are establishing a dialogue with the public, as taxpayers, voters and leaders with a responsibility in the community and government – to inform them about the work their scientists are doing.

DLR has 33 excellent institutes and facilities, and thousands of scientific professionals that are involved in exciting, cutting-edge research areas. Having such an extensive range of activities makes it hard to decide what should be communicated to the outside world. The many media channels and resources available – from the World Wide Web to social media channels and print and electronic media – give us so many ways to disseminate information that it is sometimes difficult to choose one.

What criteria do we look for? On the one hand, the social relevance of a candidate technology is very important. On the other, how do they relate to the hot topics of the day? But it is our experience in dealing with public perception and the acceptance of an issue by the media that helps us prioritise the subjects of highest potential interest.

Our analysis of the media in recent months has shown that we are going in the right direction. After all, we have the potential to reach about 1.2 billion print readers every year; and this does not include the reach of our web portal, which is enjoying increasing popularity with a current average of 1.5 million page views and half a million visitors per month.

Having to make a choice about the subjects to be covered in this edition, we opted for a combination of robotics research, traffic management, new materials, the exploration of moons in the Solar System, and the automated cars and morphing aircraft wings of the future. Encountering this variety of different subjects on a daily basis is what makes each day at DLR one-of-a-kind – just like this magazine.

Sabine Göge
Head of DLR Corporate Communications

Perspective

Taking care of turbulence

What looks like a wind tunnel is actually an air intake chamber. Engine researchers use the 16-metre-long, eight-metre-diameter enclosure to remove turbulence from air before it reaches the compressor of an engine during testing. This allows them to achieve optimal and repeatable conditions for their experiments.

Fans and compressors are important research topics at the DLR Institute of Propulsion Technology by reason of the great influence they exert on the performance of engines and their noise emissions. The researchers are working on new designs for axial and radial compressors, and verifying their multidisciplinary development techniques using prototypes. The multi-shaft compressor test facility, shown in this image being prepared for a test, is essential for this process.

Stepping over boundaries is the way to progress

By Johann-Dietrich Wörner, Chairman of the Executive Board

Johann-Dietrich Wörner, Chairman of the DLR Executive Board

Back in the 1950s and 1960s, the dominant factor governing international relations was the Cold War, especially between East and West. Even though that time was associated with the inherent competition of the Space Race, there were also exemplary collaborative ventures; the first high point being in 1975 when a US Apollo spacecraft and a Soviet Soyuz capsule linked up in Earth orbit. Since then, international cooperation has developed further in almost every related sector, especially in research.

Are international cooperative ventures nothing more than cosmetic gestures to disguise the hard political facts of existing nation-state alliances and interests?

An analysis of the situation and its implications quickly demonstrates the potential of international collaboration. Naturally, for the foreseeable future, national entities will continue to exist within Europe and pursue their own interests, giving rise to competition, especially in the industrial sector. Within this competitive environment, the positions occupied by individual countries will undoubtedly depend on their research performance. This initial view could lead one to believe that research should, to a large extent, be partitioned by country, in order to take full advantage of the results without having to share the benefits more widely. However, while there is little likelihood that changes in the political system are going to occur in the near term to facilitate increased cross-border collaboration – particularly within Europe – we know from experience that international research cooperation brings with it many advantages. This brings up two questions; firstly, do we not have a global responsibility to ensure that research should be optimised, and not be made subject to national or regional restrictions? Secondly, is it not the case that international cooperation is a significant way of progressing research more rapidly?

This second question comes out of two considerations; we are faced with a series of challenges that can only be addressed with very large-scale research infrastructures, far exceeding national capabilities and which can be used much more efficiently through cross-border cooperation. Successful examples include the European Space Agency, CERN – the European Organization for Nuclear Research, the European Transonic Windtunnel and the International Space Station. It has been repeatedly demonstrated that the very process of bringing together scientists from different countries is what drives certain specialist kinds of research work forward. For most sectors of our highly technical, ultra-specialised world, having researchers work in isolation does not constitute a model for success; instead, teams should be brought together to reach new horizons.

In addition to this international component, a multidisciplinary approach is also important for inspiring progress. Excellence in the individual scientific disciplines has always been, and continues to be an important factor and a *sine qua non* for successful research. The last few decades have shown that, to a growing extent, it is the work conducted at the intersections of different scientific disciplines that is particularly exciting. Becoming a polymath is virtually impossible today, because of the accumulated depth and complexity of each individual scientific discipline. So, instead, it is imperative that modern science management brings these separate fields of study together while also setting priorities in national research strategies. This approach offers significant possibilities for international cooperation.

These general statements hold true for DLR in the same way; it is only through cooperation between the various areas of research at DLR, and especially through collaboration at an international level, that we are able to work effectively and continue to make progress. •

Cross-border research in this issue:

More information:
www.DLR.de/blogs/en/janwoerner

In brief

The Stratospheric Observatory for Infrared Astronomy, SOFIA

Airborne observatory SOFIA goes to work

SOFIA, the Stratospheric Observatory for Infrared Astronomy, a joint project between NASA and DLR, will soon begin its routine operations. On 6 April 2011, German scientists carried out the first astronomical observations on board the world's only airborne observatory.

The first observations with the German Receiver for Astronomy at Terahertz Frequencies, GREAT, included spectra of the Omega Nebula (M17), an active star-forming region in the Milky Way, and the galaxy IC 342, located a few million light years away. Flying at altitudes above 10 kilometres, SOFIA is able to perform observations not possible with ground-based telescopes, due to atmospheric water vapour absorption. SOFIA was able to carry out observations and record important spectral lines. These very first spectra are the reward for many long years of investment in cutting-edge technology developments and they showcase the scientific potential of airborne far-infrared spectroscopy. Thanks to the large collecting area of the 2.7-metre diameter telescope, together with enormous progress in terahertz technology, the collection of data is 100 times faster when compared to earlier experiments, opening a new pathway for unique scientific experiments. The GREAT instrument was developed by a team from the Max Planck Institute for Radio Astronomy and the University of Cologne, led by Rolf Güsten, in collaboration with the Max Planck Institute for Solar System Research and the DLR Institute of Planetary Research.

"GREAT's first science flight is the beginning of German-American scientific collaboration on SOFIA. We are confidently looking forward to the upcoming routine operations," said Alois Himmes, SOFIA Project Manager at DLR.

http://s.dlr.de/m0e7

Atmospheric research – in the long run, the Ozone layer will be restored

Recent estimates suggest that, by the middle of the 21st century, the thickness of the Ozone layer will be the same as in the early 1980s. These findings are included in a report about the changes in the Ozone layer by the World Meteorological Organization, in which DLR researchers studied the state of the Ozone layer in the stratosphere. Experts believe that this positive development is due to the successful regulation of the production and use of substances containing fluoride, chlorine and bromine – for example, chlorofluorocarbons (CFCs) – through the Montreal Protocol of 1987 and subsequent international agreements.

All the predictions in the report are based on computational models that simulate physical, dynamic and chemical processes in the atmosphere. Referred to as 'climate chemistry models', these were produced at the DLR Institute of Atmospheric Physics. To investigate the Ozone layer, the Institute conducted long-term simulations, starting in the past (for example, in 1960) and extending into the distant future. The computational results for the past are compared against observation data to evaluate the quality of the models, among other things. Delivering reliable estimates relating to future developments, such as those that might affect the Ozone layer, is only possible on the basis of thoroughly tested models.

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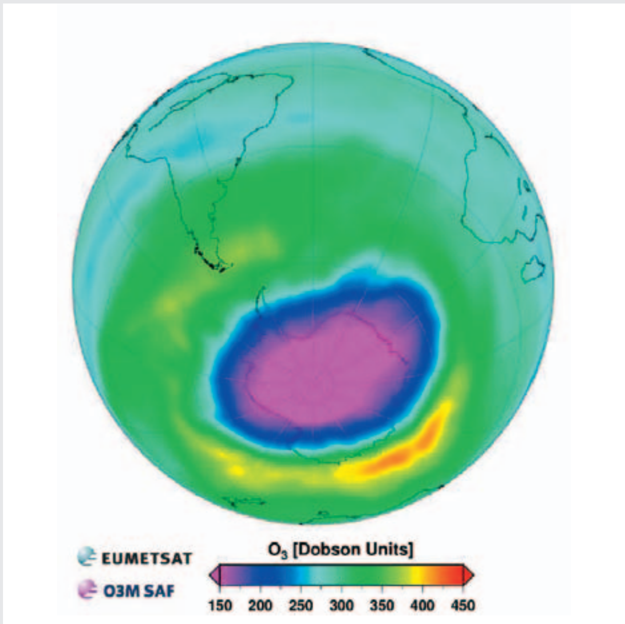
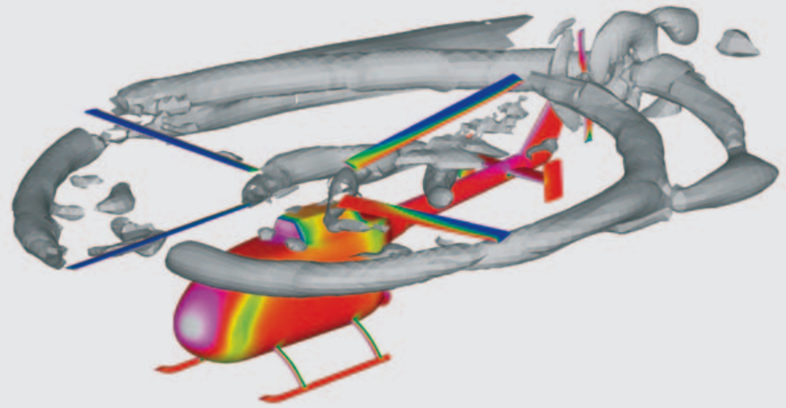


The Ozone Hole over the south polar region in October 2010: the Ozone Hole extends across most of Antarctica, but new computer models give hope

DLR and NASA – making the helicopters of the future quieter

A helicopter relies on its rotor to be able to take off and land vertically. The rotor is also responsible for the noise a helicopter makes during flight. Researchers at DLR and NASA are investigating the exact origin of this rotor noise. The aim of the ongoing research at DLR in Göttingen is to make the helicopters of the future quieter.

The DLR researchers are contributing their expertise in optical measurement technology for fluid flows, and NASA researchers are contributing the most up-to-date measurement technology and their experience with experiments in the largest wind tunnel in the world. The researchers are using a test stand with a rotor model from RWTH Aachen for their investigations and seven high-speed cameras, lasers and high-powered LEDs to make the vortex visible. What is special is the simultaneous use of three different optical measurement techniques. The density and velocity fields in the vortices and the deformation of the rotor blades are recorded. As in medicine, multiple investigative methods help to reach the correct diagnosis.



Computer simulation of vortices: reduced pressure on the top of the blade draws air upwards; this produces a vortex – the blade tip vortex – that is then directed downwards. When other rotor blades subsequently come into contact with these vortices, the 'chopping' or throbbing noise characteristic of helicopters is produced.

http://s.dlr.de/1180

Testing bacteria's survival skills

Resistant spores of *bacillus subtilis* have spent 22 months in the EXPOSE-R facility outside the International Space Station, ISS. For the first time during a long-duration mission, they were mixed with artificial meteorite dust and exposed to the harsh conditions of outer space. Scientists at DLR are now determining precisely how many of these spores have survived their stay in space. If it turns out that the meteorite dust was able to shield the spores from the hostile space environment, microorganisms may be capable of surviving in meteorites for long periods of time and, thus, of travelling from one planet to another.

Three hundred samples containing microorganisms have been exposed to ultraviolet and ionising radiation, vacuum and temperature variations from minus 20 to plus 40 degrees Celsius in the ESA EXPOSE-R facility, as well as microgravity and a complete absence of any type of nutrients. The spores of *bacillus subtilis* have proven to be true survivors, employing an effective strategy; they enter a kind of hibernation, waiting for conditions to become more favourable, and then germinate again and restart their metabolism.

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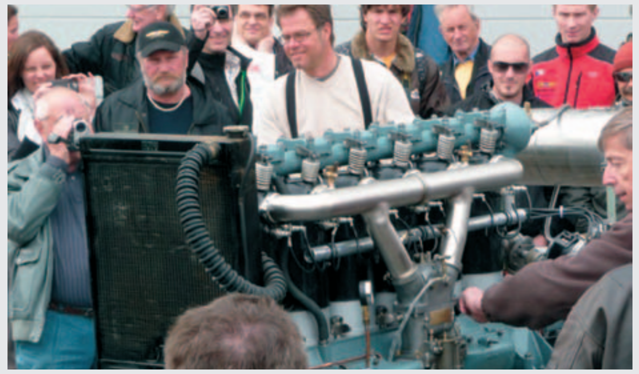
Resistant spores of *bacillus subtilis* in the EXPOSE-R facility outside the International Space Station



The Junkers L5 engine at the AERO air show

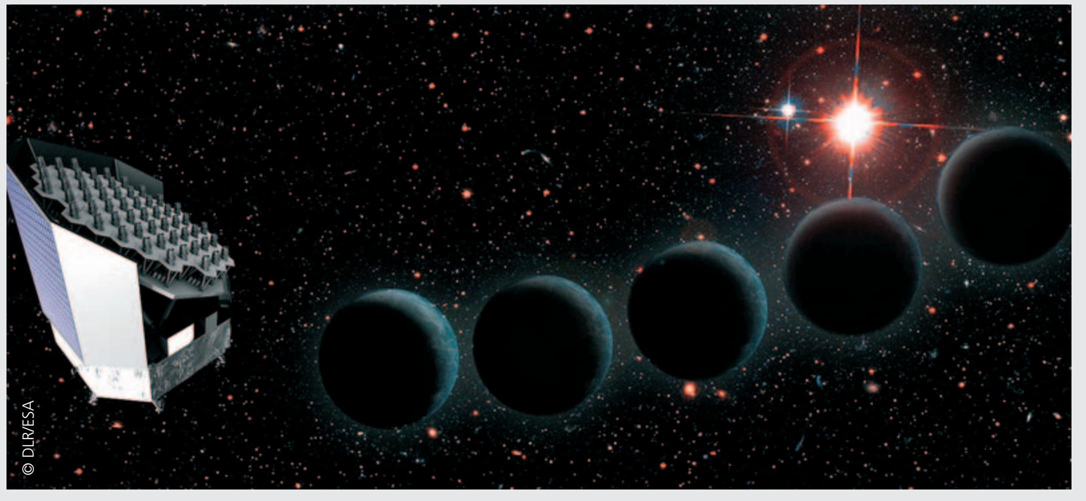
The heart of a Junkers F 13 beats again

Ninety-two years after the first flight by a Junkers F 13, one of the engines from that era ran again, and an important milestone in the construction of an airworthy replica of one of these legendary aircraft was reached. The association 'Friends of Historical Aircraft', co-initiator of the project to reconstruct a flying Junkers F 13 – the world's first all-metal commercial aircraft – demonstrated this at the 2011 AERO general aviation show in Friedrichshafen, when two aero-engine mechanics brought an original Junkers L5 power plant back to life. The six-cylinder engine, with a displacement of 22.9 litres and a take-off power of about 310 horsepower, came from a Junkers F 13 that was found some years ago in Yemen. The German Engineering Museum in Berlin received the remains of this aircraft, including the incomplete L5 engine. The Friends of Historical Aircraft rebuilt the engine over the course of many months of painstaking work at a Swiss maintenance facility. The rich sound of the engine inspired visitors and media representatives at the air show. The first flight of the reconstructed Junkers F 13 is scheduled for the autumn of 2014.

Video (Loop TV): http://s.dlr.de/5jn6

Next generation planet finder

At the science conference hosted by DLR and TU Berlin in February 2011, 150 scientists from Europe and the United States met to discuss the design of the mission PLATO, PLAnetary Transits and Oscillations of Stars. This mission, proposed by the European Space Agency, will search for extrasolar planets – planets in other star systems – and characterise their host stars. PLATO could be a successor of the successful CoRoT mission, which discovered the first terrestrial exoplanet, or 'Super Earth', and precisely determined its radius. Scientists from the DLR Institute of Planetary Research have played an important role in the development of the mission proposal. In the autumn of 2011, the European Space Agency will decide whether this mission will be conducted as part of its Cosmic Vision 2015-2025 programme.



In 2018, PLATO will detect extrasolar planets transiting their parent stars. Major breakthroughs are expected; it will be capable of observing rocky extrasolar planets around brighter and better-characterised stars than its predecessors.

DLR discussing expanded cooperation with Algeria

The Algerian Space Agency (Agence Spatiale Algérienne) and DLR have met to discuss future cooperation in space research. This country, rich in oil, gas and sunlight, is already cooperating with DLR in the field of energy research and has also had a national space programme for a number of years; two Earth observation satellites are currently in operation, and more are planned.

With a surface area six times that of Germany, Algeria wishes to improve communications, environmental protection and disaster preparedness. The visit by an Algerian delegation to the DLR sites in Bremen, Cologne and Oberpfaffenhofen yielded tangible starting points for cooperation, for example in the testing of remote sensors.

Thomas Reiter, now responsible for astronaut training at the European Space Agency

Thomas Reiter appointed ESA Director of Human Spaceflight and Operations

Thomas Reiter, a member of the DLR Executive Board for the past four years, has been appointed Director of Human Spaceflight and Operations at the European Space Agency. The former astronaut will be responsible for an area in which Germany is a leader in Europe. Among other things, he is responsible for astronaut training and research in microgravity, as well as the operational use of space infrastructure and European satellite missions.

Reiter is one of three German directors at the European Space Agency. Volker Liebig will continue as Director of Earth Observation Programmes for four more years, and Hans-Georg Mockel, who has been Chancellor of the University of Frankfurt, has been appointed Director of Human Resources, Facility Management and Informatics.

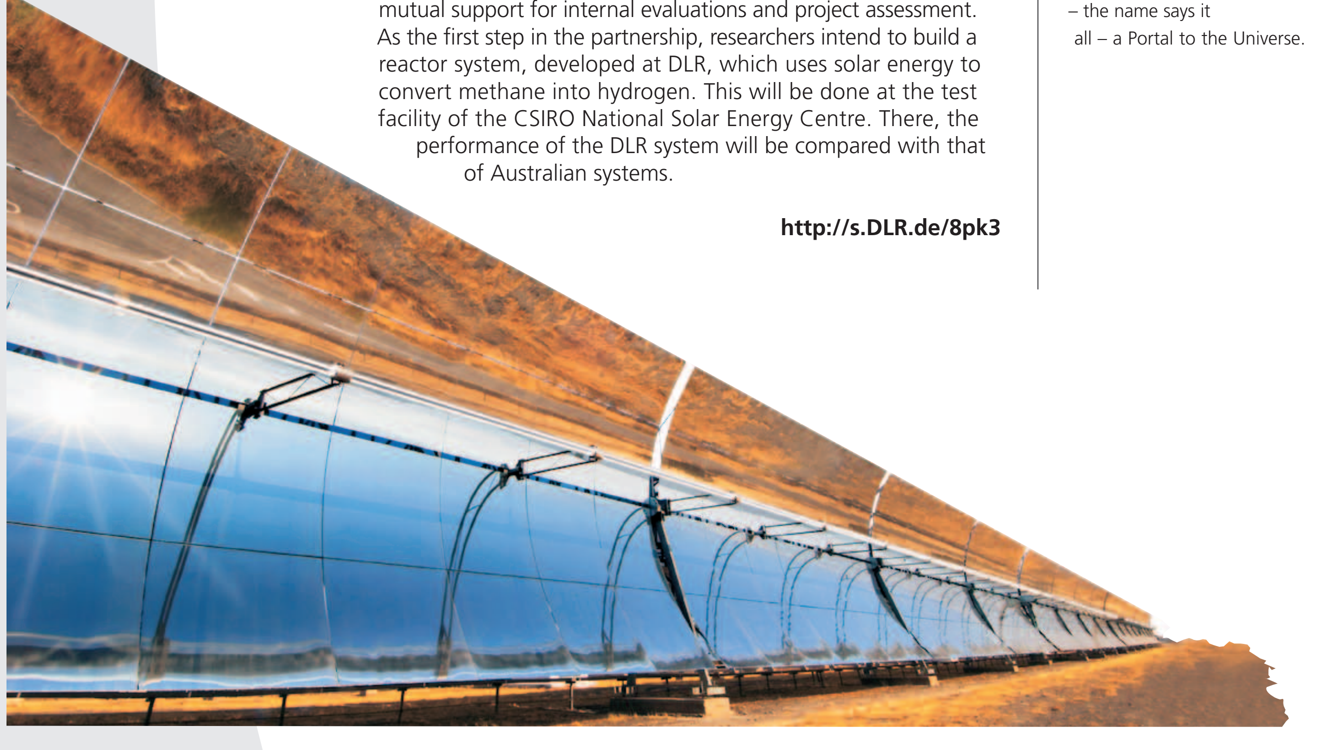
Kim Carr, Australian Minister for Innovation, Industry, Science and Research (right) and DLR Executive Board Member Ulrich Wagner

DLR technology under the Australian sun

DLR is now collaborating with the Australian Solar Institute in the field of concentrating solar energy technology. "Australia's commitment to a climate-friendly energy supply, its excellent research infrastructure and, of course, its high levels of solar radiation are an excellent basis for us to work together on reducing the cost of solar power," stated DLR Executive Board member Ulrich Wagner. DLR has been conducting research into concentrating solar energy technology for more than 30 years and has one of the world's largest research teams in this field.

The Australian government has allocated five billion Australian dollars for the research, development and demonstration of low carbon dioxide energy technologies, and for the establishment of the Australian Solar Institute. To employ the resources of both countries as effectively as possible, the partners intend to conduct joint research projects and exchange their views regarding the opportunities presented and risks faced by various technologies and markets. They also intend to offer mutual support for internal evaluations and project assessment. As the first step in the partnership, researchers intend to build a reactor system, developed at DLR, which uses solar energy to convert methane into hydrogen. This will be done at the test facility of the CSIRO National Solar Energy Centre. There, the performance of the DLR system will be compared with that of Australian systems.

http://s.DLR.de/8pk3



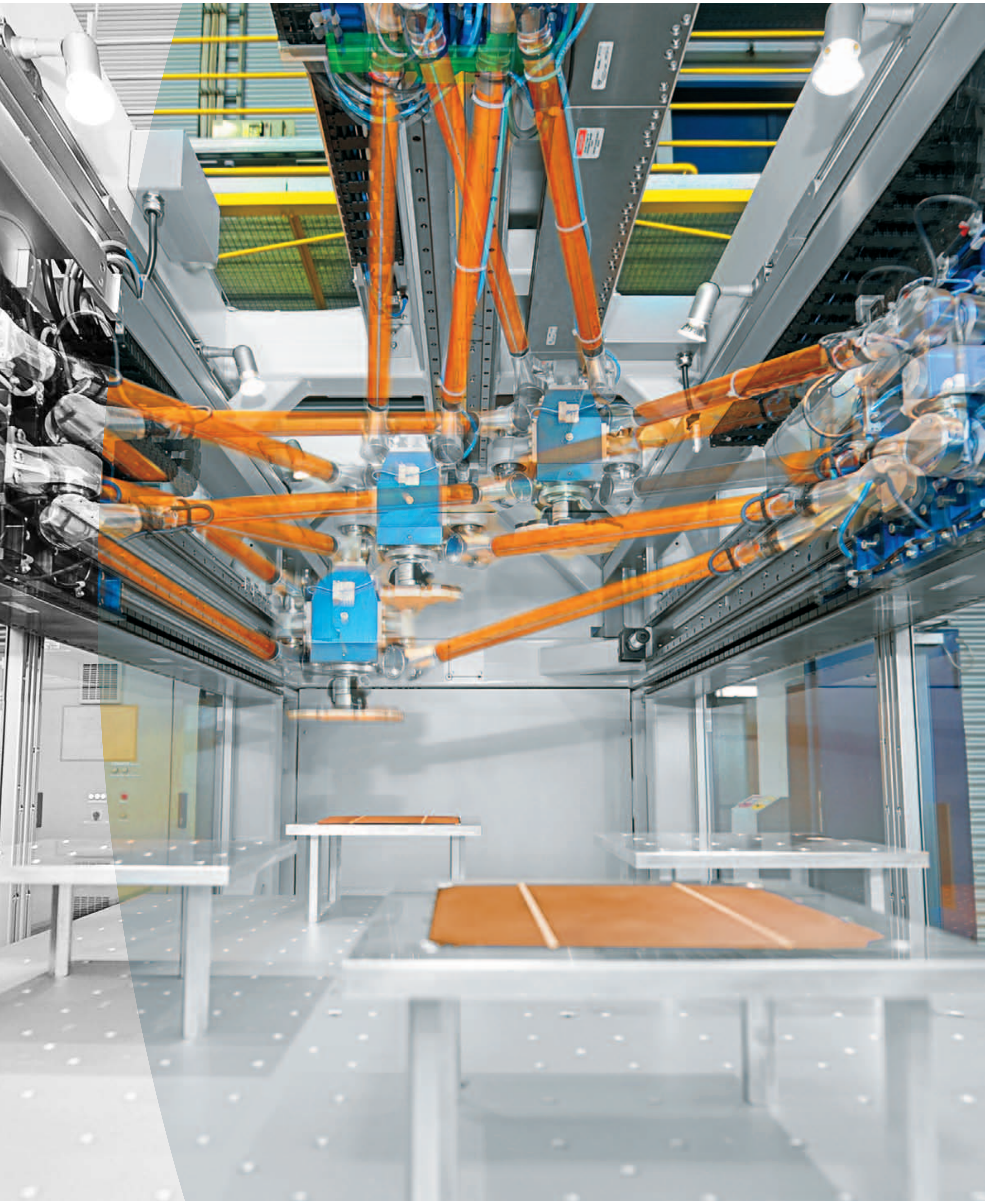
FROM INCREDIBLY TINY TO TRULY GIGANTIC
http://htwins.net/scale/
From the elementary building blocks of matter to the vast expanses of the cosmos – following in the tradition of the well-known 'Powers of Ten' (http://apod.nasa.gov/apod/ap110201.html), an interactive graphic illustrates fundamental facts and figures on a journey through the different scales of the Universe. Physics comes to life!

AN ALTERNATIVE VIEW OF NATURE
http://timescapes.org
Seen from an unusual viewpoint, the beauty of nature is captured using time-lapse photography: an atmospheric and impressive video.

RUSSIAN SPACEFLIGHT
www.federalspace.ru
What is happening in the Russian space programme? The Roscosmos website reveals the history and present status of Russian space research. An interesting web page was created to celebrate this year's 50th anniversary of Yuri Gagarin's first human spaceflight.

WANT TO GO ON A TOUR?
www.realitymaps.de/en
The pictures, videos, maps and route planners on the website of the company 3D RealityMaps GmbH will leave you wanting more.

A WINDOW TO THE UNIVERSE
www.portaltotheuniverse.org
If you would like to keep up to date with the latest astronomy and space science breakthroughs, this is the place to go. From news, blogs, podcasts, images and videos to the real-time position of the International Space Station – the name says it all – a Portal to the Universe.



Parallel evolution

The task of parallel robots is to perform assembly tasks in a series of fast, precise movements. They only move small masses and are substantially lighter than standard industrial robots. But their speed also presents them with a problem; when a robot first increases its speed at 10 times the acceleration due to Earth's gravity and then slows down at a similar rate, it is affected by a simple law of nature and starts to vibrate. The valuable time wasted waiting for these vibrations to decay reduces the advantage that a parallel robot has over slower mechanisms. This is where Michael Rose, Ralf Keimer and Stephan Algermissen from the DLR Institute of Composite Structures and Adaptive Systems come in. They have ensured that the Triglide robot can fulfil both requirements – it can be fast and precise.

Novel robots outrun their industrial brethren

By Lena Fuhrmann

A typical robot arm can perform a wide array of movements; parallel robots, in development for the last 10 years at DLR, aim to duplicate such performance in a more efficient way, with many small arms doing the same work as one big one. The final 'Robot systems for handling and assembly – highly-dynamic parallel structures with adaptronic components' project was completed in June 2010, representing the combined work of a DLR team and seven institutes at the Technical University of Braunschweig; a total of 29 doctorate-level staff and vast amounts of passion, sweat and night shifts, because work on parallel robots doesn't usually stop at the end of the normal working day. The result is a highly impressive robotic system known as Triglide; it is way ahead of its brethren – industrial robots – when it comes to assembly work.

"Industrial robots are constructed like a human arm; a joint connects to a strut or beam, then to another joint, then to another strut," explains DLR's Ralf Keimer. "Such a robot needs a drive unit for every joint that it is required to move, so it has a motor and a gearbox at each joint – a lot of metal – which is heavy." If the robot's lower arm has to move, the upper joint must rotate simultaneously. With additional mass having to be accelerated, more power is required and larger motors must be used, further increasing the mass of the robot. A parallel robot moves several arms in parallel; this only requires drive units at its 'shoulders', making it lighter and therefore also faster.

Piezoelectric ceramic actuators damp vibrations

Rapid acceleration causes vibration, and this is where the work at DLR has been focussed. The solution takes the form of rods made of a carbon-fibre composite fitted with small plates called actuators, which are made of piezoelectric ceramic. These rods are only able to expand by one thousandth of their overall length, but that is sufficient to damp undesirable vibration. "Piezoelectric ceramics change shape when a voltage is applied," explains Keimer, who devised these rods. "But their volume does not change. In other words, the ceramic 'grows' in one direction and, in so doing, becomes smaller in the cross section, much like the way a rubber band becomes longer and thinner when stretched." The direction of the electric field determines the direction of expansion. Rods fitted with piezoelectric ceramic actuators were used to replace the conventional rods on the parallel robot. These actuators are driven at the same frequency as the vibration affecting the Triglide, almost completely cancelling it out. Since mathematical models of the robotic motion are only ever able to approximate reality, total suppression is impossible. In addition, there is a delay before the damping system reacts, albeit a very small one. Despite this, Ralf Keimer has ensured that the rods satisfy all the requirements; that is, that their actuators deliver enough force to be able to alter their length sufficiently and the completed arms are able to withstand the forces with which the robot is required to contend.

To achieve precision, the Triglide robot must not vibrate. Researchers at DLR Braunschweig are engaged in joint research with colleagues at a nearby university.

Once Keimer had completed his work, Stephan Algermissen was able to get started. His task was to set up the control system on the Triglide in such a way that it was able to identify precisely how to respond to each vibration source – no easy undertaking. The researcher spent many hours at the computer, testing the parallel robot in different positions, because the vibrations vary in every individual configuration. The intention was to determine which vibrations could be excited using the piezoelectric actuators. Before an undesirable vibration can be counteracted, the system must first be able to recreate it.

Determining the robot's mechanical characteristics

An acceleration sensor in the upper section of the Triglide robot measures vibrations. Algermissen positioned the robot in various configurations and transmitted test signals at frequencies of between zero and 120 hertz to the three actuators. Two rods arranged in parallel on the Triglide were used as actuators in each case. "The sensor then showed me the frequencies at which the robot responds strongly," explains Algermissen. "The really interesting points are those where powerful vibrations occur; we need to use the feedback controller to damp them. This has to do with the natural resonant frequency that every structure possesses – the frequency at which it vibrates particularly strongly." A robot is nowhere near as simple to analyse as a springboard; depending upon its configuration, it can start to vibrate with a lower frequency at one location than at another. A complex mathematical model incorporating the vibration levels of the robot at defined positions has been derived from these measurements. This information is used as input to the robot control system; when the robot vibrates at a particular position, it transmits a signal to the feedback controller, which in turn initiates an opposing movement. The feedback controller performs these calculations one thousand times per second.

Michael Rose taught the Triglide to move precisely from one position to another along a prescribed path by calculating the forces required to make this happen. Since the robot structure, with its various components, has a certain mass, inertia plays a role in this. With a carefully chosen force, the Triglide is set in motion: "the parallel robot is able to follow the selected path precisely, even at very high accelerations – up to 10 times the acceleration due to Earth's gravity (10 g)," recalls Rose. "I equipped the motor controllers with the necessary information. When I was informed by a colleague that my model had made it possible to reduce the deviation from the required path by up to 90 percent, it was a satisfying moment of success."

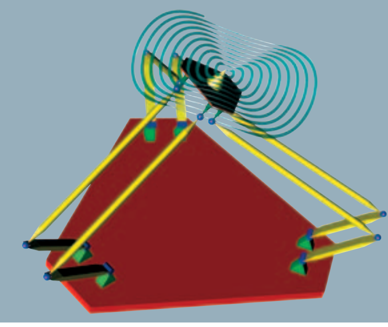
Cooperation with the Technical University in Braunschweig was an obvious course of action; the skill sets of the two parties complemented one another well. DLR has a unique selling proposition in Europe with its research work on adaptive systems. The Institute of Machine Tools and Production Engineering at the Technical University of Braunschweig was able to build the robots in collaboration with the departments of Mechanical Engineering, Electrical Engineering and Information Technology. As well as the Triglide and many other robots for various investigations, this work has also given rise to another parallel robot, Hexa 2, which operates with six motors. Another important aspect of this research was to give talented young researchers the opportunity to prepare dissertations and doctoral theses.

When work started in the year 2000, the Triglide was still a distant prospect, but six years later the parallel robot was ready for action. Tests were conducted as 'dry runs' on a computer and were then transferred to the robot. The result, after 10 years of research, is extremely positive: "we have learned a great deal in our basic research and are making steady progress," notes Stephan Algermissen. The researchers were also able to assist a partner in France with a parallel robot that was intended to mount solar panels.

Transferring expertise to other fields

Will my calculations also work during a practical test? Have I really taken everything into account? These are the questions that all researchers must ask themselves before the first 'real' tests begin. "After all," says Ralf Keimer with a wry grin, "physics does not forget its principles, but an engineer sometimes makes that mistake." The fields that the DLR researchers are working on are breaking new ground so there are no books or academic papers to guide them. Researchers are themselves responsible for defining the safety areas. Practical experience has now corroborated their belief that everything functions the way it is supposed to.

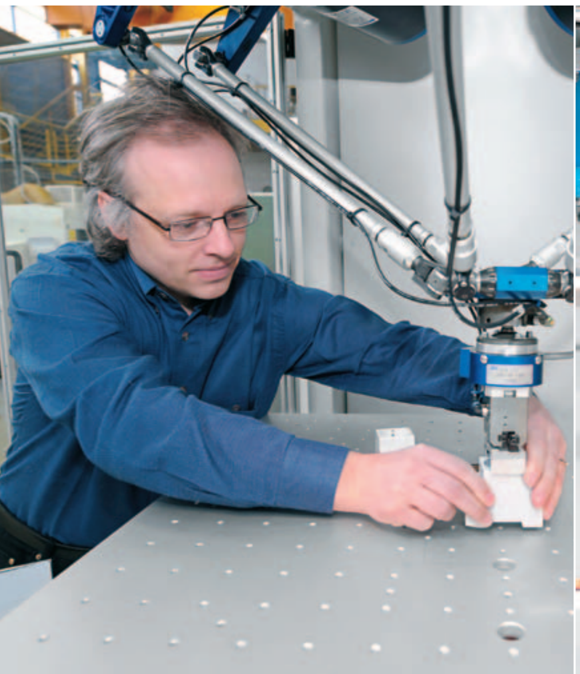
Now that their work in this special research sector has been completed, the expertise obtained will be transferred to other areas. Undesirable vibration affects far more than parallel robots; other sectors such as aviation must also address this problem. The airflow past the outer skin of the fuselage induces vibration in an aircraft body. The resultant noise propagates throughout the airframe and into the cabin itself, causing the background noises familiar to every traveller. The current task of the adaptronics specialists is to apply vibration suppression techniques to reduce noise levels inside the aircraft cabin. To accomplish this, small piezoelectric panels are bonded to the interior of the aircraft. The principle is the same as for a parallel robot; vibration is measured and then damped by means of counter-vibrations. To this end, researchers have scheduled joint tests with the DLR Institute of Aerodynamics and Flow Technology. In 2012/2013, the cabin research aircraft at DLR in Göttingen, a Dornier 728, will be subjected to noise from a large loudspeaker system imitating engine noise. Of course, small ceramic panels will not be able to deliver complete noise suppression, but they are one of many components that will reduce noise levels. •

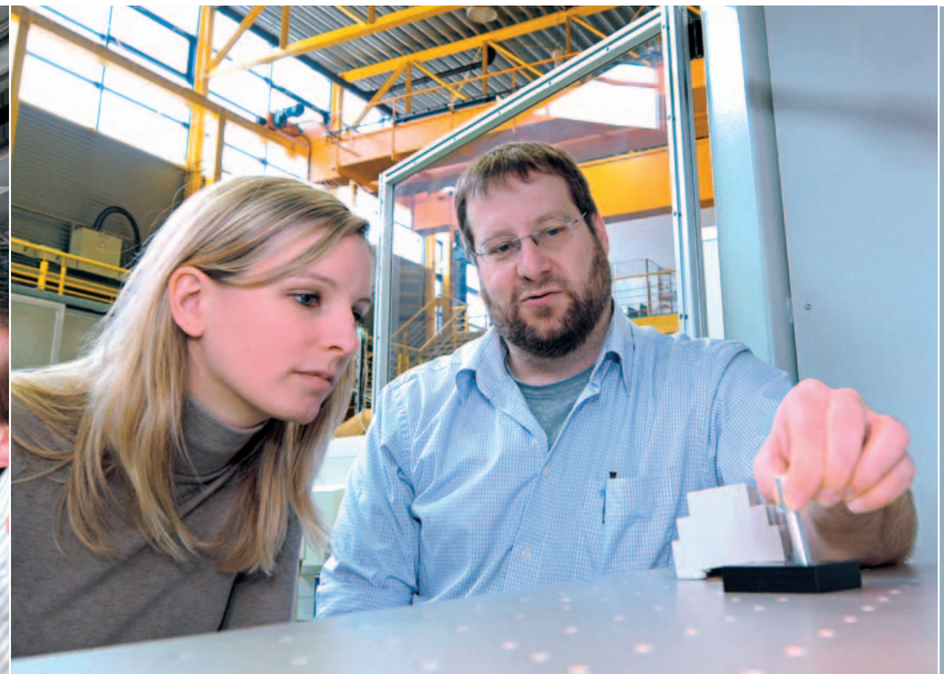


Above: Small plates with piezoelectric ceramic actuators. Using this material, vibrations can be damped. Piezoelectric ceramics deform when subjected to an electric field. This technology can be used to make aircraft quieter for the passengers.

Left: Vibrations occur when the robot slows down following rapid acceleration. Hexa 2 can move like a wrist, with six degrees of freedom.

More information:
www.DLR.de/fa/en
www.tu-braunschweig.de/sfb562

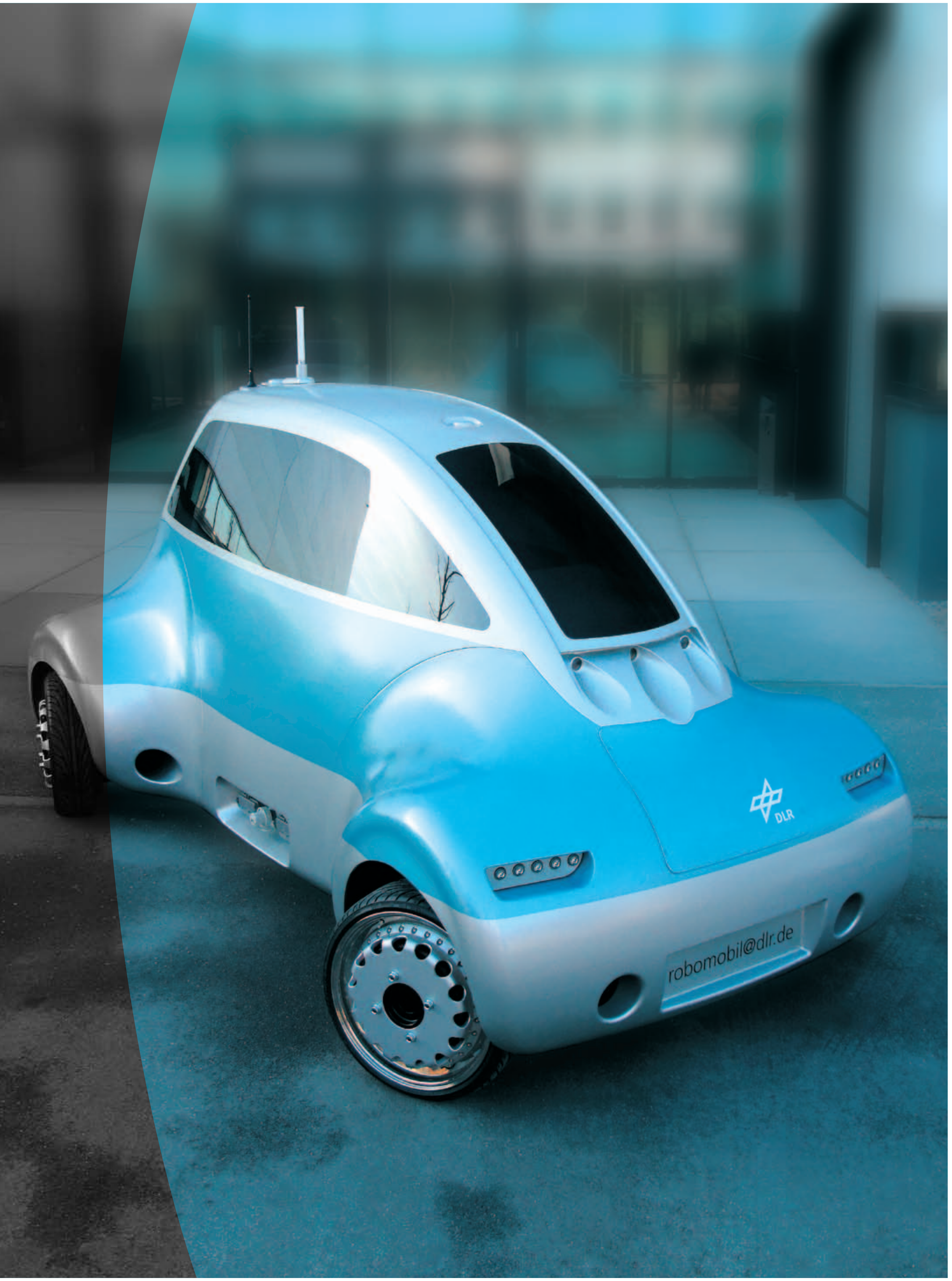




Left: Michael Rose with Hexa 2 at the Technical University of Braunschweig. Hexa 2 can travel at up to five metres per second and carry a three kilogram load.

Middle: Stephan Algermissen checks one of the joints on the Triglide parallel robot

Right: Ralf Keimer shows DLR editor Lena Fuhrmann an assembly task performed by the Hexa 2 parallel robot. The robot has to fit a metal pin into a hole. While this is easy for humans, using their various senses, a robot must be taught how to do it. This area was studied for, among other things, installation planning and monitoring.



Driving with robot technology

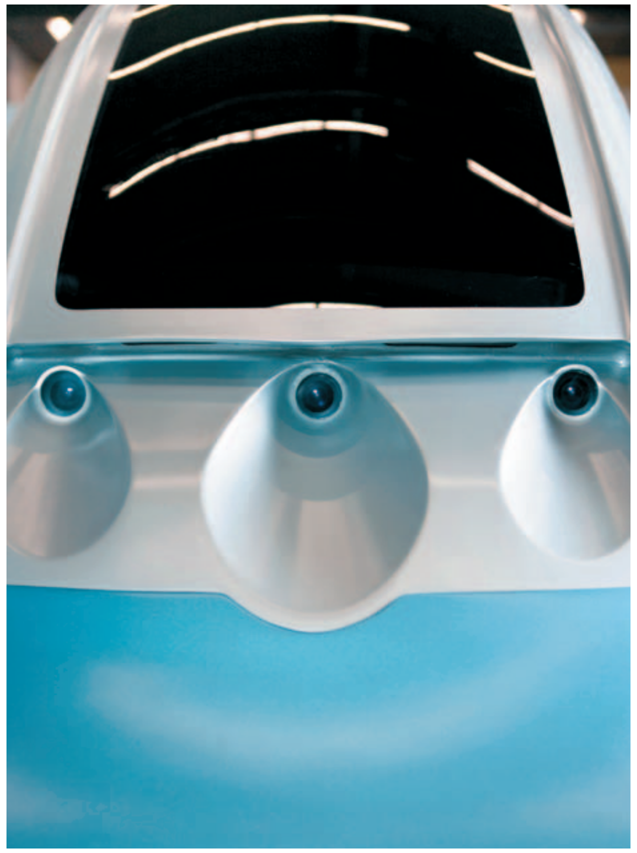
The systems concealed on or under the Robomobil's gently curving bodywork have already proven their capabilities many times elsewhere. The three lunar rovers used by the Apollo astronauts to roam Earth's natural satellite had drive mechanisms integrated into each wheel and Europe's Mars rover, ExoMars, scheduled for launch in 2018, relies on the same concept. In another parallel, the vehicle is controlled with a sidestick, the type of joystick that also steered the lunar rovers. The cameras that will be attached to the roof to survey the road ahead are already being employed to help the robot Justin catch balls. The knowledge that robotics engineers at DLR Oberpfaffenhofen have gained from modern robotic systems is also being applied to the development of this two-seater electric car. The key is to combine many different areas of expertise to produce something innovative.

Working on the urban car of the future

By Manuela Braun

The Robomobil, or ROMO: manoeuvrable, light and driving towards complete autonomy

With a click of the mouse, the Robomobil's wheels slowly turn outwards. Clemens Satzger and Neal Lii from the DLR Institute of Robotics and Mechatronics sit in front of their computer screens as they test the car's performance. The blue-painted vehicle looks a bit like a toy car on its hydraulic lift in the otherwise business-like Techlab hall. Smoothly shaped and resembling a city car, it appears almost delicate. However, nothing about this car is 'normal'. Pedals – none. Steering wheel – none. Engine under the bonnet – none. "The pedals, steering wheel and steering column are all consigned to history," says Jonathan Brembeck, dismissing them with a wave of his hand. The researchers at the Institute are the project leaders for the car, in which robotic and electric vehicle technologies are being combined. The Robomobil works differently to conventional vehicles; the steering mechanism, drivetrain and brakes are all located within its four wheels. Driver commands are not transmitted mechanically by means of pedals and a steering wheel, but via a central computer. "The pedals and steering column are always major risk factors in accidents." Without these elements, the car looks quite empty inside; other than a sidestick, similar to the joysticks used for playing computer games, and some touchscreens in the cockpit, there is nothing to be seen. Located under the chassis is a battery that could easily be replaced with a new one at a service station.



The powertrain, steering wheel and pedals in their conventional form are no longer used in the Robomobil. Cameras keep an eye on the vehicle's surroundings while driving.

The Robomobil's wheels have now swivelled to a 90-degree angle; if the vehicle were on the ground instead of the hydraulic lift, it would be able to move sideways like a crab, perpendicular to the normal driving direction. In the driving simulator, the team can test what this feels like. With Brembeck's right hand on the joystick and his eyes fixed on the display, the car moves to the left and out of the tight parking space in 'crab mode'. At first, the steering seems a bit unusual: "you get used to steering with a joystick very quickly," says Brembeck. "A steering wheel and steering column could be put back in again if necessary but, of course, a mechanical connection to the wheels is not required." Within the simulator, the screen now shows that the Robomobil has moved onto the road. A driver in a normal car would probably have had to perform several backwards and forwards manoeuvres due to the limitations imposed by the turning circle of conventionally steered wheels. As Brembeck searches in vain for the accelerator, his legs move one last time, and the virtual Robomobil drives off. Accelerating, braking, and steering all go smoothly. The next test is to turn the vehicle around in its own length, which it is able to do as well. "The Robomobil is extremely manoeuvrable," says Brembeck. This type of flexibility would be a big advantage in city driving.

The robotics engineers have drawn heavily on their own areas of expertise to design the blue electric car. Pointing to the vehicle's tyres, Brembeck comments: "the wheels were designed using the principle that a robot's main components are in its joints." The hub motor and integrated steering mechanism demonstrate the use of this principle, already well proven for robots, on a car. This system was also used for the Apollo lunar rovers and the development of ExoMars, Europe's first Martian rover. Three cameras are located at the front and rear of the Robomobil. Soon, it will carry additional cameras on the roof that will monitor the road at the sides of the vehicle, providing a stereoscopic 360-degree view. A robot known as Justin is already using this system to track and then catch a ball thrown into the air. The Robomobil should be able to perform a similar action with its cameras – that is, assess its surroundings. This will enable the vehicle to reach another goal that has already been achieved elsewhere. If a robotic arm like ROKVISS, which is on the International Space Station, can be controlled from Earth, the same should apply to a vehicle on Earth. The researchers have tested this 'telepresence' and would like to use it in the electric car as well.

The vision of the robotics researchers is of a vehicle that does most of the work for the driver or, as Brembeck explains: "we want to reduce drivers' freedom; for example, the freedom to drive less than optimally. The driver's control commands are entered into the computer, but they are optimised before being executed. For example, the human sets the destination and the machine takes over control of the route." To do this, the vehicle uses data from the camera system. The amount of freedom to be taken away from the driver will vary. Firstly, the driver can specify the actions to be taken by the vehicle using the sidestick and, as with space robotics, the instructions are refined once the Robomobil has evaluated its vicinity in three dimensions and real time. The driver can also sit outside the vehicle, at a teleoperator station, and use a remote control system to send instructions to the Robomobil, which will then execute the commands while analysing its surroundings. In the most optimistic vision, the vehicle has the maximum autonomy. "In this case, the driver enters the chosen destination and the computer then calculates the route and checks for objects heading towards the vehicle."

This might still be in the distant future, but Gerd Hirzinger, the director of the Institute, already has a very clear idea of how the Robomobil could be used. The manoeuvrable electric cars could be parked at suitable storage sites in cities and activated when required. The Robomobil would make its way to the requested location autonomously – without a driver – at a moderate and appropriate speed. The users could then use the vehicle – perhaps to go shopping – and return home with their purchases. Once their journey is complete, they would instruct the vehicle to drive back to the storage depot on its own. If something were to go wrong on the return trip, an operator could safely guide the Robomobil back to its base using a remote control.

What the vehicle will look like in the future is open to debate: "for example, the passenger cabin is completely interchangeable," explains Brembeck. The Robomobil is not a conventional compact car, but is made up of different modules. The battery, chassis and robotic wheel units can be selected as components of a modular assembly system. "The chassis is made of carbon-fibre reinforced composites, so it is extremely light," says Brembeck. This material, used in aircraft, allows the weight of the Robomobil to be minimised. The Robomobil has already completed its first driving tests inside a building. With a lithium-ion battery, its operating range should be about 100 kilometres – sufficient for the first trials.

In the Techlab hall, Clemens Satzger nods with satisfaction. All the systems on the Robomobil are responding as expected. The wheels are now turning back to their original, straight-ahead position. At present, the focus is mainly on system testing. "We want to make sure that all the vehicle functions operate correctly," explains Satzger. This is why the Robomobil spends most of its time on the car lift. From control technology to image processing, human-machine interfaces to telepresence, the project relies on teamwork and combines many different areas of robotics engineering expertise. Making the most economical use of the available energy, ensuring the reliable operation of the various systems, autonomous driving and the interaction between the braking systems are issues that no expert can work on alone. "The Robomobil is a typical interdisciplinary project," says Brembeck. "For us, as robotics engineers, it is an important research tool." ●

More information:
www.DLR.de/rm/en

The powertrain and brakes are built into the wheel. The electric car uses techniques from robotics. The robot-derived wheels can turn through 90 degrees, allowing the vehicle to move sideways.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Communication optimises traffic

Many major cities now have a traffic management centre. The high volume of traffic justifies the costs incurred for the installation, operation and maintenance of expensive traffic monitoring systems, typically employing induction loops and dynamic traffic information displays. What differentiates traffic management in smaller cities and towns is the simple fact that there is less traffic. But traffic congestion can still occur, particularly during rush hour and in the event of road works, accidents or diversions. This is especially likely near motorways, where sudden massive increases in the volume of traffic can occur. Low levels of noise and pollution are key indicators of a good quality of life, and it is precisely for that reason that the inhabitants of small towns choose to live there. A small number of major routes must function well to avoid desirable overspill into residential streets for short cuts. Lacking the funds to engage in conventional forms of traffic management, smaller towns can turn to alternative technologies instead. How can this be achieved? Birgit Pattberg, in charge of public relations activities at DLR's Institute of Transportation Systems, reports.

Mobile devices provide up-to-the-minute traffic data

Interview with Ronald Nippold


Ronald Nippold works at the DLR Institute of Transportation Systems, conducting traffic simulations and traffic management research

Are new technologies to enable small cities and towns to monitor their prevailing traffic situations in existence?

Until now, the preferred method for monitoring the traffic situation has involved placing induction loops under the asphalt, particularly at traffic lights. But nowadays it is also possible to use communication technologies such as the Global System for Mobile Communications, wireless LAN or Bluetooth to obtain traffic data. The big advantage of this is that many people now carry mobile devices such as a mobile phone, 'smartphone' or navigation system that can be tracked anonymously. This solution has great potential for small cities because it does not incur the costs of sensor operation and maintenance.

Is it possible to get a comparatively accurate picture of the traffic situation using mobile devices?

An even better one! Induction loops can only monitor a single point, for example, in front of traffic lights. But the mobile devices actually move with the traffic and can constantly provide information from the route. Using velocity profiles, we are able to determine the type of road user – car driver, cyclist or pedestrian. By combining the data from conventional sensors with the data from mobile devices, we get a greatly improved overall picture of the traffic situation.

How can traffic management benefit from this?

An accurate picture of the prevailing road traffic situation is the basis for traffic management. With this information, we can use a simulation to create a model of the current traffic situation, from which we can generate a short-term forecast. This computer model can then be applied to various adaptive traffic management measures.

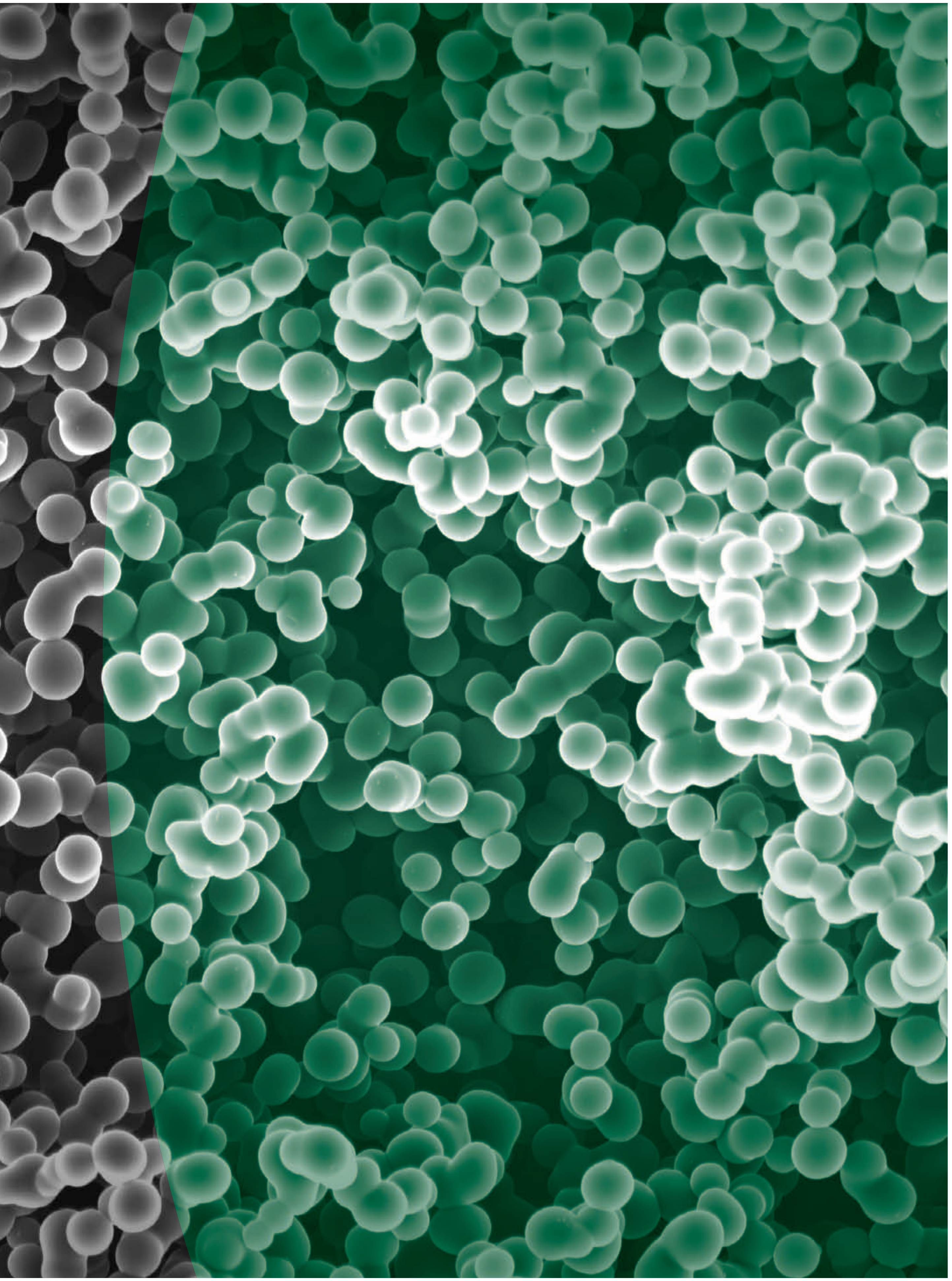
What measures are available?

It is possible to interact directly by making changes to the timing of traffic lights. Traffic light phases can be lengthened or shortened according to the volume of traffic, thereby helping to lighten congestion on the roads. Traffic can be diverted from heavily congested areas by restricting the green phase for access, making the route unattractive to drivers. This type of forward-looking traffic light control can also reduce the amount of time 'lost' at traffic lights by lengthening the green phase for approaching vehicles.

Are there alternative ways to control traffic?

Essentially, up-to-the-minute traffic data obtained across a large area can ensure that traffic is diverted from highly congested areas and distributed better across the road network. With this system, drivers will be able to adapt their route accordingly, before and even during a journey, and expensive panels displaying information about traffic congestion will no longer be needed. •

More information:
www.dlr.de/fs/en

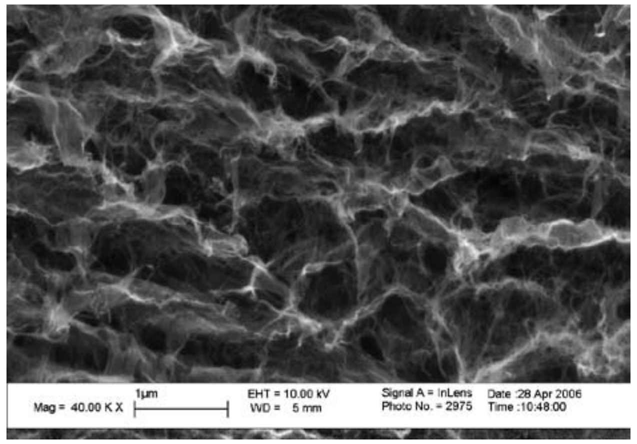


World's lightest solids

They might have a somewhat mysterious appearance, resembling mist or smoke at first glance, yet aerogels are quite solid. These extremely light materials attenuate sound and have very low thermal conductivity. Some types are translucent, looking like projections or holograms. Aerogels have a wide range of applications that have not yet been fully explored. Their versatile nature makes them particularly interesting for DLR Technology Marketing, which supports the development of aerogel products for various industrial markets.

Low density and many other extraordinary physical properties make aerogels extremely useful

By Lorenz Ratke and Tilmann Tack



Aerogels can look like frozen smoke. The carbon aerogel shown here was created from a cellulose aerogel by heat treatment at 1000 degrees Celsius in the absence of air.

Typical three-dimensional cross-linking in an aerogel, shown here in a plastic aerogel. Particles ranging in size from a few nanometres to a micron across are interconnected at their points of contact.

The main component of aerogels is air, which is surrounded by an extremely fine solid network structure. It is possible to develop aerogels with only three times the density of air, while being capable of bearing one thousand times their own weight; they are some of the lightest known solids. Aerogels combine many interesting and useful properties that usually exist separately in other materials. For example, many silica aerogels are almost as transparent as glass, possess a thermal conductivity lower than that of polystyrene or polyurethane foam, and can have very high specific surface areas like those found in activated carbon or carbon nanotubes. Their uniqueness lies in the combination of these various physical properties in one material that is also able to employ different chemical compositions. Important aspects can be combined for a wide range of uses, such as thermal insulation, optical applications, sensors, catalysts or substrates for catalyst delivery.

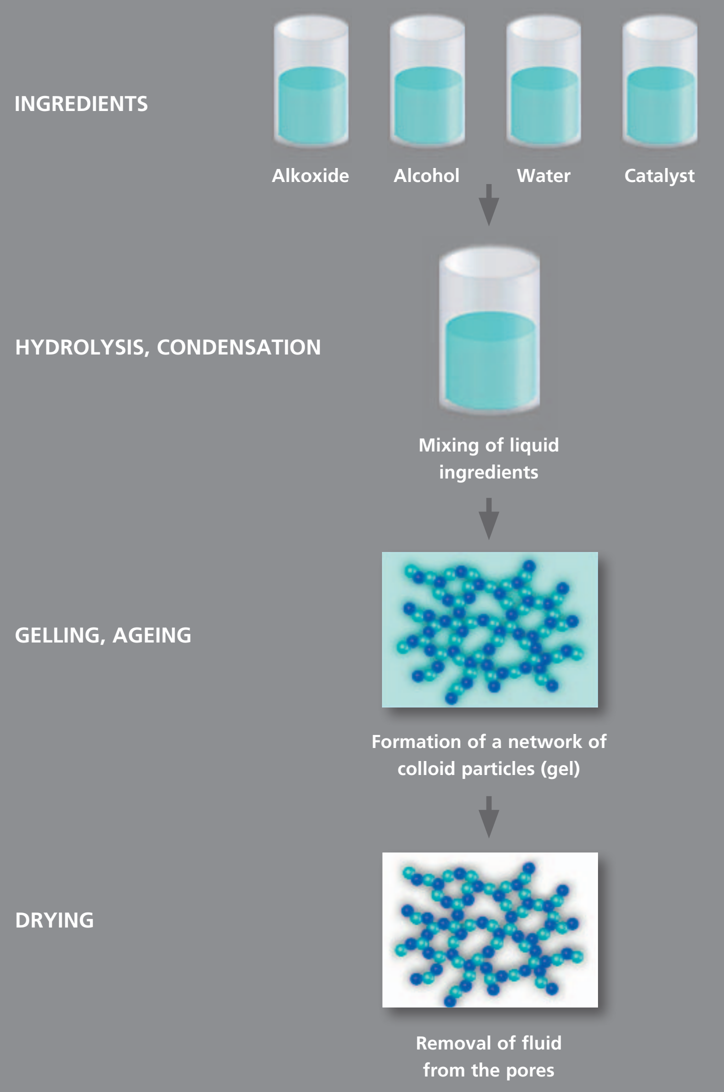
Contrary to what people may think, aerogels are not a product of recent research. The first scientific papers on the development of aerogels date back to the 1930s. Even then, their discoverer found that an aerogel could be made from anything that can be gelled. The challenge during manufacture is to retain the network of solids in the wet gel in a form that is as close as possible to its original configuration by using special drying processes and eliminating liquid from the system without shrinking the structure. One solution, discovered at an early stage of the research, was supercritical drying, a process that must be carried out in an autoclave under high pressure (about 100 bar) and slightly above room temperature. But the disadvantages of this technique are its complexity and high cost.

Although researchers seeking to develop aerogel manufacturing methods have made great progress, their use in marketed products is still limited. Cost-effective and efficient manufacturing processes are the key to bringing new aerogel-based products to market and finding a wider range of everyday applications for these unusual materials.

WHAT ARE AEROGELS?

Aerogel is a generic term for highly porous solids in which up to 99.98 percent of the volume consists of pores of empty space. Various types of aerogel can be manufactured from different initial ingredients. The different physical properties of individual aerogels and their reactivity depend largely on the type, shape and size of the pores. The manufacturing process and the chosen ingredients determine the particular structure of the network of pores and solid material. Silicate-based aerogels are the most commonly manufactured and used.

For many applications, plastic- and carbon-based aerogels can also be produced. In principle, any metal oxide or polymer, as well as other substances, can be used as a basis for aerogel synthesis using the sol-gel process. The random, branching, three-dimensional gel network is usually formed by the condensation of colloidal particles.



Aerogels are produced using the sol-gel process. The ingredients shown in the image are mixed until a clear liquid is formed. This liquid is left to settle until a gel with the consistency of dessert jelly forms. The process of gel formation is the result of chemical reactions between the ingredients. The particles formed by the reaction move through the liquid, eventually coming together and interconnecting. When this network structure extends across the entire vessel, a gel results. If the liquid is removed from the pores in this wet gel, the result is an aerogel.

Innovative materials for space, energy and transport

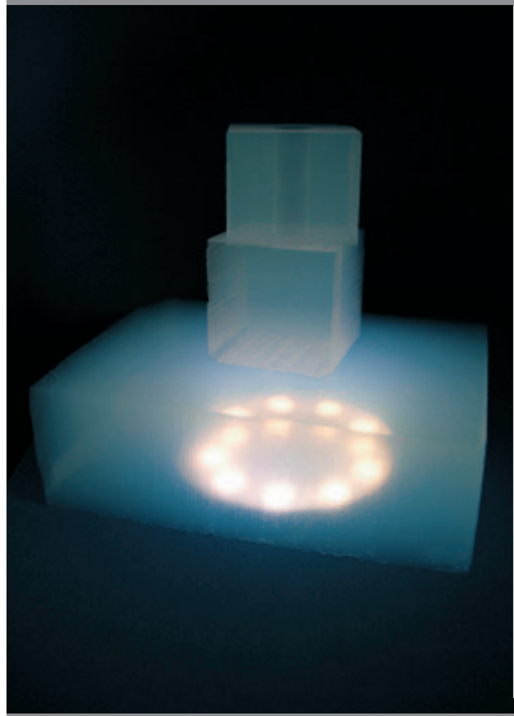
At the DLR Institute of Materials Physics in Space, research is being conducted into both new aerogels and aerogel composites; improved and more cost-effective manufacturing processes are also under development. The team is working on applications in various areas of interest to DLR, such as superinsulation for space, energy technology, lightweight construction, transport systems and a matrix material for artificial bones. Aerogels are also of great interest to various industrial sectors such as foundry technology.

Aerogels are produced in various forms, mostly as sheets or granules. The granules are used as bulk material for insulation or as an additional component in glass fibre mats, textiles and mineral wool. The silica-based granules most commonly used today are brittle, crumbling under stress and releasing very fine dust. These properties can be altered by the choice of ingredients and pore structure, enabling the resulting component to undergo elastic deformation. Cellulose- or silica-based aerogels can be made as flexible as rubber if minor chemical changes are made to the ingredients. Aerogels can also be given additional properties; for example, the surface can be made strongly hydrophobic by exchanging the OH groups normally used in glass aerogels with methyl groups. Aerogels with magnetic properties can be produced by chemical vapour deposition of magnetic layers in the pore space of the gel.

The combination of many useful properties in one material makes aerogels appealing to a wide range of applications, including specialist uses for which no other material with the required properties exists, and standard or mass-market applications for which aerogels are a convincing choice for technical or economic reasons. A considerable amount of research and development is still required, especially for aerogel composites, but also for new types of aerogel and cost-effective manufacturing processes. One thing is certain; if research, development and technology transfer work hand in hand, these mysterious materials will have what it takes to surprise us with additional applications in the near future. ●

About the authors:
Lorenz Ratke is the deputy director of the DLR Institute of Materials Physics in Space. His research focusses on aerogels and aerogel composites.

Tilmann Tack is a member of the scientific staff at DLR Technology Marketing. He analyses future markets and the potential for technological innovations based on DLR's expertise.



Aerogels might look like frozen smoke or fog, as seen here with a silica aerogel

Aerogels can be transparent, as seen here with a silica aerogel

AEROGEL APPLICATIONS: FOUR AREAS OF DLR ACTIVITY

FOUNDRY MOULDS
Casting moulds must have the capacity to withstand the thermal and mechanical loads they are subjected to during the casting process and must have smooth surfaces. Often made of sand, the moulds must not introduce any grains into the casting or be penetrated by the molten metal. The foundry supply industry has developed binders for every type of sand and for various casting processes. However, casting quality and productivity can be significantly improved by using aerogels. Adding even small amounts of aerogel granulate to the sand can make the casting less rough and facilitate the separation of the casting cores. DLR has devised a number of applications, has been granted numerous patents and cooperates with foundries in this area.

AEROGEL CONCRETE
This construction material, developed at DLR in recent years, is made by dispersing superhydrophobic aerogel granulate in a standard concrete mix. Aerogel concrete is very light and its thermal conductivity can be as much as eight times lower than standard concrete. Other advantages of aerogels are their exceptional resistance to fire (exceeding the requirements for European class F120 fire protection) and good sound insulation properties. DLR is currently collaborating with several construction material manufacturers to introduce aerogel concrete into industrial use.

SUPERINSULATION
In space systems, aerogels could help to insulate cryogenic storage tanks. Polyurethane foams are normally used for tanks containing liquid hydrogen or oxygen – for example, the external tank on the space shuttles – but they become brittle at low temperatures. The insulation properties of flexible aerogels can be up to five times better. Flexible silica aerogels are being tested at DLR; they will be used in space applications, in cooperation with partners across Europe.

COMPOSITE MATERIALS
Aerogels are being used to develop new composite materials at DLR. This primarily involves embedding aerogel granulates in fibre-reinforced materials. These materials have low thermal conductivity, but are mechanically stable and cannot be compressed as easily as felt-like materials.

ADDITIONAL APPLICATIONS

Thanks to their exceptional thermal insulation and sound attenuation properties, aerogels can be used in the construction industry as **construction or insulation material** in the form of aerogel concrete or in **vacuum insulation panels**. Inside the panels, the aerogel acts as a solid support and prevents both convection and the transmission of infrared radiation. The disadvantage of vacuum insulation panels is their fixed dimensions; they cannot be cut to size. Aerogels provide excellent insulation, even if the vacuum in the panel is lost due to damage.

Aerogels are already being used as an insulation material in the oil industry. Unless **undersea pipelines are insulated**, the viscosity of the oil being pumped through them increases and it may partially solidify due to the low temperature of the surrounding water; innovative insulation prevents this.

Aerogels with a low refractive index are almost transparent. They can be used as components in **windows** and offer unique thermal insulation properties. Aerogels can also be used as purely optical elements in **architecture**; when introduced into twin-wall sheets in granulate form, they diffuse light and prevent the casting of shadows.

Aerogels can also be used as an insulator in **sports shoes**, safety boots or thin, high-tech **outdoor jackets**. Here, superhydrophobic aerogel granulates are dispersed in textile felts or fabrics. The felt is compressed when bearing the weight of a human body, so the aerogel particles are pushed closer together and the insulating effect is increased. Insoles made of aerogel-reinforced textiles offer up to 200 percent better insulation than the best conventional materials.

Aerogels can be used as substrates for **pharmaceutical agents**. Various active ingredients can be introduced into the pores of aerogels without them crystallising. In such an amorphous form, the agents are dissolved and absorbed by the body faster and more completely. Aerogels made of cellulose, alginates or starch are excellent drug substrates and are, in many cases, superior to conventional ones.

Carbon aerogels have important applications in **electrical components** and **electrochemistry**. Their high electrical conductivity and mechanical stability play a major role in materials research for electrodes in primary batteries and fuel cells, vehicle catalytic converters and supercapacitors. The ability of aerogels to contain an enormous reactive surface area in a small volume is also of interest. For example, the adsorption of water molecules by aerogels can be employed in humidity sensors.

Due to their fine structure, aerogels can also be used as a **matrix for collecting the smallest particles**. They were used on the Stardust mission to capture cometary samples and interstellar dust. The particles and molecules were decelerated slowly enough to avoid thermally altering their physical properties. Undamaged material from a comet was successfully returned to Earth for the first time. In high-energy physics, aerogels are used as **detectors** for Cherenkov radiation.

Flexible wings – the smarter way to fly

The skies are getting crowded: air traffic volume increases by five or six percent per year, exerting stress on people and the environment, especially at places where aircraft take off and land. To make aircraft as environmentally friendly as possible, DLR scientists have identified research goals involving cross-disciplinary collaboration to be attained within the next few years. It is becoming crucial to minimise the aerodynamic drag experienced by aircraft and to reduce noise and pollutant emissions. Lightweight morphing structures are a key technology within this effort; they adapt the wing profile to suit the aerodynamic conditions during low-speed flight while enabling maximum lift during take off and landing. Researchers at the DLR Institute of Composite Structures and Adaptive Systems, alongside partners in industry, are using intelligent high-lift technology to pave the way for the eco-friendly, sustainable aircraft of the future.

Morphing structures will provide high lift for future airliners

By Markus Kintscher and Olaf Heintze

The leading edges of aircraft wings will provide optimum air flow in the future. DLR researchers are giving them the ability to vary their shape and adjust the air flow.

The aircraft of tomorrow, operating in airports close to cities, will have to be substantially more quiet and fuel-efficient. These characteristics of airliners are influenced in a major way by the high-lift devices at the leading and trailing edges of their wings. High-lift devices on today's airplanes, like the Airbus A320, generally consist of flaps on the trailing edge of the wing and slats on the leading edge. The flaps and slats are deployed during take off and landing to generate the necessary lift during these low-speed flight phases.

Conventional high-lift devices do, however, have some disadvantages; in particular, they are incompatible with future designs for laminar flow airfoils and are a source of noise once deployed. To reduce aerodynamic drag on the aircraft of the future, researchers hope to achieve laminar flow over their wing profiles, on the upper as well as on the lower side, which could reduce drag by up to 12 percent. But this type of smooth, non-turbulent flow requires a very flat, gapless, high-quality surface; this cannot be achieved with the deployable high lift devices in use today due to the interruptions they create on the surface contour of the wing, even when not deployed. In addition, extending the slats during landing opens gaps through which air from beneath the wing flows to the upper surface; this generates noise, which needs to be prevented. Researchers are actively pursuing solutions that will allow laminar flow over the wing profile while ensuring the necessary lift during take off and landing.

One alternative to conventional slats – referred to as Smart Droop Nose – is a morphing, gap-free leading edge, which is being investigated in the framework of the German national project Smart Leading Edge Device, SmartLED, in collaboration with partners Airbus, EADS-Innovation Works and Cassidian Air Systems. The idea is quite simple; instead of using slats, the structure of the leading edge is distorted so that a similar curved contour is created, but without a gap. The required lift can then continue to be delivered by lowering the leading edge, but without generating noise; at the same time, the smooth contour of the wing profile enables turbulence-free airflow.

Simultaneously flexible and rigid structures?

The difficulties of this idea come out of the conflicting requirements it presents. The structure has to be flexible and resilient enough to withstand the large deformations required without sustaining damage, but it must also be very rigid to support the heavy load it is subjected to. During landing, about a third of the weight of the aircraft must be borne by the leading edge.

Designs and concepts for structures that are flexible but at the same time rigid have been investigated by research groups around the world since the beginning of aviation. A large number of patents and designs aimed at offering solutions for various applications exist, but there has yet to be a design that can actually be used on aircraft. The main disadvantage of the concepts developed to date is their weight. To meet the requirement for flexibility, an extremely soft material such as a silicon polymer is generally used for the skin of the wing. The low stiffness of the skin requires support from a more complex and therefore heavier internal mechanism to withstand external loads. The solution involves finding a compromise between a load-bearing skin and a simpler mechanism for displacing the leading edge.

As an initial step, a suitable material had to be found to solve this conflict and prove its general feasibility. The investigations focussed mainly on glass- and carbon-fibre reinforced composites, materials often used in the aircraft industry. Those materials possessing great flexibility combined with the highest rigidity possible were of particular interest. Numerous tests and calculations finally enabled the selection of a suitable glass-fibre reinforced material.

A leading edge that can adopt the desired shape on its own

No less important than the selection of a suitable material is the underlying concept: how will the fibre-reinforced composite external structure and the internal mechanism interact to achieve the large deformations of the leading edge needed? Various concepts for implementing a morphing leading edge structure were simulated and assessed in collaboration with partners Airbus, EADS-IW and Cassidian. The most promising approach involved bent rather than stretched fibre-reinforced skin to keep the stress on the material as low as possible. Through the use of a special arrangement of individual layers, the structure of the skin incorporates a tailor-made stiffness distribution. This varying stiffness allows the leading edge to deform into the desired lowered or drooped shape.

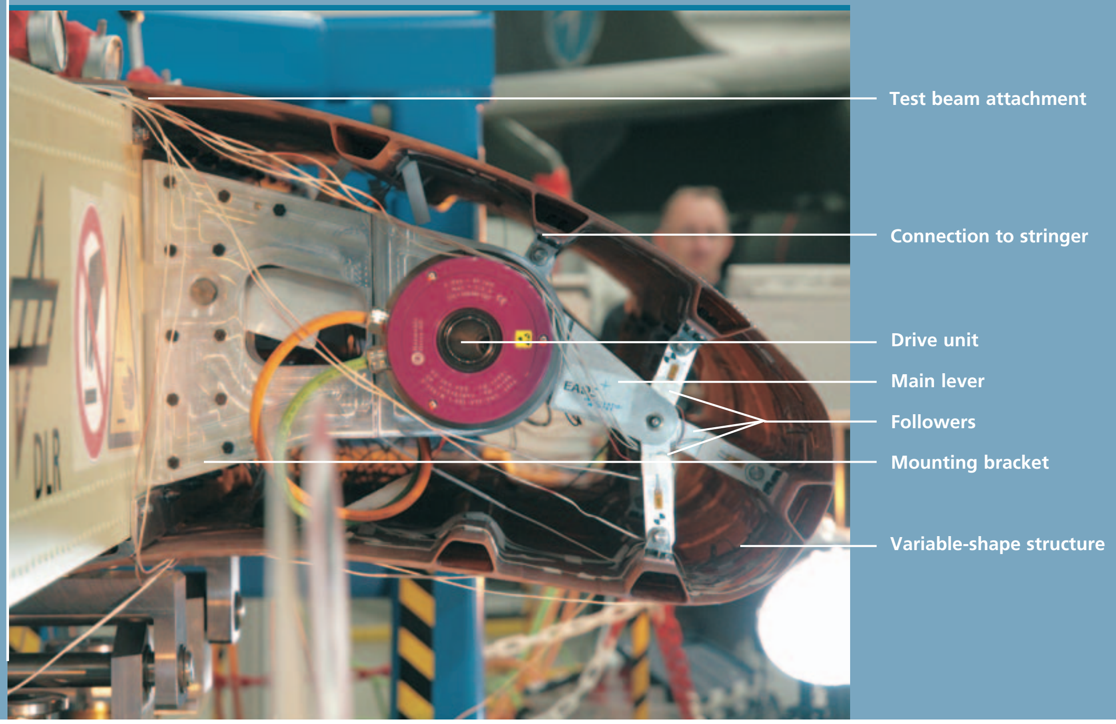
To increase stability, this 'smart' skin structure is reinforced with longitudinal stiffeners, known as stringers, running spanwise. These supporting elements are used simultaneously as a structure for the transmission of forces into the skin and as an interface for the actuation mechanism displacing the outer skin structure. During the course of the work it quickly became evident that only very closely coordinated development of the outer fibre-reinforced structure of the leading edge and the internal actuation mechanism would be successful. Unlike conventional structures, the individual components in the selected concept for this variable-shape system – the leading edge structure and the displacement mechanism – are unstable. Only when the individual components are combined will the system acquire the stability and rigidity needed to morph in the desired manner.

Simulation, ground testing and final testing in the wind tunnel

During the design and optimisation of the morphing structures, simulations were used to identify especially critical locations in the structure. Because of the high demand for the smoothness of the structure's surface, standard fastening techniques, such as rivets, could not be used. The areas where the stringers are bonded to the skin structure are especially critical. For this reason, representative sections were selected for manufacturing, and the substructures tested. The test results were integrated into the simulations, which were then repeated using three-dimensional models to acquire information on the damage characteristics of these bonds.

After evaluating these results, the first large-scale ground tests were conducted on a two-metre wide section of the variable-shape leading edge at a scale of 1:1. The main goal was to demonstrate that a three-dimensional variable-shape leading edge is feasible and functional even during wing bending. These measurements enabled the validation of the design method developed for any variable-shape structure. The researchers obtained important information about the characteristics of the morphing leading edge. The Smart Droop Nose is now being optimised and developed further, especially with regard to industry requirements such as lightning protection, de-icing and bird strike.

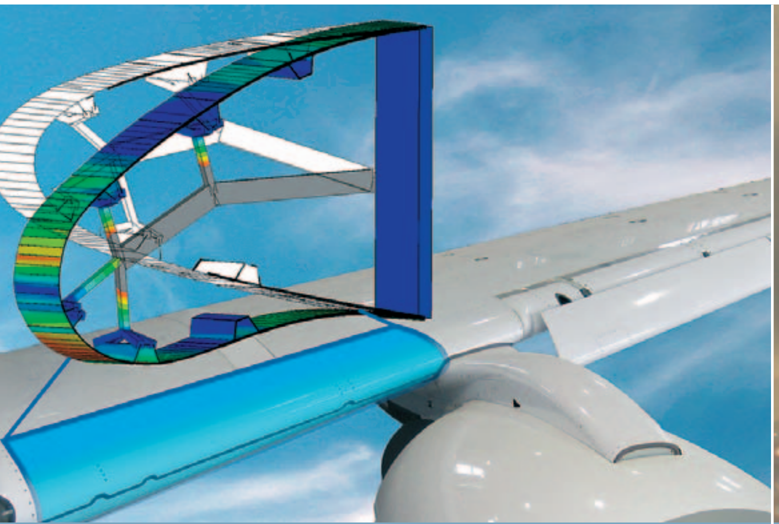
In addition to ground testing, a wind tunnel test will be carried out in November 2011 in one of the biggest wind tunnels in Europe as part of the European 'SmArt High Lift DEvices for Next Generation Wing', SADE, project, in collaboration with the Central Aerohydrodynamic Institute, TsAGI, in Moscow. The test will show the functionality and effectiveness of the system under realistic flight conditions. ●



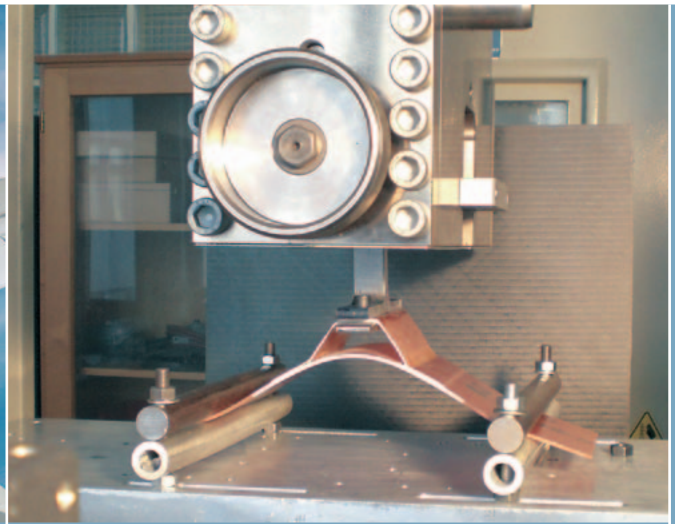
About the authors:
Olaf Heintze, currently working at Invent GmbH, Braunschweig, was previously head of the high lift team at the DLR Institute of Composite Structures and Adaptive Systems and coordinator of the SmartLED project, from which the results in this article were obtained.

Markus Kintscher was responsible for the design, evaluation, construction and testing of variable-shape leading edges in the SmartLED project and is now continuing Olaf Heintze's work as coordinator of the high-lift team at the DLR Institute of Composite Structures and Adaptive Systems.

More information:
www.DLR.de/fa/en
www.smr.ch/sade



Simplified simulation model of the concept of a morphing leading edge



Stringer undergoing testing to determine the strength of the adhesive bond to the flexible skin

A 1:1 scale variable-shape leading edge model at the test facility undergoing simulation of wing flexure corresponding to a pullout manoeuvre at 2g. The test item is coated to facilitate optical measuring techniques.

Boxing clever

Airfreight containers carry items of freight and protect them. Deutsche Post DHL, the market leader in the international logistics industry, uses them to reach some 120,000 destinations worldwide. To make airfreight transport more environmentally friendly and cost-effective, the weight of these unit load devices needs to be minimised and, at the same time, they need to become more robust. Deutsche Post DHL collaborated with DLR to achieve this objective. As part of a feasibility study for DHL Solutions and Innovations, DLR's Institute of Composite Structures and Adaptive Systems developed concepts for a container of the future. The outcome was a weight saving of 30 percent.

Lighter freight containers save fuel and reduce pollutant emissions

By Ivonne Bartsch

This is a weighty issue: the containers under study are able to transport up to six tons of freight distributed over a surface area of six square metres and weigh from 200 to 300 kilograms. Between 18 and 25 containers can fit on the main deck of a cargo carrier, depending on the type of aircraft. To increase freight capacity and reduce fuel consumption, the empty weight of these unit load devices must be kept as low as possible. Airfreight containers are regularly put through harsh treatment. On a daily basis, they are pushed along roller beds and ball tracks and, while being moved or stored in the open air, are exposed to wind and changing weather. They are also prone to damage when being moved by forklift trucks. Common repair practices increase the weight of the container and are costly and time consuming. For this reason, DLR's study focussed primarily on lightweight construction and robustness.

The greatest potential for reducing weight is in the base of the container, which weighs close to 100 kilograms. The new design for the base plate consists of a sandwich structure delivering a combination of great strength and decreased weight. Since this material is also less prone to bending, loads are distributed more evenly throughout the container and aircraft loading system. A combination of materials consisting of fibre-reinforced composites, elastomers, pressure-resistant core materials and a wear-resistant surface layer delivers a high-quality, lightweight and robust structure capable of withstanding the main stresses and strains caused by the rollers in loading and transport systems.

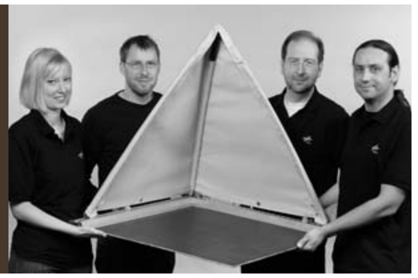
The DLR concept includes side panels made of a lightweight technical textile. The flexible properties of this material make it more resistant to damage. It is no longer necessary to replace damaged containers or send them to specialist companies for repair work. Any repair can be performed on a simple and low-cost basis, with the operation conducted on site. Radio frequency identification technologies also become much more straightforward to use because electromagnetic waves are able to pass through the fabric. Textile side panels can be adapted to suit any external contour required and are therefore suitable for any type of container.

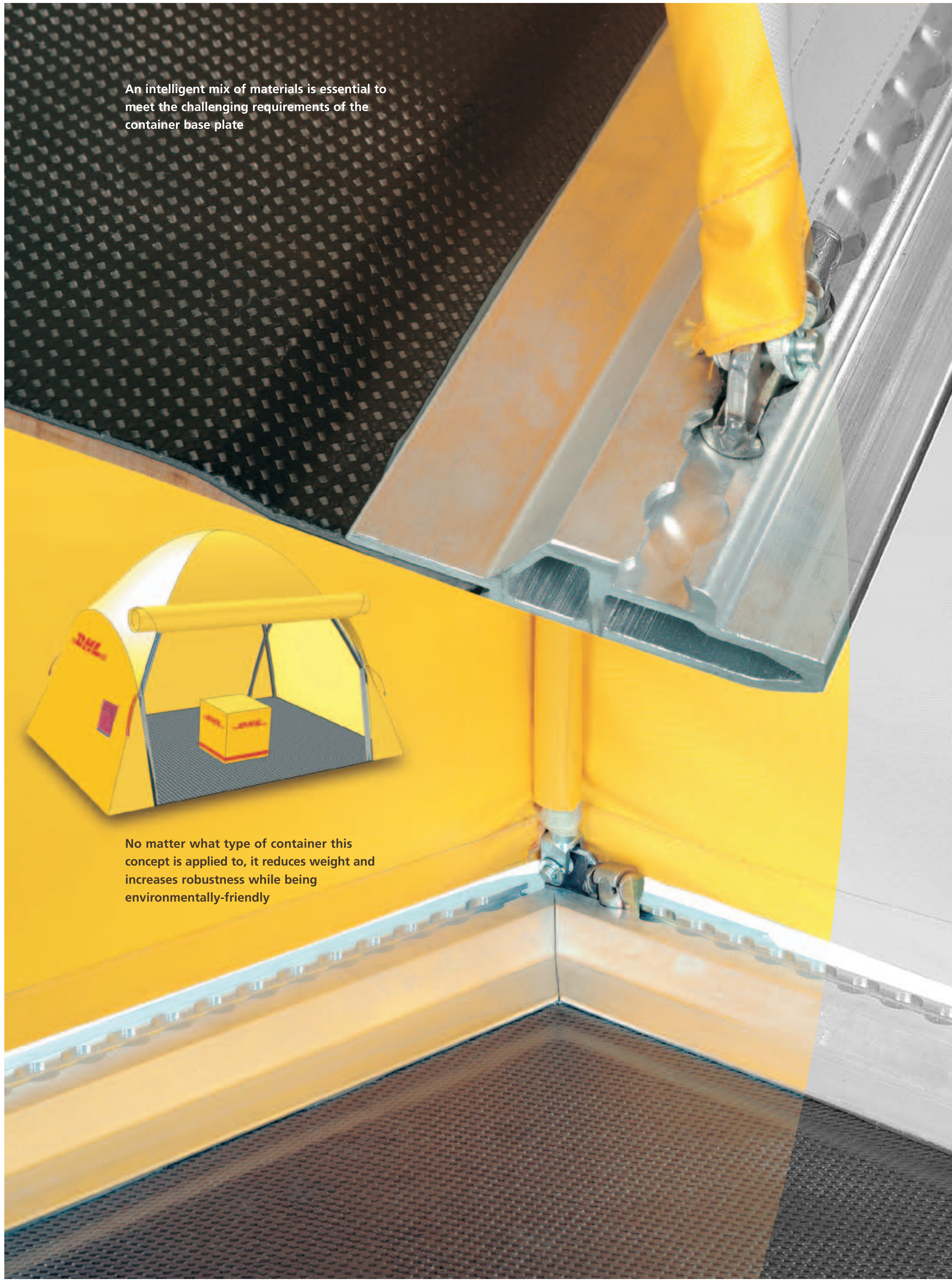
This new concept makes it possible to achieve weight savings of at least 30 percent. A one kilogram saving of airborne weight reduces annual emissions of carbon dioxide by close to 200 kilograms; this adds up to a 285-ton saving of carbon dioxide per aircraft per year. The simplified repair methods, robust construction and fuel savings associated with lightweight structures also reduce operating costs for the user.

About the author:
Ivonne Bartsch works at the DLR Institute of Lightweight Structures and Adaptive Systems. She is a researcher in the Composite Design department, where she has been working on airfreight container design since 2009.

More information:
www.DLR.de/fa/en

The container team, from left to right: Ivonne Bartsch, Olaf Mierheim, Jörg Nickel and Christian Ückert with a demonstration model of a container corner





An intelligent mix of materials is essential to meet the challenging requirements of the container base plate

No matter what type of container this concept is applied to, it reduces weight and increases robustness while being environmentally-friendly

The expedition crew sharing a meal in the middle deck of Space Shuttle Discovery during mission STS-124

A new dimension in space medicine

By Rupert Gerzer

Rupert Gerzer is the director of the Institute of Aerospace Medicine at DLR Cologne and also professor and chairman of the Institute of Flight Medicine in the Faculty of Medicine at RWTH Aachen University, Germany

A quarter of a century ago, the German D1 Spacelab mission gave the country's life scientists greatly enhanced opportunities to perform research under space conditions. At that time, the primary purposes of the space life sciences were to identify and understand the phenomena associated with weightlessness, mitigate health risks for astronauts and develop new equipment that could be used for experiments in space, but would have applications on Earth as well.

Research under microgravity conditions can also serve a different purpose; it can be used to determine whether concepts and hypotheses formulated under conditions on Earth still apply in the absence of gravity. If we encounter problems when providing medical assistance to astronauts, it generally means that the underlying scientific concepts, as developed on Earth, are incorrect. Space research can help us identify the problems in our current knowledge and focus on solving them using research, both on Earth and in a microgravity environment. Separating Earth- and microgravity-associated research would be counterproductive for such an approach.

A case in point of joint terrestrial and space research: for over 50 years scientists believed that the regulation of salt levels in the human body was understood, but studies carried out on astronauts during their stays in space and in similar long-term isolation experiments here on Earth have certainly taught us a lesson. We have learned that fluid and salt levels do not conform to the textbook definitions, according to which intake and excretion always run in parallel. In weightlessness, large amounts of salt can be accumulated without water being retained in the body. In addition, salt not only gives rise to an increase in blood pressure, but intensifies the loss of bone mass as well. This is not just the case with astronauts; these seem to be basic mechanisms at work in all healthy humans, whether on Earth or in a weightlessness environment.

These findings have a variety of consequences. Firstly, the results strongly influence our concepts about how the human body functions. A completely new research area has also arisen – the study of interactions between a wide range of control mechanisms in the human body. This will also require many strictly controlled, standardised studies on healthy subjects here on Earth with an approach that is normally taken only in space medicine. What is more, research on the International Space Station will help to test these new concepts in weightlessness conditions in close interaction with laboratory studies on Earth.

It is already apparent that this research is the starting point for new concepts in prevention and treatment, as well as new medicines for conditions such as high blood pressure, osteoporosis and arteriosclerosis. With recent findings additionally showing that the salt balance in the human body and the immune system mutually interact, we will also be able to gain a better understanding of the immune system. The potential economic impact of these new findings is enormous. It is therefore important that, over the next few years, we recognise and take advantage of the one-of-a-kind opportunity that the International Space Station has opened up by providing a basic medical research laboratory in orbit.

Undertaking this type of research is probably much more important than focussing on short-term spin-off strategies. ●

Station to station

Sergei Krikalev holds the world record for cumulative time spent in space: 803 days, 9 hours and 39 minutes. Elisabeth Mittelbach travelled to Star City, north-east of Moscow, to talk to the Chief of the Yuri Gagarin Cosmonaut Training Centre and look back at 10 years of research on the International Space Station and some of the thrilling experiences of being a 'wanderer between worlds'.

Ten years of research on the ISS: veteran cosmonaut Sergei Krikalev remembers

By Elisabeth Mittelbach

ISS Expedition 11 (15 April to 11 October 2005): the moment when Commander Sergei Krikalev opened the hatch to Space Shuttle Discovery to welcome the crew of the Space Shuttle mission STS-114. Krikalev's second ISS stay won him an all-time record of 803 days and nine hours and 39 minutes spent in space.

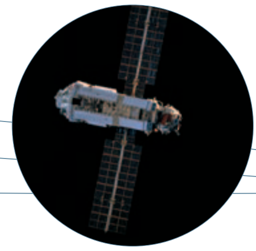
Sergei Krikalev appears in the doorway of the European Space Agency's liaison office in Star City (Zvedny Gorodok), Russia's cosmonaut training centre for 50 years, ready to talk about his three decades of space research and industry experience – two of which have been spent as a cosmonaut. Star City is a place where history still feels very close – one of its most famous inhabitants is the widow of Yuri Gagarin, the first person to fly to space in 1961. Following in the footsteps of Gagarin, Sergei Krikalev has also made it into the history books for one notable reason: he set out for Mir in May 1991 as a citizen of the Soviet Union, and in March 1992 returned to Earth as a citizen of the newly-formed Russian Federation.

In spite of his fame, Sergei Krikalev remains firmly down to Earth. "The political situation was unusual in the summer and autumn of 1991, but our daily conversations with the ground staff filled us in on what was going on. I knew that hundreds were looking after us and we were not afraid of being forgotten. We were self-sufficient; we had food, water and solar energy. I could even say that we were less affected by the political situation than anybody else," he recalls. "What concerned me most was that my stay on Mir was extended twice. I was supposed to return to Earth in November 1991, but since I was the only cosmonaut with experience in long-duration spaceflight, I had to stay on until March 1992."

Krikalev's extraordinary work on the Russian Mir, at the Russian Federal Space Agency (Roscosmos), and his experience working as part of international teams resulted in his participation in a number of international space missions. On his third space flight in February 1994, he became the first Russian cosmonaut to embark on the US Space Shuttle Discovery.

He then went on to work at NASA's Mission Control Centre under the Shuttle-Mir Program. His fourth space mission was STS-88, on Space Shuttle Endeavour. This mission saw the first two modules of the International Space Station, Zarya and Unity, get linked together.

11/1998



12/1998

In December 1998, the crew of STS-88 began active construction of the ISS. This image shows the docking of the US-built Unity module with the Russian module Zarya. Sergei Krikalev was on board.

Cosmonaut Sergei Krikalev was on board the ISS for the last time in 2005, as the Commander of ISS Expedition 11

Having lived on both outposts, what are the most important differences and similarities between Mir and the International Space Station? "The living and working conditions are very similar. Like the International Space Station, Mir consisted of various modules, and we used different sets of equipment at different times. Mir hosted some international missions as well. On my first flight, for example, I worked with the French astronaut Jean-Loup Chretien. Mir was a Russian station with Russian equipment and international participation, just as the originally planned Space Station Freedom was a US station with international participation. In this regard, the ISS is different because it is a truly international station. Roles might differ, but all partners are involved in decision making."

As far as Krikalev is concerned, the main benefit from the ISS project is "to learn to cooperate as best as we can. The ISS is the biggest international project of its kind at the moment. We are very happy to have been involved in it from the very beginning and to see it develop so successfully." The project offers opportunities to learn more about space and Earth, about adaptation to life in space under a range of conditions, and to address fundamental questions in physics and biology. "To achieve these objectives, we had to combine the best technology and resources available from the various ISS partners. For instance, Canada was responsible for the ISS robotic arm due to its extensive experience in space robotics. At present, ESA and Roscosmos are collaborating on the design of a robotic arm constructed in Europe – the European Robotic Arm." ROKVISS, a DLR-developed robotic arm, was mounted on the ISS's Russian service module, Zvezda, until November 2010, when it completed its five-year mission.

For Krikalev, an engineer from St. Petersburg, it is not the scientific experiments that present the greatest challenge, but the construction and maintenance of the Station itself. "It was our responsibility to know how to install every item and to collaborate with one another. Before the launch, we tested how everything fit together to make sure it would work properly on board. But it was not until we were in flight that we were able to actually test everything."

The first scientific experiments carried out on the ISS were biological and medical. "The most exciting experiment during my first ISS expedition in 2001 was the plasma crystal experiment run jointly by Germany and Russia. A prototype of that experiment had previously been installed on Mir and on the ISS. Such experiments are being conducted to this day. Shortly before I became the Commander of Expedition One, a new set of equipment was ready, and we were trained to use it here at Star City and at the Max Planck Institute for Extraterrestrial Physics in Munich."

Sergei Krikalev, Star City, December 2010

An unrivalled career in space

Sergei Konstantinovich Krikalev has unrivalled familiarity with the most complex international space projects in human history. He has served on both the Russian Mir (Russian for Peace) space station as well as the International Space Station, ISS. Mir orbited Earth from 1986 until 2001 when it was brought down in a controlled re-entry and splashdown, while the ISS has been growing bit by bit since 1998, and is due for completion in December 2011.

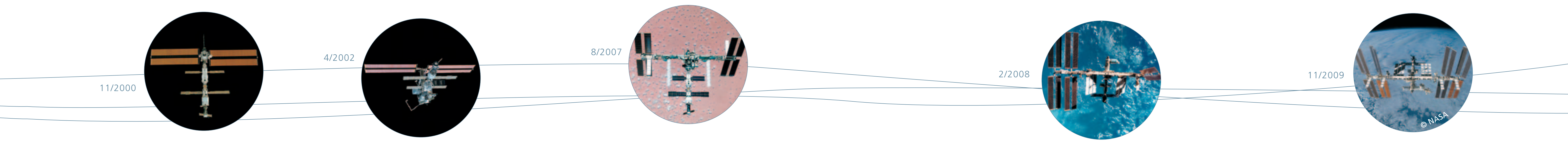
From November 2000 to March 2001, Krikalev was a member of the first long-duration crew on the ISS, serving as a flight engineer. During his sixth and last spaceflight between April and October 2005, Krikalev was the Commander of ISS Expedition 11. Based in Saint Petersburg, he has been in charge of the Yuri Gagarin Cosmonaut Training Centre since 2009. 52 year-old Krikalev spends his leisure time performing flying stunts, swimming, cycling, and operating an amateur radio. He has been awarded several international titles of honour including 'Hero of the Soviet Union' (Geroy Sovyetskogo Soyuza) and 'Hero of the Russian Federation' (Geroy Rossiyskoy Federatsii).

In his opinion, is being an astronaut more about being a scientist or engineer? "In many cases, we play both roles at the same time. On the one hand, we are engineers, but we play the role of scientists when conducting experiments. This is why part of our preparation deals with the theory underlying the experiments. The scientists in our laboratories on Earth design, construct and evaluate the experiments. For example, we didn't just activate and deactivate the plasma crystal experiment; we collaborated closely with the Principal Investigators on the ground. We supplied them with data, and they decided what the next steps should be. It was an excellent team, and we were part of it."

Although he is aware that travelling into space and spending prolonged periods of time there has potentially serious health effects including causing bone and muscle changes, Krikalev is nostalgic for his days in orbit and would relish the chance to test new space transportation systems and see Earth from the finished ISS once again. "I saw the Station for the first time 10 years ago, when it consisted of only two modules. I saw it again in 2005 when it was half finished, and now it is complete. I miss the stunning views, the sunrises and sunsets, the mountain ranges and beautiful lakes, the chance to see Africa one second, and Australia or Paris the next." On the other hand, if Krikalev did fly again, he would miss his family and friends and the ability to hold a 'normal' conversation, without millions of others tuning in. "Astronauts are a little like sailors," says Krikalev. "At sea, they miss the land, and when they have firm ground under their feet, they are drawn to their ship again."

How did he get to where he is? "I became a cosmonaut because I had an intense curiosity about space and about what happens outside of Earth. I obtained a degree in Mechanical Engineering, and once I began working for the space industry, I was given the chance to become a cosmonaut." And what now? "If I could find someone to substitute me as Director of the training centre in Star City, I would work as a full-time cosmonaut again." ●

More information:
www.jsc.nasa.gov/Bios/htmlbios/krikalev.html
www.nasa.gov/mission_pages/station
www.DLR.de/iss/en
www.federalspace.ru



Cool like astronauts

The 'Mission X: Train Like an Astronaut' project, an initiative involving 15 space agencies, was launched at the DLR_School_Lab in Cologne, Germany, at the beginning of this year. Its aim was to encourage children between the ages of eight and twelve to follow the example of astronauts, exercising and eating healthily because, according to a report by the World Health Organisation, obesity in children and young people is one of the most important health problems of the 21st century. To kick it off, 60 boys and girls came to the DLR school laboratory in Cologne and were given pointers by Reinhold Ewald, an astronaut at the European Space Agency, among other experts. In total, 131 teams from nine countries and 3800 children are taking part in the project; 300 of these schoolchildren are from Germany. Alisa Wilken attended the launch event on behalf of the DLR Magazine. She is studying technical journalism at the Bonn-Rhein-Sieg University of Applied Sciences, and has recently completed a three-month internship at DLR's Corporate Communications department where, among other things, she prepared this report.

Train Like an Astronaut – an international schools programme launched at DLR

By Alisa Wilken

How does a spacecraft work? Where does gravity go in orbit? How do you stay fit and healthy there? These are the things that aspiring astronauts need to know.

"Yuck!" echoes through the large centrifuge hall as Richard Bräucker, head of the DLR_School_Lab in Cologne, projects his next image onto the wall. It shows five sealed transparent packets with distinctly unappetising contents. The 60 school children watch sceptically. That is what astronauts have to eat? No, thank you. But it's too late to go back. The mission has begun! The menu may appear unpromising but the fascinating prospect of learning about the practical business of floating in air and looking down on the Earth from 350 kilometres in orbit should make up for that.

Those wanting to go to space must eat healthily and be perfectly fit, as weightlessness can really make you lose strength. The goal of this mission is to stay in shape through careful nutrition, following the example set by astronauts. From among the 3800 participants, there will be one winner from each of the nine participating countries.

"That will make you even fatter!" shouts one of the 60 students, mesmerised in front of the screen showing an astronaut preparing a meal while floating in the air. "I'm getting to that now," says Bräucker, as he starts the next film. For the next six weeks, the experienced student laboratory manager will be the leader of Mission X, which in Germany is based at DLR in Cologne. The screen now shows a young man firmly strapped to a bicycle while pedalling steadily. His clothes and the assorted objects floating around him suggest that this is most likely an astronaut in the International Space Station.

'Train like an astronaut' is the mission's slogan and by now the students have all come to know why. Those who don't move around or exercise in space will, not only gain weight, but also come to face an entirely different problem. Without gravity the body doesn't have to bear any weight, and muscle tissue and bone mass soon dwindle as a result. Therefore, the astronauts on the International Space Station must exercise for two hours every day to stay fit.

Pulling on the big black glove and reaching into the experiment box on the Space Station, just like real astronauts

Mission X begins with weightlessness

Off we go! All that is left is for Bräucker to wish his aspiring astronauts good luck and send them on their mission. One of the groups of the Maximilian-Kolbe High School in Cologne immediately charges to the first station: weightlessness. There, the students wait for Alexander Francke, a chemistry and materials science student that helps out with experiments at the DLR_School_Lab. Today he is conducting a weightlessness experiment using a mini drop tower to demonstrate what happens to different objects in the brief moment of weightlessness during their free-fall. The first test object is a flask with air and water. Ten-year-old Benedikt and two other students prepare the experiment. The flask and a small camera are attached to the drop tower. With the push of a button on the computer, it falls. The image obtained with the camera clearly shows a bubble of air moving to the centre of the flask. This phenomenon now requires closer analysis.

A few metres away, a group of students almost tumbles to the ground in eagerness. With all their strength, the students tug on a short piece of rope with a steel ball in the middle. But no matter how hard they try, the steel ball, consisting of two halves held together only by compressed air, remains firmly shut. This experiment dates back to 1654. The hemispheres used then were larger, but even the strength of 16 horses was not enough to separate them. University student Florian Bärenfänger comes to the rescue of the straining, red-faced students. Holding the rope with the still intact ball, he places one half on the floor and stands on one end of the rope to hold it tight. Then he bends his knees. "The right technique does the trick," he explains, as he pulls on the upper half of the ball. With a loud pop, the ball splits into two halves. Impressed, the students can't wait to try it themselves, but time is up and they must move on to the next demonstration. Among the other matters being probed, what happens if you expose a balloon to vacuum?

The entire morning is spent performing research and experimenting. The students are so spellbound that they are hardly aware of how fast time is passing. With the word 'stop' the experiments cease. It is now time for a lunch break, and the students are relieved to see that, instead of the astronaut food they were shown, they will in fact be eating baguettes, fruit and sweet pastries. By the time they are done eating, the food is almost completely gone. Clearly, research makes you hungry.

But there is no time to rest. The next item on the programme is already displayed on the big screen, informing the groups where to go next. One half of the students goes straight to the next experiments. The other half goes into the European Space Agency's Astronaut Centre, just a few metres from the centrifuge hall at the DLR site, where 16 astronauts from various ESA member states train with colleagues from the United States and Russia; definitely a good place for aspiring astronauts.

As the group enters the foyer, all eyes turn to the ceiling. Above their heads hangs a model of the ISS with the European Columbus module attached. Standing right below it, Jules Grandsire waits for them. He heads off with the group straight away to show them what astronauts must go through and to give the boys and girls an incentive to persevere. When they reach the first door he shouts: "stop!" A yellow board with black letters reads 'Authorised Personnel Only'. "Do you see that?" he asks. "Not everyone can go in here." But today is an exception. Grandsire leads them to an enormous indoor swimming pool, some 10 metres deep. It is an important training tool for the astronauts because, in water, the body behaves similarly to the way it does in weightlessness, so the astronauts can practise performing tasks and procedures under comparatively realistic conditions.

Columbus up close

Next stop: the training hall. At the back is a full-size replica of the Columbus module, which the students are now free to explore. A metal staircase leads up to the entrance, where astronaut Reinhold Ewald is waiting for them. He has already been to space and can tell the student astronauts all about the International Space Station and help them with their mission. He shows them the sleeping bunks on the Space Station and where some of the experiments are conducted. All of the students want to try on the large black gloves attached to the glass case of the Biolab apparatus, like real astronauts. Reinhold Ewald also shows them one of the items of exercise equipment used by astronauts in microgravity: a metal bar attached to the wall of the station by two strong elastic straps. In weightlessness, the astronauts can put their feet against the wall, lift the bar and pull it 'upwards'; a bit like lifting weights.

Time is gradually running out and the group must return to the centrifuge hall for the next assigned experiments. The students head back quickly and are rewarded with some fascinating practical demonstrations. University student Sabrina Seiler shows them what happens to a balloon when it is immersed in a container full of liquid nitrogen, while fellow student Francke shows them how paramecia lose their orientation in a state of weightlessness. The students are left wondering what to do with the deep-frozen balloon. "Can we tip out the nitrogen?" asks one in the crowd. Immediately, they are all excited. Bräucker smiles. "But of course. We'll do it outside." The aspiring astronauts have to stand back. With the liquid nitrogen at a temperature of minus 196 degrees Celsius, they might get a bad case of frostbite – one of many facts they have learned over the course of the day. Sabrina steps forward and empties the container out onto the small courtyard in front of the DLR_School_Lab. Dense white clouds of mist pour out onto the ground and spread quickly. Then Bräucker gives the all clear and the students charge forward, jumping and running through the slowly vanishing mist.

That was just the start of the mission. Over the next six weeks, the aspiring astronauts can expect more tasks that will make them break into a proper sweat. Strength, stamina, coordination, balance and good spatial awareness will be required, and teamwork will be essential. They will all need to learn a lot to complete the mission. But once they've done it and everything falls into place, they can become winners in more ways than one. Learning to make healthier choices over the course of Mission X will be a prize for life. ●

More information:
www.DLR.de/schoollab/en
http://trainlikeanastronaut.org

Mars' moon Phobos, as seen through the 'eyes' of the DLR operated High Resolution Stereo Camera on board Mars Express in January 2011

New light on the Martian satellites

By the mid-nineteenth century, astronomers at the observatories of the European royal courts had a remarkably accurate picture of the Solar System; they were familiar with the orbits of all eight known planets, of some of the larger asteroids and even of a few of the comets. They knew that Jupiter and Saturn, gas giants in the outer reaches of the Solar System, were themselves being orbited by several natural satellites. The inner Solar System appeared to have just one planet with a companion satellite; the Earth, with the Moon. Was this apparent fact one more indicator of the uniqueness of our home planet? Some astronomers were not entirely convinced. On 18 August 1877, US astronomer Asaph Hall peered into the largest refracting telescope of its time, the 26-inch Great Equatorial refractor, to discover two small, similarly-sized bodies orbiting the planet. Hall named the two bodies Phobos and Deimos after the sons of Ares, the Greek god of war; their names translate as fear and terror. Today, scientists at DLR are paying particular attention to Phobos, the larger of the two Martian moons. Most of their accumulated knowledge comes from images returned to Earth by the High Resolution Stereo Camera on board the European Space Agency's Mars Express spacecraft.

Mars Express and Phobos-Grunt

By Jürgen Oberst and Marita Wählisch

The origin of the two moons of Mars remains unclear. At present, three hypotheses have been proposed. The first hypothesis, stating that the satellites could be captured asteroids, follows from spectral analyses suggesting that the moons' composition closely matches that of carbonaceous chondrites, a special type of stone meteorite coming from what are known as C-type asteroids. Reflecting only about seven percent of the sunlight received, Phobos is one of the darkest objects in the Solar System. C-type asteroids can contain up to three percent carbon and are considered to be very ancient and pristine, virtually unchanged since the birth of the Sun. Phobos' irregular shape also tends to support this first theory.

The second hypothesis proposes that Phobos and Deimos were formed by gigantic collision impacts on the Red Planet. Martian surface material was ejected into space and this debris would have agglomerated to form the moons.

The third theory suggests that Phobos and Deimos were formed at the same time as their parent planet. Their orbital characteristics lend weight to this hypothesis: both moons have nearly circular orbits around Mars' equatorial plane. For reasons of orbital dynamics, these characteristics render the theory that the moons were asteroids captured by the gravitational pull of Mars. Obtaining the answer to the origin of these moons will be of fundamental importance to planetary science.

According to the third hypothesis, Mars and its satellites would share a similar composition. If that is the case, why is Phobos' density only 1.87 grams per cubic centimetre while Mars exhibits a figure of 3.93 grams per cubic centimetre? Could this indicate a high level of porosity? Particularly

Phobos and Deimos trace equatorial, almost circular orbits around Mars

Phobos lies at a distance of approximately 9400 kilometres from the centre of Mars and orbits the planet in about 7.6 hours. Deimos lies 23,500 kilometres from Mars' centre and completes an orbit in roughly 30.3 hours. Both moons are irregularly shaped, with bodies that can very approximately be described as tri-axial ellipsoids, with radii 13, 11.4 and 9.1 kilometres for Phobos, and 7.8, 6.0 and 5.1 kilometres for Deimos.

noteworthy in this context is Stickney, the largest of the impact craters on Phobos. With a diameter of approximately eight kilometres, it is only slightly smaller than Phobos' longest axis, measuring 13 kilometres. An impact capable of forming such a gigantic crater on the surface would probably have torn apart a rigid chunk of material. But Phobos didn't break up when the crater formed; this could be due to its rubble-pile nature.

The fate of the two moons

Phobos and Deimos travel around Mars in what is known as synchronous rotation, always presenting the same hemisphere to the surface of Mars. In particular, Phobos is exposed to powerful tidal forces by the gravitational field of the planet. Models of Phobos' orbital development show that, in the not too distant future, it will be torn apart by these tidal forces, becoming a ring of debris that will spiral towards Mars and may, ultimately, crash into its surface. Deimos faces a different fate; it is not destined to impact Mars like its sibling. Rather, it is slowly moving farther away and may eventually leave the orbit of its parent planet, never to be seen again. The moons' short remaining lifespan casts further light on their origin. Phobos and Deimos could be the last remnants of what may once have been a much larger population of Martian moons.

The first photographs of the two moons were taken back in 1971 and 1972 by the US Mariner 9 spacecraft. The data obtained during the close flybys performed by the US Viking Mission (1976 – 1980) allowed scientists to, for the first time, calculate the size and shape of the moons. Further observations were made by the Soviet Phobos 2 spacecraft (1988 – 1989), Mars Global Surveyor (1996 – 2006), and by the Mars Reconnaissance Orbiter (since 2005). Observations were also carried out directly from the surface of Mars using the cameras on Mars Pathfinder (1996 – 1997) and on the two Mars Exploration Rovers (since 2003).

The European Mars Express is currently the only spacecraft able to perform close flybys of Phobos. It has done precisely that 156 times to date, at distances ranging between 100 and 5000 kilometres from the Martian moon. This has enabled image data to be collected for 80 percent of its surface. The images have achieved resolution levels of up to four metres. Just one area on Phobos' anti-Mars side has managed to elude attempts to photograph it on a regular basis; this region was either not in the field of view, or was simply too dark during each flyby. But the data obtained with Mars Express is truly unique, including stereo, colour and high-resolution images, all acquired during close encounters. The data from Phobos and Deimos is being carefully studied by planetary geodesists at the DLR Institute of Planetary Research. These images have made it possible to improve the previous models of the orbits of Phobos and Deimos, and are now being used internationally. They have even made it possible to determine the fluctuations in the rotation rate of Phobos with greater precision. With the help of this new orbital data, Mars Express flybys of Phobos can now be scheduled much more accurately. An example, when a large fraction of the southern hemisphere of the moon was imaged on 9 January 2011. The sensors were active for a total of about a minute per sensor; Phobos was in the field of view for only nine seconds.

The planetary geodesists at DLR are also analysing the stereo images and are in the process of compiling a catalogue in which its surface features are being grouped into a control point network. Using the data from Mars Express, it has been possible to extend the existing network for Phobos from 300 to 600 control points. As a result, the resolution has been improved by a factor of four.

The new maps of Phobos, created from geo-referenced, individual images, are accurate to a resolution of 12 metres, and clearly show just how severely cratered its surface is. A very striking feature is the presence of many long grooves on the surface of Phobos. Were these caused by primary impacts? Gravity is almost 2000 times less strong on Phobos than on Earth. Could a piece of rock ejected after the impact of a meteorite have 'hopped' across the surface and caused these grooves? An alternate theory suggests that the grooves could be caused by material ejected from the surface of Mars after the impact of a gigantic meteorite. Another possibility involves the grooves being tectonic in origin and a result of internal structural tensions within the moon. The new data also enables this unusual geological feature to be mapped and measured precisely. DLR researchers are also evaluating the colour data obtained with Mars Express; in these images, the surface material appears mostly reddish, while the underlying substrate material at the edges of large craters has a slightly bluish tinge. Precise mapping not only provides a basis for geological interpretation of the images, but is also important in the preparation of a near-future mission to the satellite: Phobos-Grunt.

Looking to the future: the Phobos-Grunt mission

The Russian Phobos-Grunt spacecraft is scheduled for launch from the Baikonur Cosmodrome in Kazakhstan on board a Zenit-2 launch vehicle in November 2011. It will carry the Chinese spacecraft Yinghuo-1, or 'Firefly', designed to study Mars' gravitational field and external environment for one year. Phobos-Grunt is the Russian name for 'Phobos Soil'. The title of the mission defines its objective; the unmanned lander will collect material from the surface of Phobos and return a soil sample in a capsule, planned to reach Earth in August 2014.

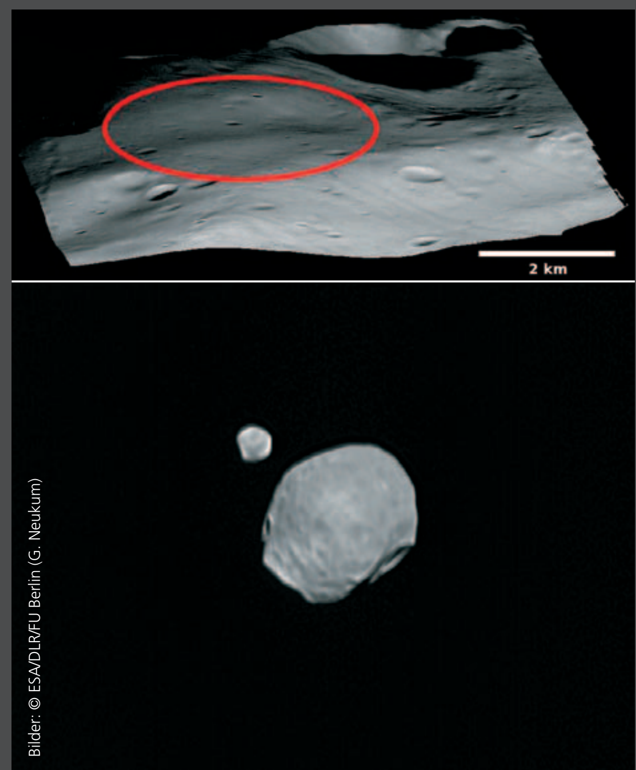
To study the environment prevailing in Martian orbit, Phobos-Grunt will carry 15 instruments, including a radar and several cameras and spectrometers. The anticipated landing site on the anti-Mars side of Phobos will be analysed very precisely before landing. The spacecraft will also trail behind the moon in its orbit around Mars before it lands. The landing sequence itself is scheduled to last only 40 minutes. To perform this complex manoeuvre, the module will be guided by laser, radar and imagers. The spacecraft will then have just 17 minutes to collect samples with its robotic arm because, during this short period of time, the landing site will be lit and contact with Earth assured. The return module, carrying about 200 grams of sample material, will then blast off from the surface and embark on its return journey to Earth. The remaining landing module, carrying a range of scientific equipment, will continue to work on the surface of Phobos for one year.

The preparations for the Phobos-Grunt mission and the subsequent data analysis will be carried out jointly with Russian colleagues from the Laboratory for the Research of Extraterrestrial Territories at the Moscow State University of Geodesy and Cartography, and the Laboratory of Comparative Planetology at the Vernadsky Institute of Geochemistry and Analytical Chemistry at the Russian Academy of Science. ●

The programming of the acquisition sequences for the Mars Express camera is carried out at the DLR Institute of Planetary Research. For the Phobos flybys, the experiment team must plan particularly thoroughly, since the orbital data for the moon is constantly being updated and improved.

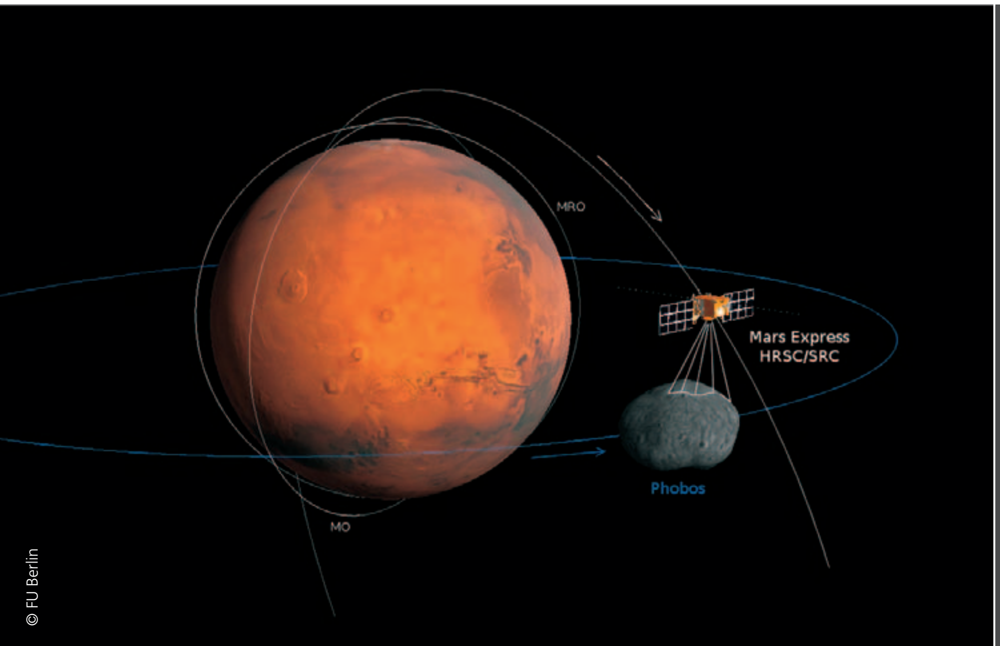
About the authors:
Jürgen Oberst is Head of Planetary Geodesy at the DLR Institute of Planetary Research, and leads an international group of experts in the study of the Martian moons, Phobos and Deimos. Marita Wählisch is a cartographer at the same Institute.

More information:
www.DLR.de/pf/en
www.DLR.de/Mars/en

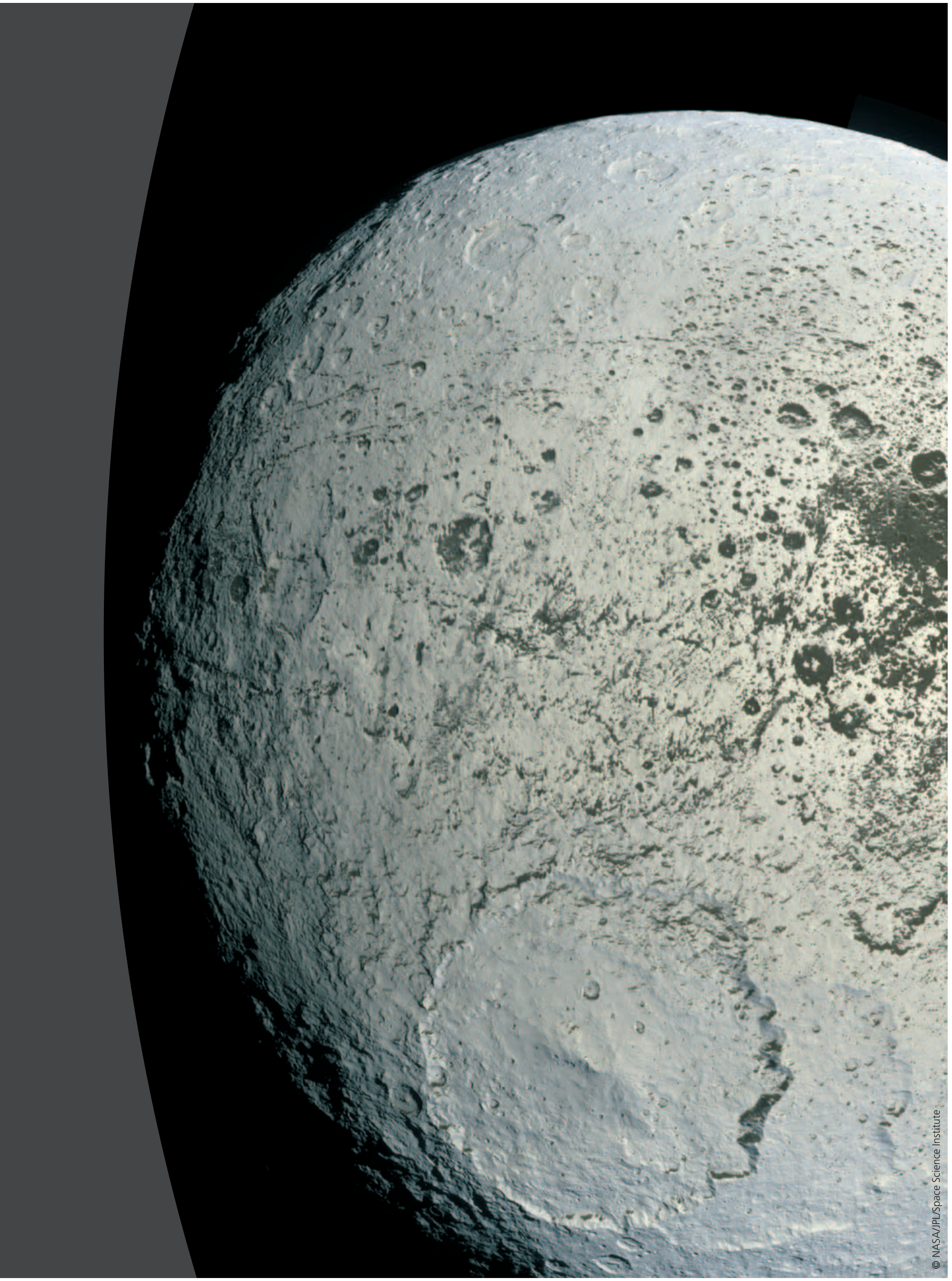


In red: the planned landing site for Phobos-Grunt. Below: Phobos and Deimos directly after each other - a rarely documented event that the Mars Express camera captured on 5 November 2009.

The Phobos-Grunt spacecraft, built by NPO Lavochkin in Moscow. A return capsule will bring samples from Phobos to Earth in 2014.



Since Mars Express flies in an elliptical orbit around the Red Planet, it regularly moves away from Mars and approaches Phobos to distances of up to 100 kilometres. This image shows the positions of Mars, Phobos and Mars Express on 9 January 2011 at a distance of 100 kilometres. The moon was only in the camera's field of view for nine seconds.



Black and white moon

For the past seven years, the Cassini spacecraft has been orbiting Saturn, the second largest planet in the Solar System. Currently one of NASA's flagship missions, it is providing a constant stream of data that is increasing our understanding of the gas giant planets and their natural satellites. During the course of its observations, Cassini has made exciting discoveries, not only about Titan and Enceladus, but also about Iapetus, one of the outer moons of Saturn. The mission has revealed that Iapetus is truly extraordinary; the ancient and cratered moon has two faces and a striking topography dominated by an equatorial ridge with peaks at least 13 kilometres high, extending for more than 4600 kilometres around it. Researchers at DLR are involved in the exploration of Iapetus, which was discovered in 1671 by Jean-Dominique Cassini – after whom the mission is named.

Saturn's moon Iapetus is black on one side and white on the other – and that is not its only extraordinary feature

By Ulrich Köhler and Bernd Giese

DLR's contributions to the Cassini mission

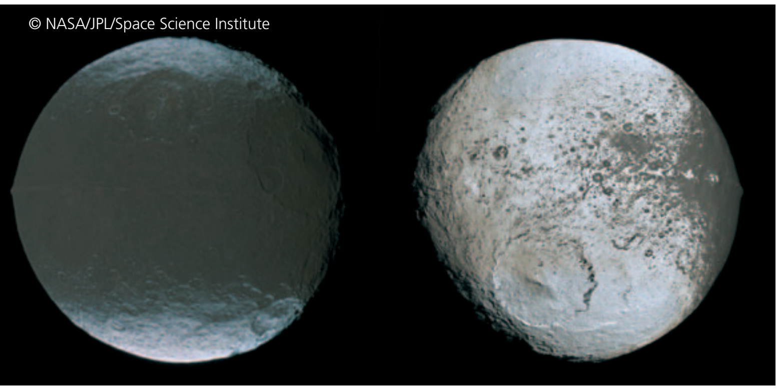
The DLR Institute of Planetary Research is heavily involved in two of the twelve experiments on board Cassini. Some of its researchers are part of a team examining the mineralogy and geochemistry of the moon's surface using a visible light and near-infrared spectrometer. Others are participating in the mission's Imaging Science Subsystem experiment. In addition, DLR has been entrusted by the mission's imaging team with compiling surface atlases for all of Saturn's large icy moons except Titan, whose surface is hidden by a dense atmosphere.

Early observations of Saturn revealed more than just the amazing rings in the equatorial plane of the planet; with the discovery of a family of large satellites in orbit around the gas giant - which had previously been observed circling Jupiter as well - astronomers began to speak of two 'Solar Systems in miniature'. This finding contributed a great deal to understanding the evolution of the Solar System as a whole. Today, amid the great age of space exploration, the planets in the outer Solar System can be examined at close quarters. The first close-up images of some of Saturn's moons, acquired by the two now legendary Voyager probes in 1980 and 1981, prompted NASA and the European Space Agency to initiate a more intensive exploration of the Saturnian system with the dual spacecraft Cassini-Huygens mission.

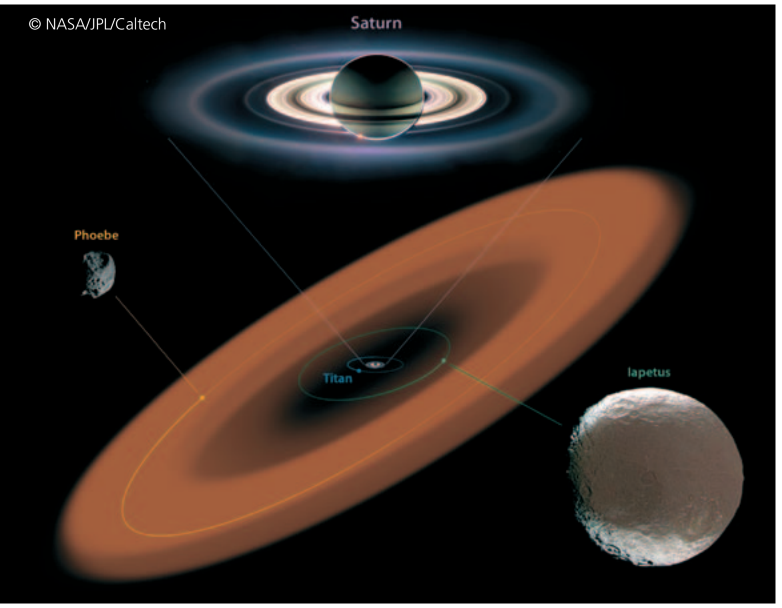
The moon Iapetus is named after one of the sons of Gaia, the Greek goddess personifying the Earth, and Uranus, the personification of the sky. With a diameter of almost 1500 kilometres, it is Saturn's third largest moon and a remarkable celestial body in many ways. Iapetus' rotation period of 79.33 days is unexpected considering it orbits Saturn at a distance of 3.5 million kilometres. It is always showing the same 'face' to its host planet, just as the Moon does to Earth. Referred to as 'synchronous rotation', this is a consequence of an interaction between the moon and Saturn known as tidal locking, and is somewhat unusual given the large distance from its host planet.

Iapetus' measured density of 1.09 grams per cubic centimetre and its unique surface spectral signatures suggest that the moon must be composed predominantly of water ice. With surface temperatures reaching as low as minus 220 degrees Celsius, it is certain that there is no liquid water beneath the surface, as might be the case with Titan and Enceladus, the two geologically active moons of Saturn. There is probably no core of silicate minerals in Iapetus.

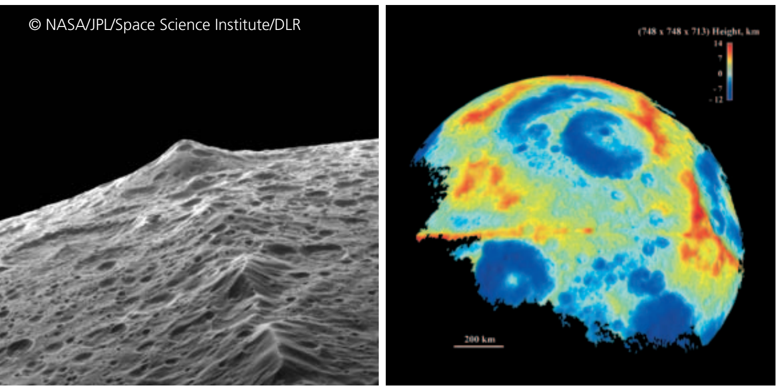
The strikingly bright trailing side of Saturn's moon Iapetus was first photographed in high resolution in 2007. Cassini acquired this image while its camera was facing against the direction of flight around the planet. The 500-kilometre wide impact crater Englier is clearly visible.



No other body in the Solar System has such sharply contrasting hemispheres as the 1500-kilometre diameter moon Iapetus. The leading hemisphere, the one facing in the direction of travel as Iapetus orbits Saturn – shown on the left – reflects only about five percent of the incident sunlight. The two poles and most of the trailing side – on the right – reflect more than 50 percent of the incoming sunlight.



A steeply inclined torus-shaped cloud of very small ice and dark dust particles, originating from impacts on Saturn's small moons, like Phoebe, lies at a distance of between six and twelve million kilometres from Saturn. Some of this debris is deposited on Iapetus' leading side.



Stereoscopic image data has enabled the creation of digital elevation models of the surface of Iapetus. The differences in height on the moon's surface are enormous; they extend from -12 kilometres (blue) to over +14 kilometres (red). Visible as a horizontal stripe in the right-hand image, an equatorial mountain ridge reaching 13 kilometres in height extends over more than half of the moon's circumference.

Long before the Voyager mission, Iapetus was known to have two strikingly contrasting and sharply demarcated hemispheres, differing greatly from one another in apparent brightness. The leading side, which always faces in the direction of orbital motion because of the moon's synchronous rotation, appears pitch black in the visible portion of the spectrum; it has only about one-tenth the reflectivity of the trailing side, which looks as bright as fresh snow. High-resolution images acquired by the imaging system on Cassini during flybys of Iapetus revealed these two differing regions in detail for the first time. Iapetus' bright trailing hemisphere reflects more than fifty percent of the incoming light, while its dark leading side reflects only about five percent. Based on the presence of bright rays of ejecta around small, young impact craters, it can be deduced that the dark layer is no more than a few tens of centimetres to perhaps a few metres thick.

The cause of the extreme brightness dichotomy on Iapetus has been a long-term mystery. The dark material could have derived from the interior of Iapetus by volcanism. The sublimation of surface ice would then have exposed the underlying dark silicates or carbon compounds. It is also possible that Iapetus could have experienced an influx of dark particulate material from neighbouring moons, distributed by impacts within the planetary system. What is difficult to explain is the fact that the boundary between the light and dark areas does not extend along a meridian; at the poles, the bright area on the trailing hemisphere extends into the other half of the moon. Viewed from certain directions, Iapetus might resemble an astronaut helmet with a black visor.

Important clues to the cause of Iapetus' most unusual characteristic were provided by image data from Cassini, processed mainly by Tilmann Denk of the Cassini working group at the Freie Universität Berlin and supported by DLR's Space Administration, along with observations made with NASA's Spitzer Space Telescope. Beyond the orbit of Iapetus, Saturn is encircled by an enormous torus of tiny ice and dust particles that is tilted 27 degrees with respect to the planet's equator and main ring plane. These particles are the result of impacts and collisions on the more remote outer moons of Saturn, such as Phoebe, whose orbit passes through the middle of the torus. It is possible that some of the material from this halo is being drawn towards the orbit of Iapetus by Saturn's gravity; these dust particles then impinge on the leading face of the icy moon and, over time, darken a large portion of its otherwise pale surface – like bugs gradually accumulated on a windshield during a high-speed summer car ride. Spectrometer analyses show that the material is partly composed of organic compounds, which are thought to have originated from the small Saturnian moons located further from the planet, and partly of nanophase particles of haematite.

Iapetus used to rotate faster

This facial dichotomy is not Iapetus' only special feature; its topography is also striking. Stereoscopic images acquired by Cassini's camera system have been processed into digital elevation models at the DLR Institute of Planetary Research. These models can help to decipher the geological history of the moon; careful evaluations have shown surface relief variations of more than 20 kilometres. The lowest points, located at the centre of impact craters with diameters of several hundred kilometres, reach depths of around 12 kilometres. In other places, ejecta from large impact basins have formed mounds that reach heights of up to 14 kilometres. This difference of 26 kilometres far exceeds the maximum variation in surface relief on Earth, and is thought to be a record, even within the Saturnian system.

Another peculiar characteristic of Iapetus is its shape, best described as a two-axis ellipsoid; it has a polar radius of 712 kilometres and an equatorial radius of 746 kilometres. But the moon's shape is inconsistent with its 79 day period of rotation. Rather, its shape matches a state in which, while still in its 'youth', Iapetus would have had a rotation period of about 17 hours. As a result of rapid cooling, the shape of the icy moon could no longer adapt to its changing rotational state (a gradual slowing down due to the tidal forces produced by Saturn's gravity), and so it froze in the state that is visible today.

The observation conditions and seasons on Iapetus – the northern polar region has been exposed to the spring Sun only since 2009 – have allowed the acquisition of stereo images of nearly half of the moon; from these, digital elevation models have been derived. This topographical data has caused considerable surprise. Another notable property of Iapetus, in comparison to Saturn's other large moons, is the presence of a number of large impact basins on its surface, with the largest having a diameter of 800 kilometres. Considering its size, it might seem surprising that this large basin is not visible in images of the moon. This is because Iapetus' surface is characterised by reflectivity contrasts caused by the properties of the surface material, as opposed to differences in brightness due to shadows cast by landscape features. Only topographic modelling has revealed the existence of these ancient impact basins. Similarly large impact basins probably also existed on other Saturnian moons, but have disappeared over the course of millions of years. Given that ice 'flows' if it is warm enough or if it is subjected to sufficient pressure to cause plastic deformation, an ice crust that has been deformed by large impacts is able to level itself over long timescales. In geophysics, this process is known as relaxation; the rapid cooling of Iapetus prevented relaxation from occurring and preserved the surface as it was in earlier times.

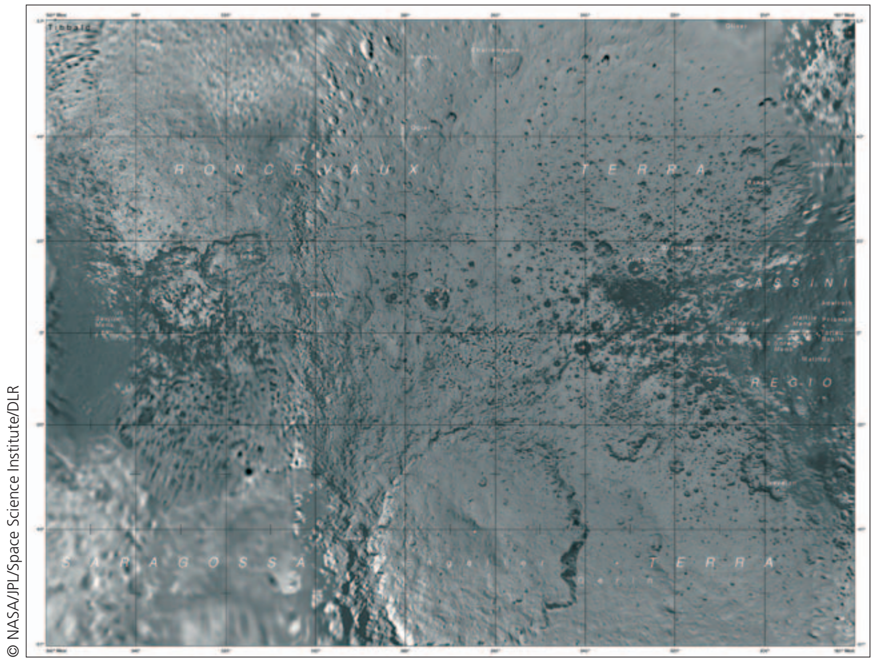
Gigantic global ridge

Another surprising feature of Iapetus' topography, which has never been observed on any other moon or planet in the Solar System, is a prominent equatorial ridge, several thousand kilometres long. The ridge is between 10 and 13 kilometres in height and in some places it might even reach up to 20 kilometres. It extends over more than half of the circumference of Iapetus; from this, we can deduce that the gigantic ridge, which is between 70 and 100 kilometres wide, once encircled the entire moon, which is only 1500 kilometres in diameter. The structure is probably over four billion years old and, could therefore have been worn down in places by erosion due to the impacts of asteroids and comets. The process that created this enormous feature is still unclear. Since the ridge runs along the centre of Cassini Regio – the moon's enigmatic dark side – and dark material has settled symmetrically on either side of the axis of the ridge, it was originally presumed that it was a mountain range that had been pushed upwards by tectonic forces accompanying volcanism. At the same time, it was also assumed that the dark substance, also formed by internal processes, was spread over the surface during volcanic eruptions. More recently, however, it has been realised that the location of dark material and the ridge is accidental and that the dark layer arrived on the moon's surface from space. Today, global tectonic stresses are favoured as the formation process for the equatorial ridge. It is likely that enormous forces built up in the crust of Iapetus as it cooled down rapidly and shrank substantially after its formation. The ice may have melted as a result of heat building up in the interior of what was still a very young moon, or its plasticity ensured that any holes and cavities were closed up, reducing the volume of the moon considerably. As a result, material was forced upwards along the equator, with the impressive result that can still be seen today. ●

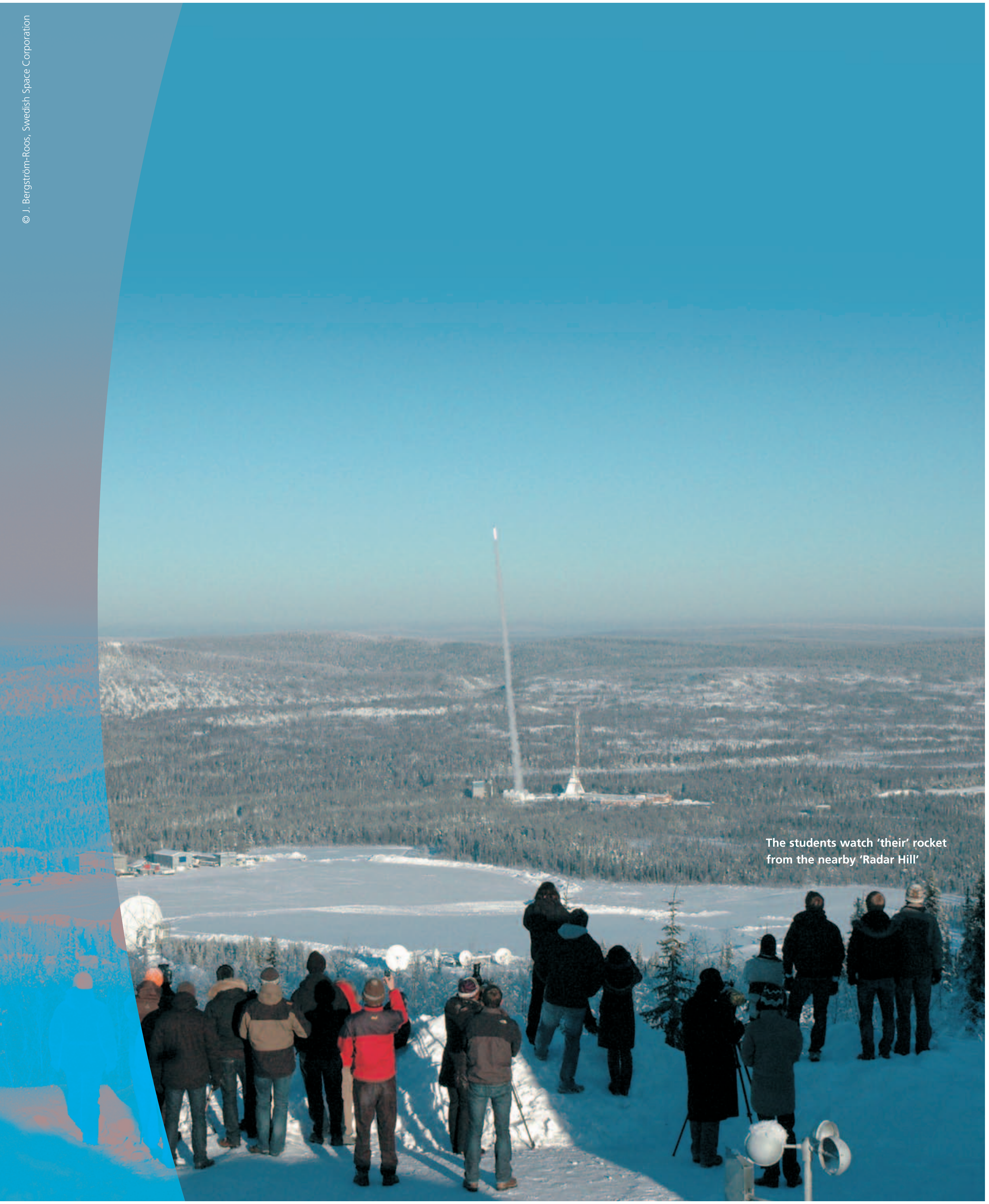
About the authors

Ulrich Köhler is a planetary geologist who is, amongst other things, responsible for public relations at the DLR Institute of Planetary Research in Berlin.
Bernd Giese is a physicist at the DLR Institute of Planetary Research specialising in the processing of stereoscopic image data from missions to planets in the outer Solar System, as well as topographical terrain models and their evaluation.

More information:
www.DLR.de/saturn/en
http://saturn.jpl.nasa.gov
www.esa.int/SPECIALS/Cassini-Huygens



With the data obtained during Cassini flybys, together with information from Voyager images, the DLR Institute of Planetary Research is compiling an atlas of Iapetus. Most of the surface features have been given names taken from the 'Song of Roland', a French epic manuscript dating back to the time of Charlemagne.



The students watch 'their' rocket from the nearby 'Radar Hill'

Vertical learning curve

How do you prepare a space project? The German-Swedish Rocket/Balloon eXperiments for University Students (REXUS/BEXUS) programme enables talented young researchers to gain their own practical experience in flying payloads off the planet. Hannah Böhrk, an expert in thermal protection systems at DLR Stuttgart, served as student advisor in the latest campaign, which she covered for this issue of the DLR magazine.

Research rockets REXUS 9 and 10 took student experiments to the edge of space

By Hannah Böhrk

Kiruna, northern Sweden, 22 February 2011. The REcession MOnitoring System (REMOS) team anxiously awaits the launch of REXUS 9, a joint venture between DLR and the Swedish National Space Board, SNSB. The rocket will carry their experiment to an altitude of about 88 kilometres, then back to the ground. With REMOS, the students from Stuttgart, supported by the DLR Institute of Structure and Design in Stuttgart, have developed a system capable of monitoring the condition of heat shields on re-entry vehicles. By measuring the electrical properties of the material, they are able to deduce the rate of material being lost from a re-entering heat shield.

The countdown starts at T-02:00:00, two hours before launch. Those working in the control centre for the REXUS campaign are concentrating extremely hard. Wide windows provide a good view of the launch pad. From here, team members Serina Latzko, Marcel Düring and Christian Blank are preparing their ground segment software to monitor the material parameters transmitted from their experiment during its flight. When the countdown starts, Düring initialises the software. Once the experiments on board the rocket are supplied with electrical power, columns of figures start to scroll down the screen of the REMOS user interface. Düring checks the numerical values, makes sure that everything is functioning as expected and that the clock is also running correctly. The clock time will be used at a later stage to correlate measurement data with flight path data.

The German REXUS projects are led by the DLR Institute of Space Systems in Bremen. The flight campaigns are carried out by EuroLaunch, a joint venture between DLR's Mobile Rocket Base and the Esrange Space Center operated by the Swedish Space Corporation. Programme management and the experiment application process are handled by DLR Space Administration in Bonn.

One hour before the launch, the siren wails. Using a live ticker on the group's website, Blank informs people about their progress and what is currently unfolding at the launch site. The siren wails two more times: 45 minutes and then 30 minutes to launch. At this point, team leader Robert Wuseni and the other members of his group, Salome Schweikle, Alena Probst, Uwe Sauter and myself are off to the snow-covered path leading uphill to the radar installations. From here, at minus 18 degrees Celsius and under a clear blue sky, there will be a good view, at a safe distance, of the launch itself. "It is very exciting," says Salome Schweikle. "You know for a fact that the experiment you have been working on for the last year and a half is actually going to fly." Since September 2009, the students have been working on this project alongside their aerospace studies. Despite living far apart, in various locations such as Bremen, Darmstadt, Toulouse and Cologne, they have managed to keep in touch and exchange information.

But right now, the connection between them has been shut down; since T-00:20:00, the door of the control centre has been locked. The room falls silent as everyone listens closely to the announcements, down to the last 10 seconds of the countdown that culminate in the rocket launch. Up on the hill under the radar systems, the spectators hold their breath in awe. "You suddenly realise that there will be no more delays and you're just really impressed," comments Robert Wuseni. In the control centre, while monitoring data reception, Blank explains: "it is particularly interesting when, after 74 seconds of flight, the fairing covering the REMOS experiment is detached and you can begin watching the live readings." The transmission of measurement data to the ground is working correctly. In the control centre, Düring, Blank and Latzko all take a deep breath.

Later that day, REMOS is recovered. The team is now ready to retrieve the camera data that is still stored inside the experiment, and begin interpreting the transmitted results. The group's hard work in collaboration will continue awhile yet. ●

More information:
www.rexusbexus.net

Hot property for future propulsion

When Franz-Josef Strauss stuck his spade into the sandy soil of the Wahner Heide in July 1959, it marked the initial groundbreaking for the construction of the German Aviation Research Laboratory's Institute of Jet Propulsion. More than 50 years later, the facility founded back then has grown into DLR's Institute of Propulsion Technology. Reinhard Mönig speaks with Michel Winand on the current developments taking place at the Institute he heads and on its future – where spades will play a role once again.

Fuel, modern testing facilities and enormous amounts of applied experience all play a part in DLR's new engine developments

Interview with Reinhard Mönig, Head of the DLR Institute of Propulsion Technology

The facilities of the Institute of Propulsion Technology at DLR Cologne

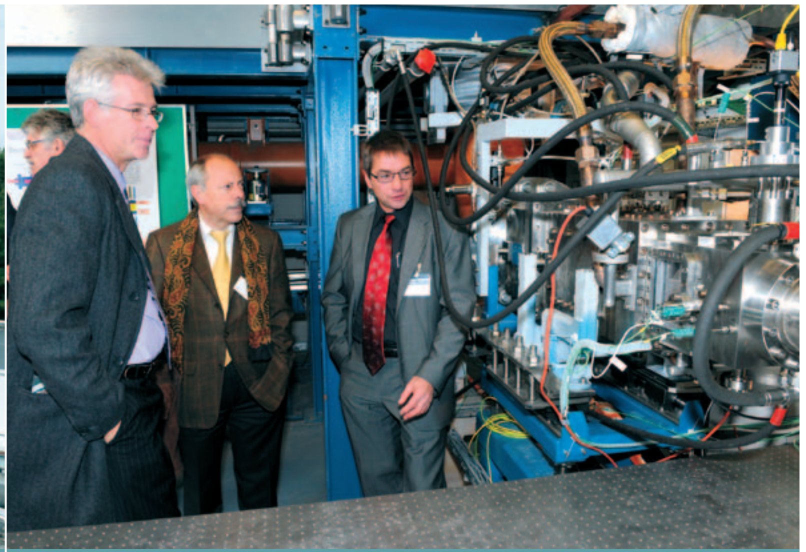
What subjects is your Institute researching?

We want to improve aircraft engines – with regard to both fuel consumption and emissions – and then transfer these technologies to power plant components. We have organised ourselves into specialist departments, each of which focusses specifically on a single major engine component. We view the engine as a complete system and try to identify the best solutions for the next and subsequent generations of engines. From this we derive the requirements for the research that we conduct.

In the next stage, detailed component research and development is performed in the corresponding specialist departments. This includes low-noise, high-efficiency engine fans, high-performance compact compressors, low-emission combustion chambers and high-temperature turbines. All these activities are supported by our in-house flow simulation programme, called the Turbomachinery Research Aerodynamic Computational Environment. This efficient and accurate simulation tool, which is under continuous development at the Institute, is the basis of all our numerical work. In addition, there are optical measurement technologies that have been developed especially for our experimental research work and which we use in almost all of the Institute's measurement activities.

Because aircraft noise reduction is of such great significance, we have specifically focussed our Berlin facility on low-noise design and both active and passive noise reduction in aircraft engines.

Reinhard Mönig – proud of the Institute's unique facilities and the skills of its employees



The inauguration of HBK1 at DLR Cologne in Autumn 2009. Both scientific researchers and industry have shown interest in the new combustion chamber test rig.

The DLR Institute of Propulsion Technology collaborates with international research and industrial partners. Why do companies from the United States, for example, come all the way to Germany to carry out their tests here at DLR?

First of all, I would like to point out that our strategic industrial partners are all based in Germany or at least in Europe. These include almost every important European engine manufacturer and power plant company.

However, we also receive enquiries from the United States, as well as the Far East, concerning research projects and component tests. This is of course very satisfying, as it reaffirms that we are performing research in areas that are highly relevant to industry, have unique facilities and capabilities, as well as associated infrastructure, and that the high quality of our work is recognised worldwide.

The infrastructure you refer to is currently being expanded and modernised. How will your Institute change over the next few years?

Our work is very application-focussed, so we work closely with our customers. In recent years, we have given great importance to identifying the requirements of our strategic industrial partners early on and adjusting our own development programme accordingly. This is the only way we can ensure that we will continue to be a preferred partner, not only in terms of technological development, but also in the development of innovative products.

We are now reaching the performance limits of air compressors and air preheaters in our existing large testing facilities. In the majority of cases they have been in use for decades and are now being expanded or replaced. This applies especially to our large combustion chamber testing facilities, which are used by both the power plant industry and aircraft engine manufacturers to thoroughly test the components in development under realistic conditions before they mature to the point where they are ready for use in marketable products.

Several years ago, we realised that we would only continue to play a significant role in engine research if we kept pace with larger air mass flows and higher temperatures in gas turbines. Hence, over the next few years we will be improving compressor performance and increasing their preheating capacity, necessary to heat greater air mass flows to higher combustion chamber inlet temperatures, which will be used in future gas turbines and aircraft engines.

We have also begun to construct new, specialised research and testing facilities both in Cologne and at our other facilities in Göttingen and Berlin.

How have you organised this complex modernisation?

All these developments are the result of an overall strategy for the Institute and a business plan that we first prepared five years ago. Back then, we asked ourselves two very simple questions: "where do we want to go, and what do we need to get there?" In the next stage, we aligned our vision with that of our most important partners and looked at financing options.

What new options do the modern testing facilities and the improved preparation of air and fuel offer you?

Following the conclusion of our building work, we will not only be in a position to handle testing of complete annular combustion chambers for aircraft engines, but we will also be perfectly prepared to test power plant components for almost any future fuels, including alternative fuels, at DLR. Furthermore, for about a year now, we have been operating a state-of-the-art testing facility to develop more environment-friendly combustion chambers.

In about two years, one of the most up-to-date testing facilities for researching multi-stage turbines will come into operation in Göttingen. This will make us the first facility in the world to simulate the interactions between the combustion chamber and turbine within a research environment.

As a final example, I would like to talk about the new hot gas acoustic testing facility that we are currently operating in conjunction with the Technical University of Berlin. One of the most challenging problems in low-emission, lean combustion chambers is thermo-acoustic combustion chamber oscillations – that is, strong pulsations in the flame combined with high pressure fluctuations – that can quickly cause an engine to fail. We have set up this testing facility to develop acoustically damping wall elements for combustion chambers and test them under realistic conditions. We want to use this to develop methods for specifically suppressing such oscillations in the combustion chamber and thus encourage use of this particularly low-emission combustion process in aircraft engines.

Environment protection plays an increasingly significant role in energy and transportation, but cost-effectiveness is equally important. Aircraft engines should ideally operate using alternative fuels, perform better, consume less fuel and be even quieter. Is it realistic to want to deal with all these challenges at once?

These aims are not necessarily contradictory but there is always a certain degree of compromise when developing a new generation of products. You can focus on emissions, on primary energy consumption or on acoustic emissions (aircraft noise).

I see alternative fuels as the least of the problems here. Today, these fuels can be produced so that they behave almost identically to kerosene in the combustion system. Importantly, however, they can also be specifically developed so that the exhaust emissions in terms of unburned hydrocarbons and soot are significantly lower than with kerosene. And there is a direct relationship between primary energy consumption and carbon dioxide emissions: every reduction in fuel consumption also improves cost-effectiveness, saves resources and reduces carbon dioxide emissions.

Noise is more difficult to deal with. You can either construct an engine for optimum fuel consumption or for the lowest possible acoustic emissions. If you decide to minimise fuel consumption, then, based on our current knowledge, this would lead to large, open, contra-rotating rotors. Such designs are, however, known to generate more noise than conventional engines.

Which do you think will prevail – shrouded engines or open, contra-rotating rotors?

This is currently one of the most exciting questions. I will not venture a prediction, as there is simply too much going on.

What will be different about the engines and turbines of the future, and what part will DLR have in this?

Leaving aside the question of engine architecture, there are very clear trends. Regardless of the type of engine selected, reduction in fuel consumption and noise are, ultimately, both very important goals. To achieve this, we need highly accurate simulation tools and sophisticated optimisation algorithms in the design process. In both cases we collaborate very closely with industry.

The algorithms we have developed already have a central role in product development, and the components designed using them are among the best in the world. Although the 'Made by DLR' stamp may not be on the full component, it is the knowledge and ideas contributed by our Institute that continue to make the development of increasingly efficient, quieter and reliable engines possible.

What is more, it is impossible to think of further development without the corresponding technical advances in materials science. Engines can only be built to an optimum size without becoming too heavy if the adequate light construction materials are available.

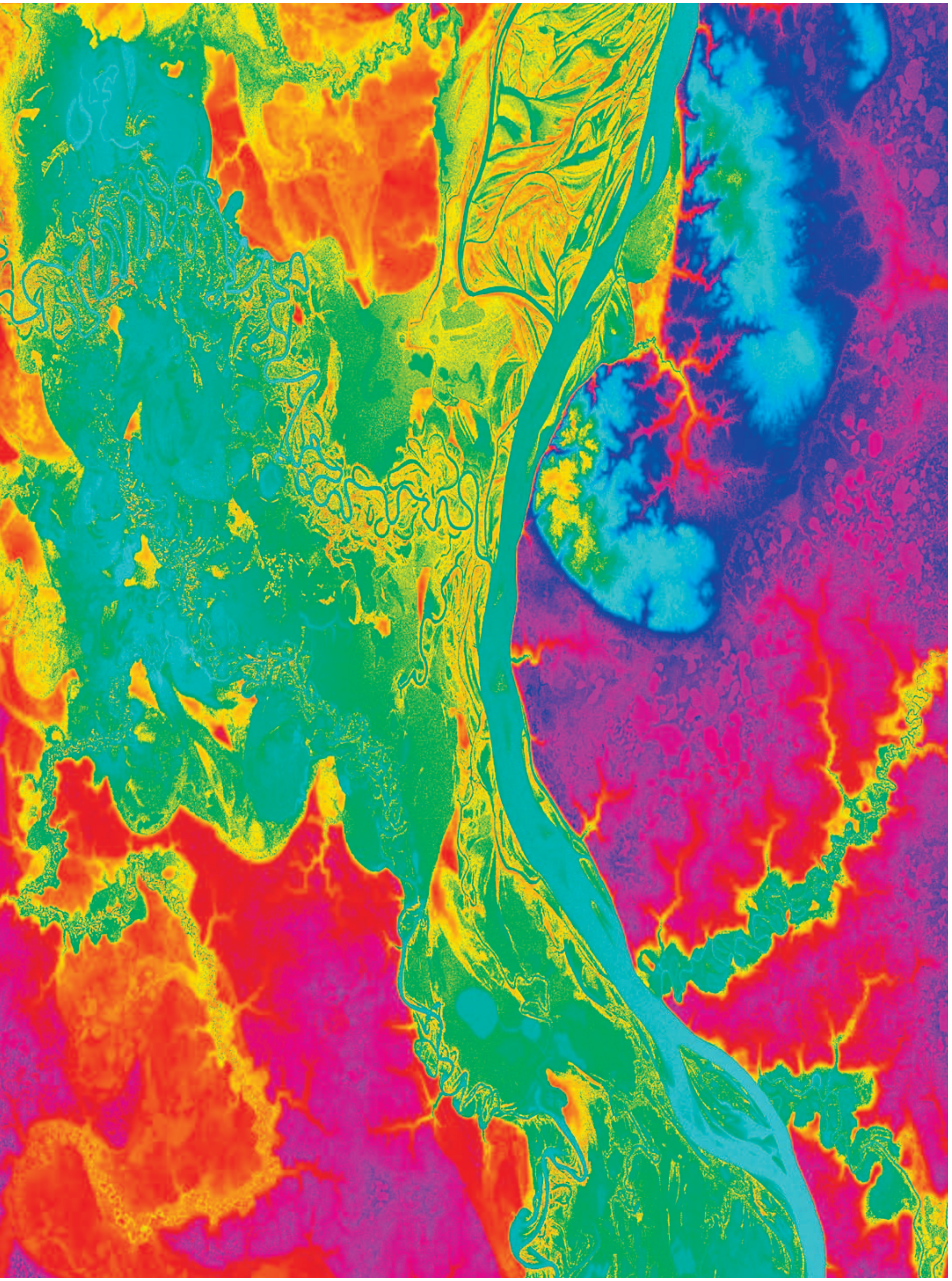
Further development is also needed in high-temperature materials and allowable mechanical stresses. The aim is to further increase the gas temperatures in combustion chambers and turbines, which increase efficiency and reduce fuel consumption. Increased power density leads to higher rotational speed and hence higher centrifugal loads. At the moment, we are operating near the limits of the available technology. Further advances will only be possible if materials science provides the foundation we need. Therefore, we are collaborating very closely with DLR's Institute of Materials Research and Institute of Structures and Design on these issues. ●

Institute of Propulsion Technology

The DLR Institute of Propulsion Technology employs a total of 170 people at locations in Cologne, Göttingen and Berlin, studying the following main areas across eight departments:

- Combustion chambers
- Combustion chamber testing
- Fans and compressors
- Numerical methods
- Engines
- Engine acoustics
- Engine measurement systems
- Turbines

More information:
www.DLR.de/at/en



Seeing double

Twin radar satellites TanDEM-X and TerraSAR-X have been orbiting the Earth together for the last year, supplying data to researchers at DLR. Their objective is to produce a high-precision digital elevation model of the land surface of the entire Earth. By 2013, the planet will have been completely mapped in three dimensions. To perform this task, the two satellites orbit in formation, sometimes closing in on one another to a minimum distance of just 200 metres. "This is a tremendous challenge," Project Manager Manfred Zink tells Manuela Braun. But the real challenge started much earlier, because the first radar satellite mission, TerraSAR-X, was already under way when implementation of the second radar satellite, TanDEM-X, started – and the new joint mission began.

Twin satellites TanDEM-X and TerraSAR-X surveying in 3D

By Manuela Braun

Flat tundra, a frozen river and many former river courses – the TanDEM-X and TerraSAR-X satellites acquired this interferogram of the River Taz near the Siberian village of Krasnoselkup on 21 December 2010. As the area is almost level, the interferogram mainly shows large areas of uniform colour.

The moment Project Manager Manfred Zink begins to talk about TanDEM-X, he enthusiastically pinpoints the features making this German satellite mission one-of-a-kind; from its ambitious aim of producing a global digital elevation model with unprecedented precision and consistency to its unique operational concept; close formation flying along sophisticated double-helix orbits, which must function perfectly for the mission to succeed. Successful implementation of this twin satellite mission involved daunting technical requirements, and the unusual start to the mission must also be mentioned. To an extent not previously experienced for any satellite mission, the launch clock for TanDEM-X was ticking inexorably right from 'day one'. In June 2007, the first radar satellite, TerraSAR-X, was launched with an anticipated service life of five and a half years. TanDEM-X had to be launched into space on schedule; otherwise, the satellites would not be able to orbit the Earth in formation long enough to collect the data necessary to create a global digital elevation model. Those involved were all-too aware of this: "with the launch of TerraSAR-X, things really got busy for TanDEM-X," recalls Zink. "It was important to strictly stick to the schedule right from the start."

The green light for the TerraSAR-X mission was given in late 2001. The satellite was to scan the Earth using radar and gather extensive scientific data. The advantage of radar over optical satellites is that they can go on imaging the Earth through cloud cover and during the hours of darkness. Then, in 2003, a new idea was developed at the DLR Microwaves and Radar Institute; using a pair of satellites that shared an identical design, researchers would be able to record the Earth simultaneously from different viewing angles – enabling precise elevation information to be determined. A preliminary study of this plan was completed in 2005. "At that time, we already knew that we would have to adapt our ongoing project with TerraSAR-X." The first radar satellite was equipped with additional hardware to enable it to cooperate seamlessly with its twin at a later date.

Two satellites, two missions but largely the same team

"The beginning of the mission was complicated," recalls Zink. A large proportion of the team was heavily involved in the TerraSAR-X mission, even before the launch of the satellite. "At that time, my colleagues had other things on their minds than preparing for a future mission. After the launch of TerraSAR-X and during the 'hot' phase of the mission in its first months in space, only a small core team was available to work on TanDEM-X. The two projects competed with one another for personnel resources."

But the mission overlaps, from the planning stage to implementation, also yielded significant advantages, Zink explains: "the experience we gained from the ongoing TerraSAR-X mission taught us some important lessons. Also, when it came to TanDEM-X, we were able to call on the services of a team that was already well established." Four DLR entities – the Microwaves and Radar Institute, the Remote Sensing Technology Institute, the German Remote Sensing Data Center and the German Space Operations Center – all worked together as a team for these radar missions. "Cooperation methods set up for the TerraSAR-X project were gradually improved. The ideal workplace culture had already been created by the time TanDEM-X was launched." Technical lessons learnt could be derived from TerraSAR-X for the new mission. Between them, TerraSAR-X and TanDEM-X are the most extensively tested radar satellite missions ever. "We can say that with complete justification," the project manager confirms. During the first six months of the commissioning phase - the first phase of TanDEM-X operations - the researchers evaluated more than 8000 SAR acquisitions.

Attitude control using magnetic fields

The launch of TerraSAR-X presented the researchers and their industrial partner, Astrium GmbH of Friedrichshafen, with yet another unprecedented challenge. One satellite was still on the ground, while its counterpart was already orbiting the Earth at an altitude of 500 kilometres – a far from straightforward starting position from which to coordinate the movements of two satellites. By way of example, it rapidly became clear that TerraSAR-X would have to change its method of performing attitude control manoeuvres while in safe mode once it was no longer flying 'solo': using its hydrazine propulsion system would no longer be possible. "The use of thrusters is unsuitable for formation flight because this type of manoeuvring alters the orbit of the satellite as well as its attitude." A solution that would enable the TerraSAR-X satellite to alter its attitude without employing its thrusters had to be found. "We had a very limited amount of time to find a solution to this problem. Our colleagues at Astrium succeeded in developing new software for TerraSAR-X and uploading it to the satellite." Now, both satellites control their attitude using 'magnetotorquers', using an internally generated magnetic field that interacts with the magnetic field of the Earth.

Researchers also had to contend with the risk that the satellites might collide or inadvertently illuminate one another with radar signals. "The satellites must not irradiate each other, as this might damage the electronics of the illuminated satellite." The ability to monitor the location of its partner satellite and shut down radar operations if problems arose was something that, initially, only the new TanDEM-X satellite was equipped with; this was implemented using the inter-satellite link, which carries status information and orbital data from its twin.Together with prime contractor Astrium, DLR researchers employed a trick that would also enable TerraSAR-X to gain awareness of its counterpart's status. The existing synchronisation system is additionally harnessed to exchange information between the satellites. Now, both satellites are able to detect if the other is experiencing a problem, at which point radar operations are suspended automatically.

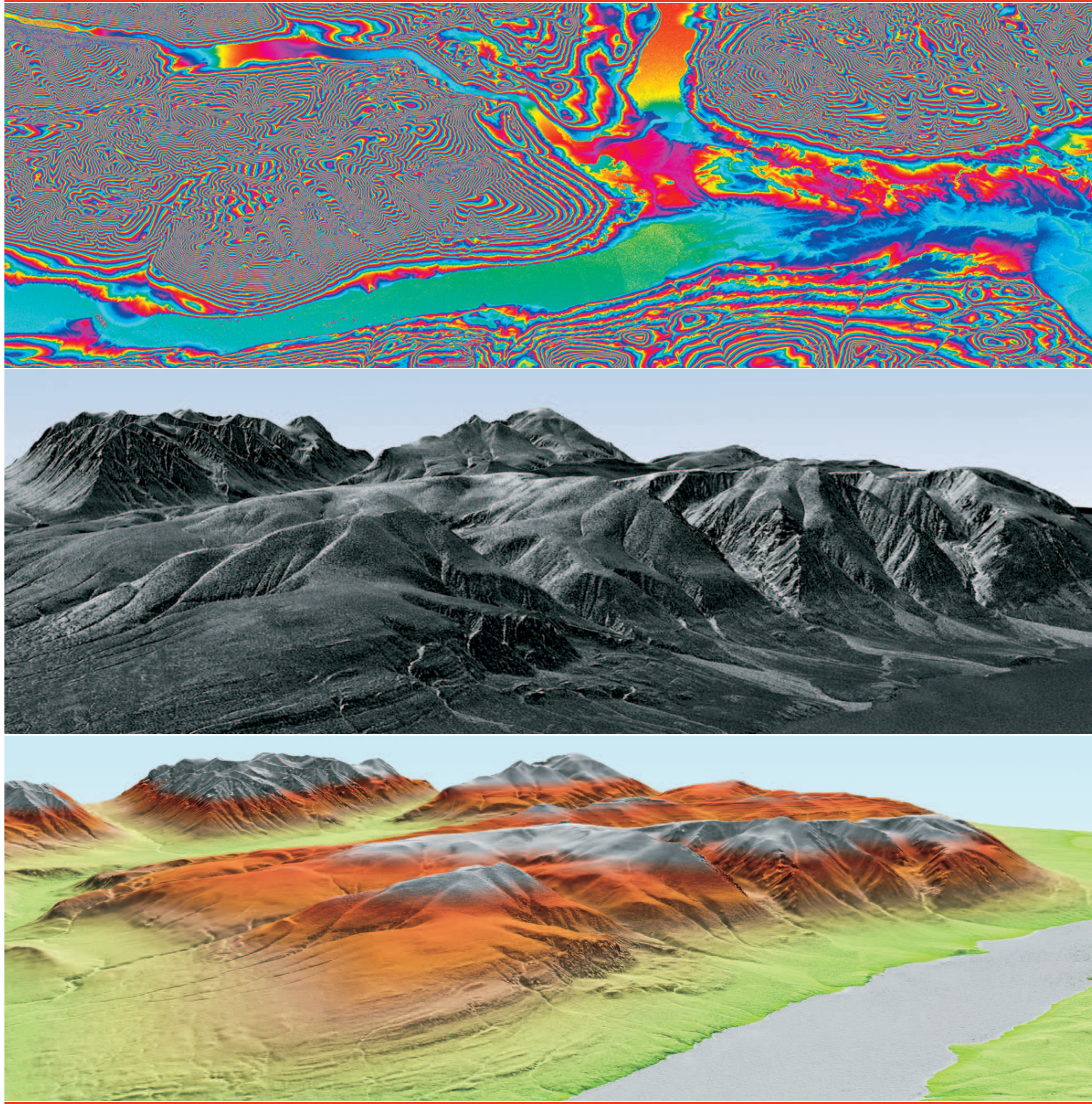
Data acquisition using the patchwork principle – the planning system puts together what belongs together

One year on from its launch, TanDEM-X has acquired radar images of just over half Earth's total land surface of 150 million square kilometres. However, the result is still only a patchwork of the Earth's surface: "we carefully plan the times at which the two satellites capture images in formation." This is tricky because, at the same time, the TerraSAR-X mission must continue to record particular areas of the Earth at the request of researchers and commercial customers. "To ensure global coverage with both satellites, we have assigned these images a relatively high priority," says Zink as he explains the balancing act that must be performed between the two missions. "There is plenty of time left for the TerraSAR-X mission; we only operate both satellites together when conditions are optimal." To carry this out, the team has developed a mission planning system that coordinates the operational timelines of both satellites. "We have two sets of input and the mission planning system is in charge of combining them." The data reception is kept strictly separate for the two missions; the data from the TerraSAR-X mission is received by the DLR ground station at Neustrelitz, in northern Germany, while data from the TanDEM-X mission is received at Kiruna, in Sweden, Inuvik in Canada, the O'Higgins Antarctic Ground Station and in Mexico. If the reception of data fails because, for instance, weather conditions at the ground station are poor, new plans are devised immediately.

Once they have completed one full year of joint operations and data for the complete land surface of the Earth has been acquired, the satellites will start to work again for a further year – this time at a different distance from one another. This will make the resulting elevation model of Earth gradually more accurate over the course of the mission. Researchers at DLR will also adjust the double helix orbits of the satellites to accomplish this. "The satellites view the Earth in a side-looking geometry which means that, during their first overflight, they are unable to record detailed information about areas facing away from them," explains Zink. In a case like this, the mountains in the Alps, for example, would then only have one flank shown in the elevation model. "By altering the configuration of both satellites during the mission, we are able to view areas whose data is yet to be acquired." This means that the elevation model is continuously growing, one small piece at a time; from mid-2013 on, these pieces will be calibrated and mosaicked into the global digital elevation model.

By the end of 2011, the joint mission will have entered the phase where the two satellites perform their closest formation flying of all – only 200 metres will be separating TanDEM-X from TerraSAR-X. "This will take us to the limit of what is permissible," says Zink. The challenges facing the TerraSAR-X and TanDEM-X satellite teams are far from over. "We expect that the TerraSAR-X radar satellite will now be in service for a year longer than was originally planned," states Zink. TanDEM-X is not going to be losing its twin any time soon. •

More information:
www.DLR.de/eo/en



The three TanDEM-X images above show the eastern coast of Greenland on 11 January 2011. The cyclically repeating colour gradients in the interferogram (top) are due to the large height variation – about 1700 metres in total. The data from the interferogram, converted into elevation values, mapped and aligned, can be seen in a three-dimensional view (centre). Bright outflows that run from the slopes into the flat, frozen water are clearly visible. In the bottom image, the height information has been colour coded to produce a figure similar to those found in atlases.

© Eric Long, National Air and Space Museum, Smithsonian Institution

A space about space

There is almost no other place in the world where you can sense the spirit of aerospace history quite as directly as at the Smithsonian National Air and Space Museum. Marco Trovatello, Head of the Crossmedia section of DLR's Corporate Communications Department takes us on a quick tour of the museum complex. The Smithsonian Institution, which comprises 19 museums, the National Zoological Park and nine research facilities, has a clear mission: the increase and diffusion of knowledge. As the many young visitors – from toddlers to school pupils and university students – leave the giant complex of buildings devoted to air and space at the end of the day, this objective seems to have been fulfilled. For some of them, the numerous fascinating air and space exhibits may have provided the inspiration to follow a career in this field.

A stroll through the largest aviation and spaceflight exhibition in the world

By Marco Trovatello

© Eric Long, National Air and Space Museum, Smithsonian Institution

The Smithsonian National Air and Space Museum is located on the National Mall, near the US Capitol

The 'Milestones of Flight' exhibition, located directly behind the two main entrances, contains many interesting exhibits

Located on the National Mall, which is also a national park and the 'Historic Mile' of the capital of the United States, this enormous aerospace museum immediately stands out. The impressive complex of buildings, completed in 1976, was a challenge for the architect, Gyo Obata. How could a structure capable of housing large exhibits including aeroplanes and spacecraft be designed without overshadowing the nearby US Capitol? Thanks to its minimalist architecture, Obata's concept seems to have accomplished this.

Walking into the large entrance hall, one looks in vain for a cash desk. As at most of the Smithsonian Institution museums, admission is free of charge. Friendly volunteers at the reception desks inform and advise visitors; behind them, newly-arrived eyes are drawn to the Apollo 11 Command Module 'Columbia', which carried astronauts Neil Armstrong, Edwin 'Buzz' Aldrin and Michael Collins to the Moon and back. The 'Milestones of Flight' gallery welcomes visitors with further highlights. Have you ever touched a piece of genuine Moon rock? The 'Touchable Moon Rock' exhibit makes this possible; it is handled by many of the 8.3 million people that visit the museum every year.

Next is the 'Space Race' exhibition, designed to amaze space enthusiasts. On display, numerous full-scale engineering and test versions of a wide range of both historical and modern spacecraft. The large and impressive test model of the Hubble Space Telescope leaves no doubt about how it has been able to capture such fascinating images of the Universe for the past 20 years. The central module of the first US space station, the 'Skylab Orbital Workshop', resembles a gigantic soft drink can that visitors are able to walk through. Its 15-metre length makes it larger than Zvezda, the biggest module of our current orbital outpost, the International Space Station.

The 'Touchable Moon Rock' is handled by many of the 8.3 million people that visit the museum every year

© Carolyn Russo/Smithsonian Institution

Bottom left: At the 'Space for you' terminal, the younger visitors try out different assignments; here we see a future flight director at work. Bottom right: What makes aircraft and spaceships fly? 'How things fly', perhaps the most interactive exhibit in the museum, explains this very clearly.

A meticulous replica of the V2 rocket, accompanied by clear exhibition panels, gives contemporary relevance to the relationship between the cruel intentions of the Nazi regime and the fact that this rocket was the first man-made object to go into space – it is truly a piece of space history that you can touch. A few steps further on, you will find the very impressive Apollo Lunar Landing Module. But it is more than a model, it is a genuine 'flight spare'; a backup for the originals that actually flew. Authenticity in its purest form.

There is still much more to discover; the Spirit of St. Louis, flown by Charles Lindbergh when he made the first non-stop transatlantic flight back in 1927; the Mercury 'Friendship 7' capsule, in which John Glenn became the first US citizen to go into space in February 1962; the engineering model used in the development of Mariner 2, the first spacecraft to send useful scientific data back to Earth about a different planet – Venus; the Bell X-1, the first aircraft to break the sound barrier; the list goes on. One cannot conclude without mentioning at least some of the wonderful interactive exhibits. At the 'Space for you' terminals, younger visitors can not only plan their future career in aerospace, but can also literally try out the various jobs. Perhaps the most interactive exhibit is 'How things fly'; it clearly explains how and why aircraft, spaceships and the people on board them can actually stay in the air.

Anyone with time to spare on the day of his or her return flight should not miss the Steven F. Udvar-Hazy Center at Washington Dulles International Airport. In the hangars, visitors will find exhibits showcasing objects such as the Space Shuttle Enterprise, the prototype for the fleet which is now being decommissioned (and in the near future Space Shuttle Discovery), a Concorde supersonic airliner and many other historic aircraft and spacecraft. This long-awaited extension to the Smithsonian National Air and Space Museum, which opened in December 2003, finally provided enough space to display exhibits that had not previously been accessible to the public.

With these two sites, the Smithsonian has the world's largest collection of aviation and spaceflight artefacts. From what you see here, it is easy to conclude that they are well worth a visit. ●

More information:
www.nasm.si.edu

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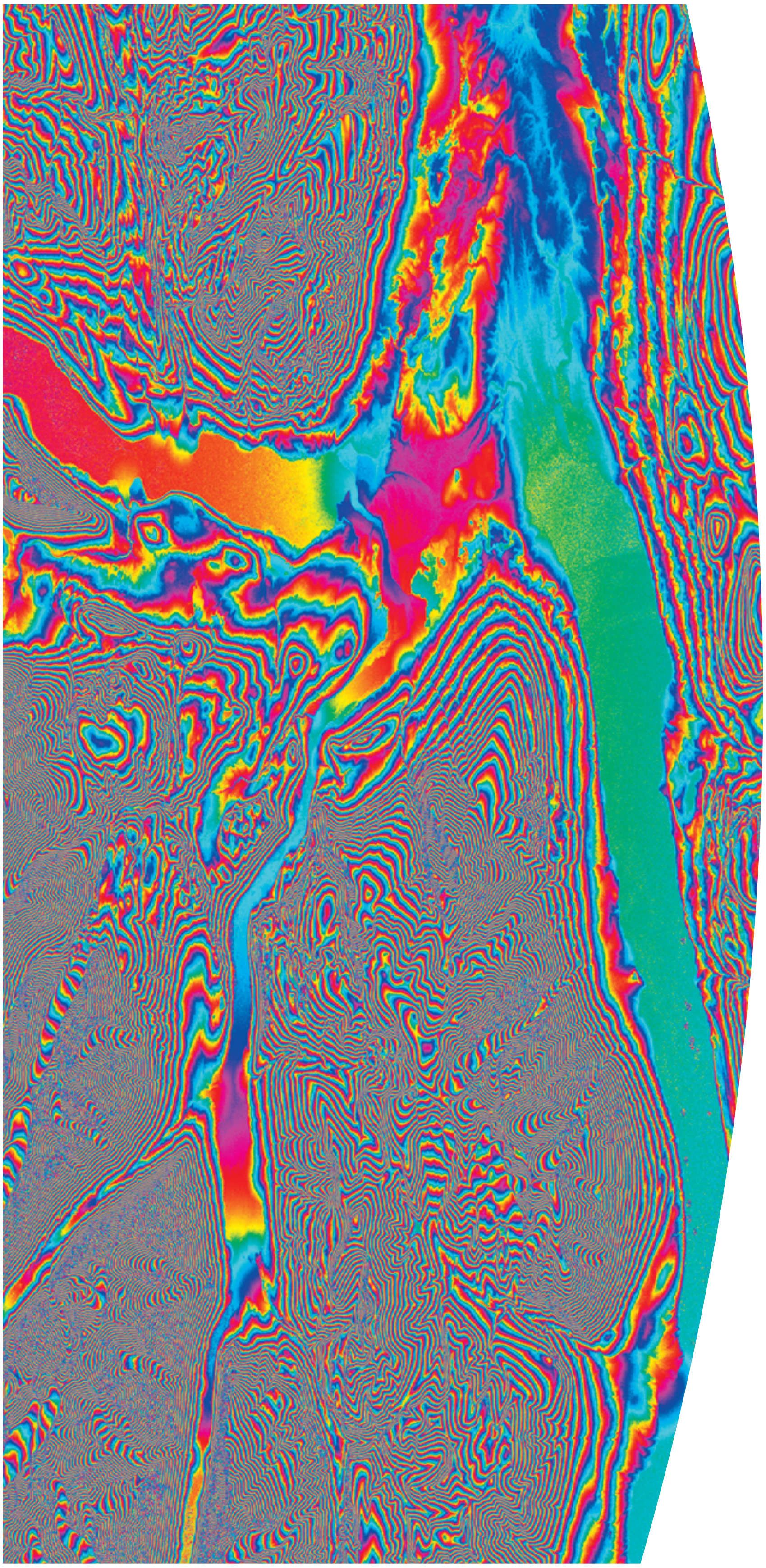
Apollo Lunar Module 2

About DLR

DLR, the German Aerospace Center, is Germany's national research centre for aeronautics and space. Its extensive research and development work in aeronautics, space, transport and energy is integrated into national and international cooperative ventures. As Germany's Space Agency, the German Federal Government has given DLR the responsibility for the planning and implementation of the German space programme, as well as the international representation of Germany's interests in this field.

Approximately 6900 people work for DLR. The Center has 33 institutes and facilities at 15 locations in Germany: Cologne (Headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Göttingen, Hamburg, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stade, Stuttgart, Trauen and Weilheim. DLR also has offices in Brussels, Paris and Washington D.C.



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